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# A Medium-Scale DSGE Model for the Integrated Policy Framework*

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This paper jointly analyzes the optimal conduct of monetary policy, foreign exchange intervention, fiscal policy, macroprudential policy, and capital flow management. This policy analysis is based on an estimated medium-scale dynamic stochastic general equilibrium (DSGE) model of the world economy, featuring a range of nominal and real rigidities, extensive macrofinancial linkages with endogenous risk, and diverse spillover transmission channels. In the pursuit of inflation and output stabilization objectives, it is optimal to adjust all policies in response to global financial cycle upturns and downturns when feasible—including foreign exchange intervention and capital flow management under some conditions—to widely varying degrees depending on the structural characteristics of the economy. The framework is applied empirically to four small open advanced and emerging market economies.

JEL Codes: E3, E5, E6.

## 1. Introduction

International financial integration has increasingly exposed small open advanced and emerging market economies to volatile global capital flows. To cope with recurrent capital inflow and outflow surges—often associated with global financial cycle upturns and downturns—policymakers in some of these economies have occasionally responded with eclectic policy mix adjustments. In particular, to maintain macroeconomic and financial stability amid

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volatile capital flows, they have occasionally deployed some combination of monetary policy, foreign exchange intervention, fiscal policy, macroprudential policy, or capital flow management measures. As discussed in International Monetary Fund (2020), analyzing such high-dimensional policy responses requires an integrated policy framework (IPF).

This paper jointly analyzes the optimal conduct of monetary policy, foreign exchange intervention, fiscal policy, macroprudential policy, and capital flow management for four small open advanced and emerging market economies. In the spirit of the inflation-targeting literature, we jointly optimize simple instrument rules governing the decentralized conduct of these policies to minimize an intertemporal loss function quadratically penalizing the deviations of inflation from target and output from potential, subject to our representation of the world economy. We then examine how the policy mix should be adjusted in response to global financial cycle upturns and downturns, with and without policy space constraints. We represent the world economy with an estimated medium-scale heteroskedastic linearized dynamic stochastic general equilibrium (DSGE) model of a pair of economies that are asymmetric in size. This framework features multiple distortions—associated with nominal rigidities and financial frictions—and internalizes extensive interactions among the policies under consideration. We consider a diverse set of small open advanced and emerging market economies that have experienced volatile capital flows, comprising Korea, South Africa, Switzerland, and Thailand. Given our focus on the global financial cycle, we represent the rest of the world with the United States.

Our DSGE model features a range of nominal and real rigidities, extensive macrofinancial linkages with endogenous risk, and diverse spillover transmission channels. The specification of nominal and real rigidities builds on the seminal work of Smets and Wouters (2003), Christiano, Eichenbaum, and Evans (2005), and Monacelli (2005). This allows our model to account for the empirical evidence concerning the monetary transmission mechanism in a small open economy, while generating reasonably accurate forecasts of inflation and output growth, as documented in Vitek (2008). To integrate the other policies under consideration, we extend this conventional framework in multiple directions. To integrate fiscal policy, we add a fiscal sector and credit constraints. The credit constraints endow our model with empirically plausible fiscal multipliers, following the theoretical fiscal policy analysis literature. To integrate macroprudential policy, we add housing and banking sectors together with financial accelerator and endogenous risk mechanisms, building on Adrian and Vitek (2020). The endogenous risk mechanism captures the negative correlation between the conditional mean and variance of output growth emphasized by the growth at risk literature introduced by Adrian, Boyarchenko, and Giannone (2019). To integrate foreign exchange intervention, we make explicit the balance sheet of the central bank, and drive a wedge into the uncovered interest parity condition spanning the globally integrated interbank market with a foreign currency liquidity regulation cost, motivated by Gabaix and Maggiori (2015). By altering the currency composition of the balance sheet of the central bank, sterilized foreign exchange intervention influences the exchange rate by inducing the banking sector to substitute between domestic- and foreign-currency-denominated interbank funding, with the latter costing an exposure-dependent premium. Finally, we integrate capital flow management by treating domestic and external mortgage and corporate debt as imperfect substitutes, and levying capital control taxes on cross-border borrowing. This is analogous to treating domestic and foreign output goods as imperfect substitutes, and levying tariffs on imports, as is standard in the theoretical trade policy analysis literature.

To our knowledge, this paper is the first to quantitatively analyze the optimal joint conduct of monetary policy, foreign exchange intervention, fiscal policy, macroprudential policy, and capital flow management. A vast literature has jointly analyzed the optimal conduct of subsets of these policies. Broadly speaking, the empirical optimal policy analysis literature has addressed positive issues using partial equilibrium reduced-form models, while the theoretical literature has tackled normative issues using general equilibrium structural models. A branch of the theoretical optimal policy analysis literature comprises papers that derive conceptual principles guiding the optimal conduct of policy using theoretically stylized models, by analytically solving for the Ramsey optimal policy mix that supports the efficient allocation, or instrument rules that decentralize its constrained counterpart. An example of a recent paper similar in scope to ours is Basu et al. (2020), which jointly analyzes the optimal conduct of monetary policy, foreign exchange intervention, macroprudential policy, and capital flow management, by solving for the Ramsey optimal policy mix that supports the constrained efficient allocation. Their paper analyzes the optimal policy mix conceptually, whereas ours does so quantitatively, using a fundamentally different theoretical framework. In particular, their model features occasionally binding borrowing constraints, whereas ours always bind. Another branch of the theoretical optimal policy analysis literature consists of papers that generate quantitative policy prescriptions using empirically congruent models, typically by numerically optimizing the response coefficients of simple instrument rules under a flexible inflation-targeting regime. An example of a recent paper related to ours is Lama and Medina (2020), which jointly optimizes simple instrument rules governing the conduct of monetary policy, foreign exchange intervention, macroprudential policy, and capital flow management, to minimize an intertemporal loss function quadratically penalizing the deviations of inflation from target and output from potential. Another example is Adrian et al. (2021), which examines how foreign exchange intervention and capital flow management can improve monetary policy trade-offs and promote financial stability. Our paper contributes to this quantitative branch of the theoretical optimal policy analysis literature, expanding the range of policies considered.

Our optimal policy analysis broadly supports the observed tendency for policymakers in some small open advanced and emerging market economies to respond to recurrent capital inflow and outflow surges with eclectic policy mix adjustments. A general principle that emerges is that economies with larger international trade and financial exposures should more actively use foreign exchange intervention and capital flow management if these policies are effective and their response thresholds are crossed. Intuitively, foreign exchange intervention tends to be more effective at stabilizing inflation and output in economies with higher trade openness due to stronger exchange rate pass-through and expenditure switching. In parallel, capital flow management tends to be more effective at stabilizing economies with larger unhedged external foreign-currency-denominated debt exposures due to more sensitive financial conditions and vulnerabilities, which influence growth at risk. We illustrate this general principle by simulating global financial cycle upturn and downturn scenarios using our model, conditional on our optimized policy rules. When unconstrained, monetary policy plays the primary role in stabilizing consumption price inflation and output. Foreign exchange intervention enhances monetary autonomy through a supporting role in stabilizing consumption price inflation, while its destabilizing effect on output under these scenarios is offset by fiscal policy. Finally, macroprudential policy and capital flow management have much smaller effects on the conditional means of consumption price inflation and the output gap under these scenarios, but help maintain macroeconomic stability by safeguarding financial stability, by leaning against financial developments that put growth at risk.

The organization of this paper is as follows. The next section develops the theoretical framework, while Section 3 describes the corresponding empirical framework. These sections are necessarily technically complex given the scope of our policy analysis, and readers content to understand our results at an intuitive level without fully knowing their underpinnings can skip them. Estimation of our empirical framework, and examination of its goodness of fit, is the subject of Section 4. Policy analysis using this empirical framework is conducted in Section 5. Finally, Section 6 concludes.

## 2. The Theoretical Framework

Consider a pair of structurally isomorphic open economies that are asymmetric in size and constitute the world economy. Each of these economies consists of households, firms, banks, and a government, which in turn consists of a monetary authority, a fiscal authority, and a macroprudential authority. Households, firms, and banks optimize intertemporally, interacting with the government in an uncertain environment to determine equilibrium prices and quantities under rational expectations in globally integrated output and financial markets. All transactions in the foreign exchange market are intermediated by banks.

### *2.1 The Household Sector*

There exists a continuum of households indexed by $h \in [0, 1]$. Households are differentiated according to whether they are credit constrained, but are otherwise identical. Credit-unconstrained households of type $Z = U$ and measure $\phi^U$ have access to domestic banks where they accumulate deposits, to global banks from which they secure mortgage loans, to the domestic housing market where they trade houses, and to domestic financial markets where they trade government bonds, firm stocks, and bank stocks, where $0 < \phi^U < 1$. These mortgage loans are composites of domestic-currency-denominated mortgage loans from domestic banks, and unhedged foreign-currency-denominated mortgage loans from foreign banks, giving rise to a balance sheet currency mismatch. In contrast, credit-constrained households of type $Z = C$ and measure $\phi^C$ do not have access to banks, or to the housing and financial markets, where $0 < \phi^C < 1$ and $\phi^U + \phi^C = 1$. Houses are in fixed supply at one per credit-unconstrained household. Government bonds are perpetual bonds with coupon payments that decay exponentially at rate $\omega^G$ where $0 < \omega^G \leq 1$, following Woodford (2001).

In a reinterpretation of the labor market in the model of nominal wage rigidity proposed by Erceg, Henderson, and Levin (2000) to incorporate involuntary unemployment along the lines of Galí (2011), each household consists of a continuum of members represented by the unit square and indexed by $(i, j) \in [0, 1] \times [0, 1]$. There is full risk-sharing among household members, who supply indivisible differentiated intermediate labor services indexed by $i \in [0, 1]$, incurring disutility from work determined by $j \in [0, 1]$ if they are employed and zero otherwise. Trade-specific intermediate labor services supplied by credit-unconstrained and credit-constrained households are perfect substitutes.

#### *2.1.1 Consumption, Saving, and Residential Investment*

Each infinitely lived household $h$ has preferences defined over consumption $C_{h,s}$, housing $S^H_{h,s} H_{h,s}$, labor supply $\{L_{h,i,s}\}^1_{i=0}$, houses $S^H_{h,s+1}$, government bonds $\{S^G_{h,v,s+1}\}^s_{v=1}$, and firm stocks $\{S^F_{h,f,s+1}\}^1_{f=0}$ represented by intertemporal utility function

$$U_{h,t} = \mathrm{E}_t \sum_{s=t}^{\infty} \beta^{s-t} u(C_{h,s}, S^H_{h,s} H_{h,s}, \{L_{h,i,s}\}^1_{i=0}, S^H_{h,s+1},$$
$$\{S^G_{h,v,s+1}\}^s_{v=1}, \{S^F_{h,f,s+1}\}^1_{f=0}), \tag{1}$$

where $\mathrm{E}_t$ denotes the expectations operator conditional on information available in period $t$, and $0 < \beta < 1$. The intratemporal utility function is additively separable and represents external habit formation preferences in consumption and labor supply,

$$\begin{aligned}
& u(C_{h,s}, S_{h,s}^H H_{h,s}, \{L_{h,i,s}\}_{i=0}^1, S_{h,s+1}^H, \{S_{h,v,s+1}^G\}_{v=1}^s, \{S_{h,f,s+1}^F\}_{f=0}^1) \\
& \quad = \upsilon_s^C \left[ \frac{1}{1-1/\sigma} \left( C_{h,s} - \alpha^C \frac{C_{s-1}^Z}{\phi^Z} \right)^{1-1/\sigma} + \upsilon_s^D \frac{(S_{h,s}^H H_{h,s})^{1-1/\varsigma}}{1-1/\varsigma} \right. \\
& \qquad - \upsilon_s^N \int_0^1 \int_{\alpha^L \frac{L_{i,s-1}^Z}{\phi^Z}}^{L_{h,i,s}} \left( j - \alpha^L \frac{L_{i,s-1}^Z}{\phi^Z} \right)^{1/\eta} dj di - \upsilon_s^H \frac{V_{h,s}^H S_{h,s+1}^H}{(1+\tau_s^C) P_s^C} \\
& \qquad \left. - \upsilon_s^B \sum_{v=1}^s \frac{V_{v,s}^G S_{h,v,s+1}^G}{(1+\tau_s^C) P_s^C} - \upsilon_s^S \int_0^1 \frac{V_{f,s}^F S_{h,f,s+1}^F}{(1+\tau_s^C) P_s^C} df \right],
\end{aligned} \tag{2}$$

where $0 \leq \alpha^C < 1$ and $0 \leq \alpha^L < 1$. To introduce exogenous asset risk premiums that affect intertemporal substitution, we specify preference shifters $\upsilon_s^C$, $\upsilon_s^H$, $\upsilon_s^B$, and $\upsilon_s^S$ as functions of aggregate endogenous variables or structural shocks,

$$\begin{aligned}
& \upsilon_t^C = \nu_t^C - \frac{\phi_H^C}{1-\rho_H} \nu_t^H - \frac{\phi_B^C}{1-\rho_B} \tilde{\nu}_t^B - \frac{\phi_S^C}{1-\rho_S} \tilde{\nu}_t^S, \\
& \upsilon_s^H = \frac{\tilde{\nu}_s^B + \nu_s^H}{v(C_s^Z, C_{s-1}^Z)}, \ \upsilon_s^B = \frac{\tilde{\nu}_s^B}{v(C_s^Z, C_{s-1}^Z)}, \ \upsilon_s^S = \frac{\tilde{\nu}_s^B + \tilde{\nu}_s^S}{v(C_s^Z, C_{s-1}^Z)}, \\
& v(C_s^Z, C_{s-1}^Z) = \left( \frac{C_s^Z}{\phi^Z} - \alpha^C \frac{C_{s-1}^Z}{\phi^Z} \right)^{1/\sigma},
\end{aligned} \tag{3}$$

where $\phi_H^C > 0$, $\phi_B^C > 0$, and $\phi_S^C > 0$. To support the existence of a long-run balanced-growth path, we also specify preference shifters $\upsilon_s^D$ and $\upsilon_s^N$ as functions of aggregate endogenous variables or structural shocks,

$$\begin{aligned}
& \upsilon_s^D = \frac{\nu^D}{v(C_s^Z, C_{s-1}^Z)} (C_s)^{1/\varsigma}, \ \upsilon_s^N = \frac{A_s^T}{v(C_s^Z, C_{s-1}^Z)} \frac{(L_s/\nu_s^N)^{\mu/\eta}}{w(L_s^Z, L_{s-1}^Z)}, \\
& w(L_s^Z, L_{s-1}^Z) = \left( \frac{L_s^Z}{\phi^Z} - \alpha^L \frac{L_{s-1}^Z}{\phi^Z} \right)^{1/\eta},
\end{aligned} \tag{4}$$

where $\mu > 0$. We assume that the intratemporal utility function is strictly increasing with respect to consumption and housing, and is strictly decreasing with respect to labor supply. This implies restrictions on serially correlated private consumption demand shock $\nu_s^C$ and labor supply shock $\nu_s^N$, given mean zero and serially correlated housing risk premium shock $\nu_s^H$, as well as mean zero and internationally and serially correlated duration risk premium shock $\tilde{\nu}_s^B$ and equity risk premium shock $\tilde{\nu}_s^S$. Given these and other restrictions, this intratemporal utility function is strictly concave with respect to consumption, housing, and labor supply if $\sigma > 0$, $\varsigma > 0$, and $\eta > 0$.

The household enters period $s$ with previously accumulated wealth, allocated across the values of bank deposits, mortgage loans, houses, government bonds, firm stocks, and bank stocks. In particular, it holds bank deposits $B_{h,s}^{H,D}$ which pay interest at risk-free deposit rate $i_{s-1}^D$, secures new borrowing $B_{h,s}^{H,H}$ from global banks on its $S_{h,s}^H$ mortgage loans, owns $S_{h,s}^H$ houses worth $V_{h,s}^H$, owns $\{S_{h,v,s}^G\}_{v=1}^{s-1}$ vintage-specific government bonds worth $\{V_{v,s}^G\}_{v=1}^{s-1}$ which pay coupons $\{\Pi_{v,s}^G\}_{v=1}^{s-1}$, owns $\{S_{h,f,s}^F\}_{f=0}^1$ firm stocks worth $\{V_{f,s}^F\}_{f=0}^1$ which pay dividends $\{\Pi_{f,s}^F\}_{f=0}^1$, and owns $\{S_{h,b,s}^B\}_{b=0}^1$ bank stocks worth $\{V_{b,s}^B\}_{b=0}^1$ which pay dividends $\{\Pi_{b,s}^B\}_{b=0}^1$. The user cost per house $\Pi_{h,s}^H$ satisfies $\Pi_{h,s}^H = P_s^H H_{h,s} + (B_{h,s}^{H,H} - C_{h,s}^{H,H}) - P_s^{I^H} I_{h,s}^H$, where $P_s^H$ denotes the implicit rental price of housing. The coupon payment per government bond $\Pi_{v,s}^G$ satisfies $\Pi_{v,s}^G = (1 + i_v^G - \omega^G)(\omega^G)^{s-v} V_{v,v}^G$, where $i_v^G$ denotes the vintage-specific yield to maturity on government bonds at issuance when $V_{v,v}^G = 1$. During period $s$, the household receives profit income $\Pi_{h,s}^D$ from global banks, where $\Pi_{h,s}^D = \Pi_{h,s}^{D,H} + \Pi_{h,s}^{D,F}$. It also supplies differentiated intermediate labor services $\{L_{h,i,s}\}_{i=0}^1$, earning labor income at trade-specific wages $\{W_{i,s}\}_{i=0}^1$. The government levies a tax on household labor income at rate $\tau_s^L$, and remits household type specific lump-sum transfer payment $T_{h,s}^Z$. These sources of funds are summed in the household dynamic budget constraint:

$$B_{h,s+1}^{H,D} + S_{h,s}^H C_{h,s}^{H,H} + V_{h,s}^H S_{h,s+1}^H + \sum_{v=1}^{s} V_{v,s}^G S_{h,v,s+1}^G$$
$$+ \int_0^1 V_{f,s}^F S_{h,f,s+1}^F df + \int_0^1 V_{b,s}^B S_{h,b,s+1}^B db$$

$$+ (1+\tau_s^C)P_s^C C_{h,s} + P_s^{I^H} S_{h,s}^H I_{h,s}^H = (1+i_{s-1}^D)B_{h,s}^{H,D}$$

$$+ S_{h,s}^H B_{h,s}^{H,H} + V_{h,s}^H S_{h,s}^H + \sum_{v=1}^{s-1}(\Pi_{v,s}^G + V_{v,s}^G)S_{h,v,s}^G$$

$$+ \int_0^1 (\Pi_{f,s}^F + V_{f,s}^F)S_{h,f,s}^F df + \int_0^1 (\Pi_{b,s}^B + V_{b,s}^B)S_{h,b,s}^B db + \Pi_{h,s}^D$$

$$+ (1-\tau_s^L)\int_0^1 W_{i,s}L_{h,i,s}di + T_{h,s}^Z. \tag{5}$$

According to this dynamic budget constraint, at the end of period $s$ the household reallocates its wealth across the values of bank deposits, mortgage loans, houses, government bonds, firm stocks, and bank stocks. In particular, it holds bank deposits $B_{h,s+1}^{H,D}$, pays debt service cost $C_{h,s}^{H,H}$ to global banks on its $S_{h,s}^H$ mortgage loans, owns $S_{h,s+1}^H$ houses worth $V_{h,s}^H$, owns $\{S_{h,v,s+1}^G\}_{v=1}^s$ vintage-specific government bonds worth $\{V_{v,s}^G\}_{v=1}^s$, owns $\{S_{h,f,s+1}^F\}_{f=0}^1$ firm stocks worth $\{V_{f,s}^F\}_{f=0}^1$, and owns $\{S_{h,b,s+1}^B\}_{b=0}^1$ bank stocks worth $\{V_{b,s}^B\}_{b=0}^1$. Finally, the household purchases private consumption good $C_{h,s}$ at price $P_s^C$, and residential investment good $I_{h,s}^H$ for its $S_{h,s}^H$ houses at price $P_s^{I^H}$. The government levies a tax on household consumption expenditures at rate $\tau_s^C$.

The household enters period $s$ with housing of previously accumulated quality $H_{h,s}$, which subsequently evolves according to accumulation function

$$H_{h,s+1} = (1-\delta_H)H_{h,s} + \mathcal{H}^H(I_{h,s}^H, I_{h,s-1}^H), \tag{6}$$

where $0 \leq \delta_H \leq 1$. Effective residential investment function $\mathcal{H}^H(I_{h,s}^H, I_{h,s-1}^H)$ incorporates convex adjustment costs in the gross growth rate of the ratio of nominal residential investment to nominal output,

$$\mathcal{H}^H(I_{h,s}^H, I_{h,s-1}^H) = \nu_s^{I^H}\left[1 - \frac{\chi^H}{2}\left(\frac{P_s^{I^H} I_{h,s}^H}{P_{s-1}^{I^H} I_{h,s-1}^H}\frac{P_{s-1}^Y Y_{s-1}}{P_s^Y Y_s} - 1\right)^2\right] I_{h,s}^H, \tag{7}$$

where serially correlated residential investment demand shock $\nu_s^{I^H}$ satisfies $\nu_s^{I^H} > 0$, while $\chi^H > 0$. In steady-state equilibrium, these adjustment costs equal zero, and effective residential investment equals actual residential investment.

The household enters period $s$ with previously accumulated mortgage debt $D_{h,s}^H$, which subsequently evolves according to accumulation function

$$D_{h,s+1}^H = (1 - \alpha^H) D_{h,s}^H + B_{h,s}^{H,H}, \tag{8}$$

where $0 \leq \alpha^H \leq 1$. Adopting the collateralized borrowing variant of the financial accelerator mechanism due to Kiyotaki and Moore (1997), the household secures new mortgage borrowing from global banks to finance a fraction of the installed value of residential investment,

$$B_{h,s}^{H,H} = \phi_s^H Q_s^H I_{h,s}^H, \tag{9}$$

given by regulatory mortgage loan-to-value ratio limit $\phi_s^H$. Its debt service cost satisfies $C_{h,s}^{H,H} = (1 - \delta_s^H)(\alpha^H + i_{s-1}^{H^E}) D_{h,s}^H$, reflecting an amortization payment at rate $\alpha^H$ and an interest payment at effective mortgage loan rate $i_{s-1}^{H^E}$ on the outstanding stock of mortgage debt, net of a writedown at mortgage loan default rate $\delta_s^H$.

**Credit-Unconstrained Households.** In period $t$, the credit-unconstrained household chooses state-contingent sequences for consumption $\{C_{h,s}\}_{s=t}^{\infty}$, residential investment $\{I_{h,s}^H\}_{s=t}^{\infty}$, housing quality $\{H_{h,s+1}\}_{s=t}^{\infty}$, labor force participation $\{\{N_{h,i,s}\}_{i=0}^{1}\}_{s=t}^{\infty}$, bank deposits $\{A_{h,s+1}^D\}_{s=t}^{\infty}$, mortgage debt $\{D_{h,s+1}^H\}_{s=t}^{\infty}$, houses $\{S_{h,s+1}^H\}_{s=t}^{\infty}$, government bonds $\{\{S_{h,v,s+1}^G\}_{v=1}^{s}\}_{s=t}^{\infty}$, firm stocks $\{\{S_{h,f,s+1}^F\}_{f=0}^{1}\}_{s=t}^{\infty}$, and bank stocks $\{\{S_{h,b,s+1}^B\}_{b=0}^{1}\}_{s=t}^{\infty}$ to maximize intertemporal utility function (1) subject to dynamic budget constraint (5), housing quality accumulation function (6), mortgage debt accumulation function (8), and terminal non-negativity constraints $H_{h,T+1} \geq 0$, $A_{h,T+1}^D \geq 0$, $D_{h,T+1}^H \geq 0$, $S_{h,T+1}^H \geq 0$, $S_{h,v,T+1}^G \geq 0$, $S_{h,f,T+1}^F \geq 0$, and $S_{h,b,T+1}^B \geq 0$ for $T \to \infty$. In equilibrium, the solutions to this utility maximization problem satisfy intertemporal and intratemporal optimality conditions

$$\mathrm{E}_t \frac{\beta u_C(h,t+1)}{u_C(h,t)} \frac{1 + \tau_t^C}{1 + \tau_{t+1}^C} \frac{P_t^C}{P_{t+1}^C} (1 + i_t^D) = 1, \tag{10}$$

$$\frac{Q^H_{h,t}}{P^{I^H}_t}\mathcal{H}^H_1(h,t) + \phi^H_t(1+R^H_{h,t})\frac{Q^H_t}{P^{I^H}_t} + \mathrm{E}_t\frac{\beta u_C(h,t+1)}{u_C(h,t)}\frac{1+\tau^C_t}{1+\tau^C_{t+1}}\frac{P^C_t}{P^C_{t+1}}\frac{P^{I^H}_{t+1}}{P^{I^H}_t}\frac{Q^H_{h,t+1}}{P^{I^H}_{t+1}}\mathcal{H}^H_2(h,t+1) = 1, \quad (11)$$

$$\frac{Q^H_{h,t}}{P^{I^H}_t} = \mathrm{E}_t\frac{\beta u_C(h,t+1)}{u_C(h,t)}\frac{1+\tau^C_t}{1+\tau^C_{t+1}}\frac{P^C_t}{P^C_{t+1}}\frac{P^{I^H}_{t+1}}{P^{I^H}_t} \times \left[\frac{P^H_{t+1}}{P^{I^H}_{t+1}} + (1-\delta_H)\frac{Q^H_{h,t+1}}{P^{I^H}_{t+1}}\right], \quad (12)$$

$$\frac{u_{S^H H}(h,t)}{u_C(h,t)} = \frac{1}{1+\tau^C_t}\frac{P^H_t}{P^C_t}, \quad (13)$$

$$R^H_{h,t} = \mathrm{E}_t\frac{\beta u_C(h,t+1)}{u_C(h,t)}\frac{1+\tau^C_t}{1+\tau^C_{t+1}}\frac{P^C_t}{P^C_{t+1}} \times \left[(1-\alpha^H)R^H_{h,t+1} - (1-\delta^H_{t+1})(\alpha^H + i^{H^E}_t)\right], \quad (14)$$

$$-\frac{u_{L_i}(h,i,t)}{u_C(h,t)} = \frac{1-\tau^L_t}{1+\tau^C_t}\frac{W_{i,t}}{P^C_t}, \quad (15)$$

$$\mathrm{E}_t\frac{\beta u_C(h,t+1)}{u_C(h,t)}\frac{1+\tau^C_t}{1+\tau^C_{t+1}}\frac{P^C_t}{P^C_{t+1}}\left[\frac{\Pi^H_{h,t+1}+V^H_{h,t+1}}{V^H_{h,t}} - (1+i^D_t)\right] = \frac{u_C(t)}{u_C(h,t)}(\tilde{\nu}^B_t + \nu^H_t), \quad (16)$$

$$\mathrm{E}_t\frac{\beta u_C(h,t+1)}{u_C(h,t)}\frac{1+\tau^C_t}{1+\tau^C_{t+1}}\frac{P^C_t}{P^C_{t+1}}\left[\frac{\Pi^G_{v,t+1}+V^G_{v,t+1}}{V^G_{v,t}} - (1+i^D_t)\right] = \frac{u_C(t)}{u_C(h,t)}\tilde{\nu}^B_t, \quad (17)$$

$$\mathrm{E}_t\frac{\beta u_C(h,t+1)}{u_C(h,t)}\frac{1+\tau^C_t}{1+\tau^C_{t+1}}\frac{P^C_t}{P^C_{t+1}}\left[\frac{\Pi^F_{f,t+1}+V^F_{f,t+1}}{V^F_{f,t}} - (1+i^D_t)\right] = \frac{u_C(t)}{u_C(h,t)}(\tilde{\nu}^B_t + \tilde{\nu}^S_t), \quad (18)$$

$$\mathrm{E}_t \frac{\beta u_C(h,t+1)}{u_C(h,t)} \frac{1+\tau_t^C}{1+\tau_{t+1}^C} \frac{P_t^C}{P_{t+1}^C} \left[ \frac{\Pi_{b,t+1}^B + V_{b,t+1}^B}{V_{b,t}^B} - (1+i_t^D) \right] = 0. \tag{19}$$

Here $Q_{h,s}^H$ denotes the shadow price of housing, which is proportional to the Lagrange multiplier on the period $s$ housing quality accumulation function, while $R_{h,s}^H$ denotes the shadow price of mortgage debt, which is proportional to the Lagrange multiplier on the period $s$ mortgage debt accumulation function.

**Credit-Constrained Households.** In period $t$, the credit-constrained household chooses state-contingent sequences for consumption $\{C_{h,s}\}_{s=t}^{\infty}$ and labor force participation $\{\{N_{h,i,s}\}_{i=0}^{1}\}_{s=t}^{\infty}$ to maximize intertemporal utility function (1) subject to dynamic budget constraint (5) and the applicable access restrictions. In equilibrium, the solutions to this utility maximization problem satisfy

$$(1+\tau_t^C)P_t^C C_{h,t} = (1-\tau_t^L)\int_0^1 W_{i,t}L_{h,i,t}di + T_{h,t}^C, \tag{20}$$

$$-\frac{u_{L_i}(h,i,t)}{u_C(h,t)} = \frac{1-\tau_t^L}{1+\tau_t^C}\frac{W_{i,t}}{P_t^C}. \tag{21}$$

Here household static budget constraint (20) equates consumption expenditures to disposable labor income plus transfers.

### *2.1.2 Labor Supply*

The unemployment rate $u_t^L$ measures the share of the labor force $N_t$ in unemployment $U_t$, that is, $u_t^L = U_t/N_t$, where unemployment equals the labor force less employment $L_t$, that is, $U_t = N_t - L_t$. The labor force satisfies $N_t = \int_0^1 N_{i,t}di$.

There exist a large number of perfectly competitive firms which combine differentiated intermediate labor services $\{L_{i,t}\}_{i=0}^{1}$ supplied by trade unions of workers to produce final labor service $L_t$ according to constant elasticity of substitution production function

$$L_t = \left[\int_0^1 (L_{i,t})^{\frac{\theta_t^L-1}{\theta_t^L}} di\right]^{\frac{\theta_t^L}{\theta_t^L-1}}. \tag{22}$$

The representative final labor service firm maximizes profits from production of the final labor service with respect to inputs of intermediate labor services, implying

$$L_{i,t} = \left( \frac{W_{i,t}}{W_t} \right)^{-\theta_t^L} L_t, \tag{23}$$

$$W_t = \left[ \int_0^1 (W_{i,t})^{1-\theta_t^L} di \right]^{\frac{1}{1-\theta_t^L}}. \tag{24}$$

Serially uncorrelated wage markup shock $\vartheta_t^L$ satisfies $\vartheta_t^L = \theta_t^L / (\theta_t^L - 1)$, where the wage elasticity of demand for intermediate labor services $\theta_t^L$ satisfies $\theta_t^L > 1$.

In an extension of the model of nominal wage rigidity proposed by Erceg, Henderson, and Levin (2000) along the lines of Smets and Wouters (2003), each period a randomly selected fraction $1 - \omega^L$ of trade unions adjust their wage optimally, where $0 \leq \omega^L < 1$. The remaining fraction $\omega^L$ of trade unions adjust their wage to account for past wage inflation, as well as past consumption price inflation and trend productivity growth, according to partial indexation rule

$$W_{i,t} = \left[ \left( \frac{W_{t-1}}{W_{t-2}} \right)^{1-\mu^L} \left( \frac{P_{t-1}^C A_{t-1}^T}{P_{t-2}^C A_{t-2}^T} \right)^{\mu^L} \right]^{\gamma^L} \times \left[ \left( \frac{\bar{W}_{t-1}}{\bar{W}_{t-2}} \right)^{1-\mu^L} \left( \frac{\bar{P}_{t-1}^C \bar{A}_{t-1}}{\bar{P}_{t-2}^C \bar{A}_{t-2}} \right)^{\mu^L} \right]^{1-\gamma^L} W_{i,t-1}, \tag{25}$$

where $0 \leq \gamma^L \leq 1$ and $0 \leq \mu^L \leq 1$. If trade union $i$ can adjust its wage optimally in period $t$, then it does so to maximize intertemporal utility function (1) subject to dynamic budget constraint (5), intermediate labor service demand function (23), and the assumed form of nominal wage rigidity. Since all trade unions that adjust their wage optimally in period $t$ solve an identical utility maximization problem, in equilibrium they all choose a common wage $W_t^*$ given by necessary first-order condition

$$\frac{W_t^*}{W_t} = -\frac{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty} (\omega^L)^{s-t} \frac{\beta^{s-t} u_C(h,s)}{u_C(h,t)} \theta_s^L \frac{u_{L_i}(h,i,s)}{u_C(h,s)} \\ \times \left\{ \left[ \left( \frac{W_{t-1}}{W_{s-1}} \right)^{1-\mu^L} \left( \frac{P_{t-1}^C A_{t-1}^T}{P_{s-1}^C A_{s-1}^T} \right)^{\mu^L} \right]^{\gamma^L} \right. \\ \times \left. \left[ \left( \frac{\bar{W}_{t-1}}{\bar{W}_{s-1}} \right)^{1-\mu^L} \left( \frac{\bar{P}_{t-1}^C \bar{A}_{t-1}}{\bar{P}_{s-1}^C \bar{A}_{s-1}} \right)^{\mu^L} \right]^{1-\gamma^L} \frac{W_s}{W_t} \right\}^{\theta_s^L} \\ \times \left( \frac{W_t^*}{W_t} \right)^{-\theta_s^L} L_{h,s} \end{array}}{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty} (\omega^L)^{s-t} \frac{\beta^{s-t} u_C(h,s)}{u_C(h,t)} (\theta_s^L - 1) \frac{1-\tau_s^L}{1+\tau_s^C} \frac{W_s}{P_s^C} \\ \times \left\{ \left[ \left( \frac{W_{t-1}}{W_{s-1}} \right)^{1-\mu^L} \left( \frac{P_{t-1}^C A_{t-1}^T}{P_{s-1}^C A_{s-1}^T} \right)^{\mu^L} \right]^{\gamma^L} \right. \\ \times \left. \left[ \left( \frac{\bar{W}_{t-1}}{\bar{W}_{s-1}} \right)^{1-\mu^L} \left( \frac{\bar{P}_{t-1}^C \bar{A}_{t-1}}{\bar{P}_{s-1}^C \bar{A}_{s-1}} \right)^{\mu^L} \right]^{1-\gamma^L} \frac{W_s}{W_t} \right\}^{\theta_s^L - 1} \\ \times \left( \frac{W_t^*}{W_t} \right)^{-\theta_s^L} L_{h,s} \end{array}}. \tag{26}$$

Aggregate wage index (24) equals an average of the wage set by the fraction $1 - \omega^L$ of trade unions that adjust their wage optimally in period $t$, and the average of the wages set by the remaining fraction $\omega^L$ of trade unions that adjust their wage according to partial indexation rule (25):

$$W_t = \left\{ (1-\omega^L)(W_t^*)^{1-\theta_t^L} + \omega^L \left\{ \left[ \left( \frac{W_{t-1}}{W_{t-2}} \right)^{1-\mu^L} \left( \frac{P_{t-1}^C A_{t-1}^T}{P_{t-2}^C A_{t-2}^T} \right)^{\mu^L} \right]^{\gamma^L} \right. \right.$$
$$\left. \left. \times \left[ \left( \frac{\bar{W}_{t-1}}{\bar{W}_{t-2}} \right)^{1-\mu^L} \left( \frac{\bar{P}_{t-1}^C \bar{A}_{t-1}}{\bar{P}_{t-2}^C \bar{A}_{t-2}} \right)^{\mu^L} \right]^{1-\gamma^L} W_{t-1} \right\}^{1-\theta_t^L} \right\}^{\frac{1}{1-\theta_t^L}}. \tag{27}$$

Since those trade unions able to adjust their wage optimally in period $t$ are selected randomly from among all trade unions, the average wage set by the remaining trade unions equals the value of the aggregate wage index that prevailed during period $t-1$, rescaled to account for past wage inflation, as well as past consumption price inflation and trend productivity growth.

## *2.2 The Production Sector*

The production sector supplies a final output good for absorption by domestic and foreign households, firms, and governments. In doing so, firms demand the final labor service from households, obtain corporate loans from global banks, and accumulate private physical capital through business investment. These corporate loans are composites of domestic-currency-denominated corporate loans from domestic banks, and unhedged foreign-currency-denominated corporate loans from foreign banks, giving rise to a balance sheet currency mismatch.

### *2.2.1 Output Demand*

There exist a large number of perfectly competitive firms which combine differentiated intermediate output goods $\{Y_{f,t}\}_{f=0}^{1}$ supplied by intermediate output good firms to produce final output good $Y_t$ according to constant elasticity of substitution production function

$$Y_t = \left[\int_0^1 (Y_{f,t})^{\frac{\theta_t^Y - 1}{\theta_t^Y}} df\right]^{\frac{\theta_t^Y}{\theta_t^Y - 1}}. \tag{28}$$

The representative final output good firm maximizes profits from production of the final output good with respect to inputs of intermediate output goods, implying

$$Y_{f,t} = \left(\frac{P_{f,t}^Y}{P_t^Y}\right)^{-\theta_t^Y} Y_t, \tag{29}$$

$$P_t^Y = \left[\int_0^1 (P_{f,t}^Y)^{1-\theta_t^Y} df\right]^{\frac{1}{1-\theta_t^Y}}. \tag{30}$$

Serially uncorrelated output price markup shock $\vartheta_t^Y$ satisfies $\vartheta_t^Y = \theta_t^Y/(\theta_t^Y - 1)$, where the price elasticity of demand for intermediate output goods $\theta_t^Y$ satisfies $\theta_t^Y > 1$.

### *2.2.2 Labor Demand and Business Investment*

There exists a continuum of monopolistically competitive intermediate output good firms indexed by $f \in [0, 1]$. Intermediate output good firms supply differentiated intermediate output goods, but are otherwise identical.

Each intermediate output good firm $f$ sells shares to domestic credit-unconstrained households at price $V_{f,t}^{F}$. Acting in the interests of its shareholders, it maximizes its pre-dividend stock market value,

$$\Pi_{f,t}^{F} + V_{f,t}^{F} = \mathrm{E}_t \sum_{s=t}^{\infty} \frac{\beta^{s-t}\lambda_s^F}{\lambda_t^F} \Pi_{f,s}^{F}, \tag{31}$$

where $\lambda_s^F = \lambda_s^U \prod_{r=1}^{s-1}(1 + \tilde{\nu}_r^B + \tilde{\nu}_r^S)^{-1}$, while $\lambda_{h,s}$ denotes the Lagrange multiplier on the period $s$ household dynamic budget constraint. Shares entitle households to dividend payments equal to net profits $\Pi_{f,s}^{F}$, defined as after-tax earnings, plus new corporate borrowing $B_{f,s}^{F,F}$ less debt service cost $C_{f,s}^{F,F}$, minus business investment expenditures,

$$\begin{aligned} \Pi_{f,s}^{F} = {} & (1 - \tau_s^K)(P_{f,s}^{Y} Y_{f,s} - W_s L_{f,s} - \Phi_{f,s}^{F}) + (B_{f,s}^{F,F} - C_{f,s}^{F,F}) \\ & - P_s^{I^K} I_{f,s}^{K}, \end{aligned} \tag{32}$$

where $Y_{f,s} = \mathcal{F}(u_{f,s}^{K} K_{f,s}, A_s L_{f,s})$. Earnings are defined as revenues from sales of differentiated intermediate output good $Y_{f,s}$ at price $P_{f,s}^{Y}$ less expenditures on final labor service $L_{f,s}$, and other variable costs $\Phi_{f,s}^{F}$. The government levies a tax on corporate earnings at rate $\tau_s^K$.

The intermediate output good firm utilizes private physical capital $K_{f,s}$ at rate $u_{f,s}^{K}$ and rents final labor service $L_{f,s}$ to produce differentiated intermediate output good $Y_{f,s}$ according to production function

$$\mathcal{F}(u_{f,s}^{K} K_{f,s}, A_s L_{f,s}) = (u_{f,s}^{K} K_{f,s})^{\phi^Y} (A_s L_{f,s})^{1-\phi^Y}. \tag{33}$$

This production function exhibits constant returns to scale, with $0 \leq \phi^Y \leq 1$. Productivity $A_s$ depends on the ratio of the public capital stock to the aggregate labor force,

$$A_s = (\tilde{\nu}_s^A)^{\phi^A} \left( \frac{K_s^G}{N_s} \right)^{1-\phi^A}, \tag{34}$$

where internationally and serially correlated productivity shock $\tilde{\nu}_s^A$ satisfies $\tilde{\nu}_s^A > 0$, while $0 < \phi^A \leq 1$. Trend productivity $A_s^T$ exhibits partial adjustment dynamics, that is, $A_s^T = (A_{s-1}^T)^{\rho^{A^T}} (A_s)^{1-\rho^{A^T}}$ where $0 \leq \rho^{A^T} < 1$.

In utilizing private physical capital to produce output, the intermediate output good firm incurs a cost $\mathcal{G}^K(u_{f,s}^K, K_{f,s})$ denominated in terms of business investment:

$$\Phi_{f,s}^F = P_s^{I^K} \mathcal{G}^K(u_{f,s}^K, K_{f,s}) + F_s^F. \tag{35}$$

Following Christiano, Eichenbaum, and Evans (2005), this capital utilization cost is increasing in the capital utilization rate at an increasing rate,

$$\mathcal{G}^K(u_{f,s}^K, K_{f,s}) = \mu^K \left[ e^{\eta^K (u_{f,s}^K - 1)} - 1 \right] K_{f,s}, \tag{36}$$

where $\mu^K > 0$ and $\eta^K > 0$. In steady-state equilibrium, the capital utilization rate equals one, and the cost of utilizing capital equals zero. Fixed cost $F_s^F$ ensures that $\int_0^1 \Phi_{f,s}^F df = 0$.

The intermediate output good firm enters period $s$ with previously accumulated private physical capital stock $K_{f,s}$, which subsequently evolves according to accumulation function

$$K_{f,s+1} = (1 - \delta_K) K_{f,s} + \mathcal{H}^K(I_{f,s}^K, I_{f,s-1}^K), \tag{37}$$

where $0 \leq \delta_K \leq 1$. Motivated by Christiano, Eichenbaum, and Evans (2005), effective business investment function $\mathcal{H}^K(I_{f,s}^K, I_{f,s-1}^K)$ incorporates convex adjustment costs in the gross growth rate of the ratio of nominal business investment to aggregate nominal output,

$$\mathcal{H}^K(I_{f,s}^K, I_{f,s-1}^K) = \nu_s^{I^K} \left[ 1 - \frac{\chi^K}{2} \left( \frac{P_s^{I^K} I_{f,s}^K}{P_{s-1}^{I^K} I_{f,s-1}^K} \frac{P_{s-1}^Y Y_{s-1}}{P_s^Y Y_s} - 1 \right)^2 \right] I_{f,s}^K, \tag{38}$$

where serially correlated business investment demand shock $\nu_s^{I^K}$ satisfies $\nu_s^{I^K} > 0$, while $\chi^K > 0$. In steady-state equilibrium, these adjustment costs equal zero, and effective business investment equals actual business investment.

The intermediate output good firm enters period $s$ with previously accumulated corporate debt $D_{f,s}^F$, which subsequently evolves according to accumulation function

$$D_{f,s+1}^F = (1 - \alpha^F) D_{f,s}^F + B_{f,s}^{F,F}, \tag{39}$$

where $0 \leq \alpha^F \leq 1$. Adopting the collateralized borrowing variant of the financial accelerator mechanism due to Kiyotaki and Moore (1997), the intermediate output good firm secures new corporate borrowing from global banks to finance a fraction of the installed value of business investment,

$$B_{f,s}^{F,F} = \phi_s^F Q_s^K I_{f,s}^K, \tag{40}$$

given by regulatory corporate loan-to-value ratio limit $\phi_s^F$. Its debt service cost satisfies $C_{f,s}^{F,F} = (1 - \delta_s^F)(\alpha^F + i_{s-1}^{F^E}) D_{f,s}^F$, reflecting an amortization payment at rate $\alpha^F$ and an interest payment at effective corporate loan rate $i_{s-1}^{F^E}$ on the outstanding stock of corporate debt, net of a writedown at corporate loan default rate $\delta_s^F$.

In period $t$, the intermediate output good firm chooses state-contingent sequences for employment $\{L_{f,s}\}_{s=t}^{\infty}$, the capital utilization rate $\{u_{f,s}^K\}_{s=t}^{\infty}$, business investment $\{I_{f,s}^K\}_{s=t}^{\infty}$, the private physical capital stock $\{K_{f,s+1}\}_{s=t}^{\infty}$, and corporate debt $\{D_{f,s+1}^F\}_{s=t}^{\infty}$ to maximize pre-dividend stock market value (31) subject to production function (33), private physical capital accumulation function (37), corporate debt accumulation function (39), and terminal non-negativity constraints $K_{f,T+1} \geq 0$ and $D_{f,T+1}^F \geq 0$ for $T \rightarrow \infty$. In equilibrium, the solutions to this value maximization problem satisfy necessary first-order conditions

$$\mathcal{F}_{AL}(f,t)\Psi_{f,t} = (1 - \tau_t^K)\frac{W_t}{P_t^Y A_t}, \tag{41}$$

$$\mathcal{F}_{u^K K}(f,t)\frac{P_t^Y}{P_t^{I^K}}\Psi_{f,t} = (1 - \tau_t^K)\frac{\mathcal{G}_{u^K}^K(f,t)}{K_{f,t}}, \tag{42}$$

$$\begin{aligned} &\frac{Q_{f,t}^K}{P_t^{I^K}}\mathcal{H}_1^K(f,t) + \phi_t^F(1 + R_{f,t}^K)\frac{Q_t^K}{P_t^{I^K}} \\ &\quad + \mathrm{E}_t\frac{\beta\lambda_{t+1}^F}{\lambda_t^F}\frac{P_{t+1}^{I^K}}{P_t^{I^K}}\frac{Q_{f,t+1}^K}{P_{t+1}^{I^K}}\mathcal{H}_2^K(f,t+1) = 1, \end{aligned} \tag{43}$$

$$\begin{aligned} \frac{Q_{f,t}^K}{P_t^{I^K}} = \mathrm{E}_t\frac{\beta\lambda_{t+1}^F}{\lambda_t^F}\frac{P_{t+1}^{I^K}}{P_t^{I^K}}\Bigg[&u_{f,t+1}^K\mathcal{F}_{u^K K}(f,t+1)\frac{P_{t+1}^Y}{P_{t+1}^{I^K}}\Psi_{f,t+1} \\ &- (1 - \tau_{t+1}^K)\mathcal{G}_K^K(f,t+1) + (1 - \delta_K)\frac{Q_{f,t+1}^K}{P_{t+1}^{I^K}}\Bigg], \end{aligned} \tag{44}$$

$$R^K_{f,t} = \mathrm{E}_t \frac{\beta \lambda^F_{t+1}}{\lambda^F_t} \left[ (1-\alpha^F) R^K_{f,t+1} - (1-\delta^F_{t+1})(\alpha^F + i^{F^E}_t) \right]. \quad (45)$$

Here $\Psi^F_{f,s}$ denotes real marginal cost, which is proportional to the Lagrange multiplier on the period $s$ production technology constraint, while $Q^K_{f,s}$ denotes the shadow price of private physical capital, which is the Lagrange multiplier on the period $s$ private physical capital accumulation function, and $R^K_{f,s}$ denotes the shadow price of corporate debt, which is proportional to the Lagrange multiplier on the period $s$ corporate debt accumulation function.

### 2.2.3 Output Supply

In an extension of the model of nominal output price rigidity proposed by Calvo (1983) along the lines of Smets and Wouters (2003), each period a randomly selected fraction $1-\omega^Y$ of intermediate output good firms adjust their price optimally, where $0 \leq \omega^Y < 1$. The remaining fraction $\omega^Y$ of intermediate output good firms adjust their price to account for past output price inflation according to partial indexation rule

$$P^Y_{f,t} = \left( \frac{P^Y_{t-1}}{P^Y_{t-2}} \right)^{\gamma^Y} \left( \frac{\bar{P}^Y_{t-1}}{\bar{P}^Y_{t-2}} \right)^{1-\gamma^Y} P^Y_{f,t-1}, \quad (46)$$

where $0 \leq \gamma^Y \leq 1$. If the intermediate output good firm can adjust its price optimally in period $t$, then it does so to maximize pre-dividend stock market value (31) subject to production function (33), intermediate output good demand function (29), and the assumed form of nominal output price rigidity. We consider a symmetric equilibrium under which all firm-specific endogenous state variables are restricted to equal their aggregate counterparts. It follows that all intermediate output good firms that adjust their price optimally in period $t$ solve an identical value maximization problem, which implies that they all choose a common price $P^{Y,*}_t$ given by necessary first-order condition

$$\frac{P_t^{Y,*}}{P_t^Y} = \frac{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty} (\omega^Y)^{s-t} \frac{\beta^{s-t}\lambda_s^F}{\lambda_t^F} \theta_s^Y \Psi_{f,s} \\ \quad \times \left[ \left( \frac{P_{t-1}^Y}{P_{s-1}^Y} \right)^{\gamma^Y} \left( \frac{\bar{P}_{t-1}^Y}{\bar{P}_{s-1}^Y} \right)^{1-\gamma^Y} \frac{P_s^Y}{P_t^Y} \right]^{\theta_s^Y} \left( \frac{P_t^{Y,*}}{P_t^Y} \right)^{-\theta_s^Y} P_s^Y Y_s \end{array}}{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty} (\omega^Y)^{s-t} \frac{\beta^{s-t}\lambda_s^F}{\lambda_t^F} (\theta_s^Y - 1)(1 - \tau_s^K) \\ \quad \times \left[ \left( \frac{P_{t-1}^Y}{P_{s-1}^Y} \right)^{\gamma^Y} \left( \frac{\bar{P}_{t-1}^Y}{\bar{P}_{s-1}^Y} \right)^{1-\gamma^Y} \frac{P_s^Y}{P_t^Y} \right]^{\theta_s^Y - 1} \left( \frac{P_t^{Y,*}}{P_t^Y} \right)^{-\theta_s^Y} P_s^Y Y_s \end{array}}. \tag{47}$$

Aggregate output price index (30) equals an average of the price set by the fraction $1-\omega^Y$ of intermediate output good firms that adjust their price optimally in period $t$, and the average of the prices set by the remaining fraction $\omega^Y$ of intermediate output good firms that adjust their price according to partial indexation rule (46):

$$P_t^Y = \Bigg\{ (1-\omega^Y)(P_t^{Y,*})^{1-\theta_t^Y} + \omega^Y \left[ \left( \frac{P_{t-1}^Y}{P_{t-2}^Y} \right)^{\gamma^Y} \left( \frac{\bar{P}_{t-1}^Y}{\bar{P}_{t-2}^Y} \right)^{1-\gamma^Y} P_{t-1}^Y \right]^{1-\theta_t^Y} \Bigg\}^{\frac{1}{1-\theta_t^Y}}. \tag{48}$$

Since those intermediate output good firms able to adjust their price optimally in period $t$ are selected randomly from among all intermediate output good firms, the average price set by the remaining intermediate output good firms equals the value of the aggregate output price index that prevailed during period $t-1$, rescaled to account for past output price inflation.

## *2.3 The Banking Sector*

The banking sector supplies global financial intermediation services subject to financial frictions and regulatory constraints. In particular, global banks issue risky mortgage or corporate loans to domestic and foreign households or firms. These mortgage or corporate loans are composites of domestic-currency-denominated mortgage or corporate loans from domestic banks, and foreign-currency-denominated mortgage or corporate loans from foreign banks. These currency-specific mortgage and corporate loans are issued at infrequently adjusted predetermined mortgage and corporate loan rates. Mortgage and corporate borrowing by households and firms is subject to regulatory loan-to-value ratio limits. Cross-border mortgage and corporate borrowing is also subject to capital controls, represented by taxes on capital inflows.

Domestic banks accumulate bank capital from retained earnings given credit losses to satisfy a regulatory capital ratio requirement. They obtain funding from domestic households via deposits and from the globally integrated interbank market via loans, giving rise to a balance sheet currency mismatch. Cross-border interbank borrowing is subject to a foreign currency liquidity regulation cost, which is influenced by foreign exchange intervention.

#### *2.3.1 Credit Demand*

There exist a large number of perfectly competitive risk-neutral banks owned by domestic credit-unconstrained households which combine the domestic final mortgage or corporate loan $D_{t+1}^{Z,h}$ with the foreign final mortgage or corporate loan $D_{t+1}^{Z,f}$ to produce global mortgage or corporate loan $D_{t+1}^{Z}$ according to constant elasticity of substitution portfolio aggregator

$$D_{t+1}^{Z} = \left[ (1-\phi_Z^B)^{\frac{1}{\psi^B}} (D_{t+1}^{Z,h})^{\frac{\psi^B-1}{\psi^B}} + (\phi_Z^B)^{\frac{1}{\psi^B}} (\mathcal{E}_t D_{t+1}^{Z,f})^{\frac{\psi^B-1}{\psi^B}} \right]^{\frac{\psi^B}{\psi^B-1}}, \tag{49}$$

where $Z \in \{H, F\}$, while $0 \leq \phi_Z^B < 1$ and $\psi^B > 0$. The government levies a tax on cross-border mortgage or corporate borrowing at rate $\tau_t^Z$. The representative global bank maximizes expected profits from intermediation of the global mortgage or corporate loan, with respect to inputs of the domestic and foreign final mortgage or corporate loans, implying

$$D_{t+1}^{Z,h} = (1-\phi_Z^B)\left[\frac{\mathrm{E}_t(1-\delta_{t+1}^Z)(\alpha^Z+i_t^Z)}{E_t(1-\delta_{t+1}^Z)(\alpha^Z+i_t^{Z^E})}\right]^{-\psi^B} D_{t+1}^Z,$$

$$D_{t+1}^{Z,f} = \phi_Z^B\left[\frac{E_t(1+\tau_t^Z)(1-\delta_{t+1}^Z)(\alpha^Z+i_t^{Z,f})\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}}{\mathrm{E}_t(1-\delta_{t+1}^Z)(\alpha^Z+i_t^{Z^E})}\right]^{-\psi^B} \frac{D_{t+1}^Z}{\mathcal{E}_t}, \tag{50}$$

$$\mathrm{E}_t(1-\delta_{t+1}^Z)(\alpha^Z+i_t^{Z^E}) = \Bigg\{(1-\phi_Z^B)\left[E_t(1-\delta_{t+1}^Z)(\alpha^Z+i_t^Z)\right]^{1-\psi^B} + \phi_Z^B\left[E_t(1+\tau_t^Z)(1-\delta_{t+1}^Z)(\alpha^Z+i_t^{Z,f})\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right]^{1-\psi^B}\Bigg\}^{\frac{1}{1-\psi^B}}. \tag{51}$$

The effective mortgage or corporate loan rate $i_t^{Z^E}$ equals the minimum expected cost of producing one unit of the global mortgage or corporate loan, given the expected domestic-currency-denominated costs of borrowing from domestic and foreign final banks.

There exist a large number of perfectly competitive banks which combine differentiated intermediate mortgage or corporate loans $\{A_{b,t+1}^{B,Z}\}_{b=0}^1$ supplied by intermediate banks to produce final mortgage or corporate loan $A_{t+1}^{B,Z}$ according to constant elasticity of substitution portfolio aggregator

$$A_{t+1}^{B,Z} = \left[\int_0^1 (A_{b,t+1}^{B,Z})^{\frac{\theta_{t+1}^Z-1}{\theta_{t+1}^Z}} db\right]^{\frac{\theta_{t+1}^Z}{\theta_{t+1}^Z-1}}, \tag{52}$$

where $Z \in \{H,F\}$. The representative domestic final bank maximizes profits from intermediation of the final mortgage or corporate loan with respect to inputs of intermediate mortgage or corporate loans, implying

$$A_{b,t+1}^{B,Z} = \left(\frac{\alpha^Z+i_{b,t}^Z}{\alpha^Z+i_t^Z}\right)^{-\theta_{t+1}^Z} A_{t+1}^{B,Z}, \tag{53}$$

$$\alpha^Z+i_t^Z = \left[\int_0^1 (\alpha^Z+i_{b,t}^Z)^{1-\theta_{t+1}^Z} db\right]^{\frac{1}{1-\theta_{t+1}^Z}}. \tag{54}$$

Serially correlated mortgage or corporate loan markup shock $\vartheta_{t+1}^{Z}$ satisfies $\vartheta_{t+1}^{Z} = \theta_{t+1}^{Z}/(\theta_{t+1}^{Z} - 1)$, where the rate elasticity of demand for intermediate mortgage or corporate loans $\theta_{t+1}^{Z}$ satisfies $\theta_{t+1}^{Z} > 1$.

### *2.3.2 Funding Demand and Bank Capital Accumulation*

There exists a continuum of monopolistically competitive intermediate banks indexed by $b \in [0, 1]$. Intermediate banks supply differentiated intermediate mortgage and corporate loans, but are otherwise identical.

Each intermediate bank $b$ sells shares to domestic credit-unconstrained households at price $V_{b,t}^{B}$. Acting in the interests of its shareholders, it maximizes its pre-dividend stock market value:

$$\Pi_{b,t}^{B} + V_{b,t}^{B} = \mathrm{E}_t \sum_{s=t}^{\infty} \frac{\beta^{s-t}\lambda_s^U}{\lambda_t^U} \Pi_{b,s}^{B}. \tag{55}$$

Shares entitle households to dividend payments $\Pi_{b,s}^{B}$, defined as profits from providing financial intermediation services less retained earnings $I_{b,s}^{B}$:

$$\begin{aligned} \Pi_{b,s}^{B} = {} & (B_{b,s+1}^{B,D} - (1 + i_{s-1}^{D})B_{b,s}^{B,D}) + (B_{b,s+1}^{B,B^h} - (1 + i_{s-1}^{B})B_{b,s}^{B,B^h}) \\ & + \mathcal{E}_s(B_{b,s+1}^{B,B^f} - (1 + i_{s-1}^{B,f})B_{b,s}^{B,B^f}) \\ & - (B_{b,s}^{B,H} - C_{b,s}^{B,H}) - (B_{b,s}^{B,F} - C_{b,s}^{B,F}) - \Phi_{b,s}^{B} - I_{b,s}^{B}. \end{aligned} \tag{56}$$

Profits are defined as the increase in deposits $B_{b,s+1}^{B,D}$ from domestic households net of interest payments at the deposit rate $i_{s-1}^{D}$, plus the increase in net loans $B_{b,s+1}^{B,B^h}$ from the domestic interbank market net of interest payments at the domestic interbank rate $i_{s-1}^{B}$, plus the domestic-currency-denominated increase in net loans $B_{b,s+1}^{B,B^f}$ from the foreign interbank market net of interest payments at the foreign interbank rate $i_{s-1}^{B,f}$, minus new mortgage lending $B_{b,s}^{B,H}$ net of mortgage loan income $C_{b,s}^{B,H}$, minus new corporate lending net of corporate loan income $C_{b,s}^{B,F}$, minus regulation costs $\Phi_{b,s}^{B}$.

The intermediate bank enters period $s$ with previously accumulated mortgage or corporate credit outstanding $A_{b,s}^{B,Z}$, which subsequently evolves according to accumulation function

$$A_{b,s+1}^{B,Z} = (1 - \alpha^Z)A_{b,s}^{B,Z} + B_{b,s}^{B,Z}, \tag{57}$$

where $Z \in \{H, F\}$, while $0 \leq \alpha^Z \leq 1$. During period $s$, the intermediate bank extends new mortgage or corporate credit $B_{b,s}^{B,Z}$ to satisfy demand, ultimately from domestic and foreign households or firms. Its mortgage or corporate loan income $C_{b,s}^{B,Z}$ satisfies

$$C_{b,s}^{B,Z} = (\alpha^Z + i_{b,s-1}^Z)A_{b,s}^{B,Z}, \tag{58}$$

reflecting amortization income at rate $\alpha^Z$ and interest income at variable mortgage or corporate loan rate $i_{s-1}^Z$ on the outstanding stock of mortgage or corporate credit.

The intermediate bank transforms deposit and money market funding into risky differentiated intermediate mortgage and corporate loans according to balance sheet identity:

$$A_{b,s+1}^{B,H} + A_{b,s+1}^{B,F} = B_{b,s+1}^{B,D} + B_{b,s+1}^{B,B^h} + \mathcal{E}_s B_{b,s+1}^{B,B^f} + K_{b,s+1}^{B}. \tag{59}$$

The bank credit stock $A_{s+1}^B$ measures aggregate bank assets, that is, $A_{s+1}^B = A_{s+1}^{B,H} + A_{s+1}^{B,F}$, while the money stock $M_{s+1}^S$ measures aggregate bank funding, that is, $M_{s+1}^S = B_{s+1}^{B,D} + B_{s+1}^{B,B^h} + \mathcal{E}_s B_{s+1}^{B,B^f}$. The bank capital ratio $\kappa_{s+1}$ equals the ratio of aggregate bank capital to assets, that is, $\kappa_{s+1} = K_{s+1}^B / A_{s+1}^B$. The banking sector takes offsetting positions in the domestic and foreign interbank markets, that is, $B_{s+1}^{B,B^h} + \mathcal{E}_s B_{s+1}^{B,B^f} = 0$.

In transforming deposit and money market funding into risky mortgage and corporate loans, the intermediate bank incurs costs of satisfying the regulatory capital and foreign currency liquidity requirements:

$$\Phi_{b,s}^B = \mathcal{G}^{B,C}(A_{b,s}^{B,H}, A_{b,s}^{B,F}, K_{b,s}^B) + \mathcal{G}^{B,L}(B_{b,s}^{B,B^f}) + F_s^B. \tag{60}$$

Motivated by Gerali et al. (2010), the capital regulation cost is decreasing in the ratio of bank capital to assets at a decreasing rate,

$$\mathcal{G}^{B,C}(A^{B,H}_{b,s+1}, A^{B,F}_{b,s+1}, K^{B}_{b,s+1})$$
$$= \mu^B \left[ e^{(2+\eta^B)\left(1-\frac{1}{\kappa^R_{s+1}}\frac{K^B_{b,s+1}}{A^{B,H}_{b,s+1}+A^{B,F}_{b,s+1}}\right)} - 1 \right] K^B_{b,s+1}, \tag{61}$$

given bank capital requirement $\kappa^R_{s+1}$, where $\mu^B > 0$ and $\eta^B > 0$. In steady-state equilibrium, the bank capital ratio equals its required value, and the cost of capital regulation is constant. Motivated by Gabaix and Maggiori (2015), the foreign currency liquidity regulation cost is convex with respect to the ratio of net foreign interbank market funding to nominal output,

$$\mathcal{G}^{B,L}(B^{B,B^f}_{b,s+1}) = \frac{1}{\beta}\left[\frac{\gamma^B_s}{2}\left(\frac{\mathcal{E}_s B^{B,B^f}_{b,s+1}}{P^Y_s Y_s}\right)^2 - \gamma^B r \frac{\mathcal{E}_s B^{B,B^f}_{b,s+1}}{P^Y_s Y_s}\right] P^Y_s Y_s, \tag{62}$$

given foreign currency liquidity shifter $\gamma^B_s$, where $\gamma^B_s > 0$. Fixed cost $F^B_s$ ensures that $\int_0^1 \Phi^B_{b,s} db = -\Delta K^B_{s+1}$.

The intermediate bank enters period $s$ with previously accumulated bank capital stock $K^B_{b,s}$, which subsequently evolves according to accumulation function

$$K^B_{b,s+1} = (1-\delta^B_{b,s})K^B_{b,s} + \mathcal{H}^B(I^B_{b,s}, I^B_{b,s-1}). \tag{63}$$

The bank capital destruction rate $\delta^B_{b,s}$ equals the ratio of credit losses on mortgage and corporate loans to capital, given mortgage credit loss rate $\delta^{H^E}_s$ and corporate credit loss rate $\delta^{F^E}_s$:

$$\delta^B_{b,s}K^B_{b,s} = \delta^{H^E}_s(\alpha^H + i^H_{b,s-1})A^{B,H}_{b,s} + \delta^{F^E}_s(\alpha^F + i^F_{b,s-1})A^{B,F}_{b,s}. \tag{64}$$

The intermediate bank smooths retained earnings intertemporally, and effective retained earnings function $\mathcal{H}^B(I^B_{b,s}, I^B_{b,s-1})$ incorporates convex adjustment costs,

$$\mathcal{H}^B(I^B_{b,s}, I^B_{b,s-1}) = \left[1 - \frac{\chi^B}{2}\left(\frac{I^B_{b,s}}{I^B_{b,s-1}} - 1\right)^2\right] I^B_{b,s} - F^C_s, \tag{65}$$

where $\chi^B > 0$. In steady-state equilibrium, these adjustment costs equal zero, and effective retained earnings equals actual retained earnings. Fixed cost $F^C_s$ ensures that $\int_0^1 \mathcal{H}^B(I^B_{b,s}, I^B_{b,s-1})db = I^B_s$.

In period $t$, the intermediate bank chooses state-contingent sequences for deposit funding $\{B_{b,s+1}^{B,D}\}_{s=t}^{\infty}$, net domestic interbank market funding $\{B_{b,s+1}^{B,B^h}\}_{s=t}^{\infty}$, net foreign interbank market funding $\{B_{b,s+1}^{B,B^f}\}_{s=t}^{\infty}$, retained earnings $\{I_{b,s}^{B}\}_{s=t}^{\infty}$, and the bank capital stock $\{K_{b,s+1}^{B}\}_{s=t}^{\infty}$ to maximize pre-dividend stock market value (55) subject to balance sheet identity (59), bank capital accumulation function (63), mortgage and corporate credit accumulation functions (57), and terminal non-negativity constraint $K_{b,T+1}^{B} \geq 0$ for $T \to \infty$. In equilibrium, the solutions to this value maximization problem satisfy necessary first-order conditions

$$1 + i_t^B = 1 + i_t^D, \tag{66}$$

$$\mathrm{E}_t \frac{\beta\lambda_{t+1}^U}{\lambda_t^U}\left[(1 + i_t^B) - (1 + i_t^{B,f})\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right] = \mathrm{E}_t \frac{\beta\lambda_{t+1}^U}{\lambda_t^U}\frac{\mathcal{G}_B^{B,L}(b, t+1)}{\mathcal{E}_t}, \tag{67}$$

$$\frac{Q_{b,t}^B}{P_t^Y}\mathcal{H}_1^B(b,t) + \mathrm{E}_t \frac{\beta\lambda_{t+1}^U}{\lambda_t^U}\frac{Q_{b,t+1}^B}{P_{t+1}^Y}\mathcal{H}_2^B(b, t+1) = 1, \tag{68}$$

$$\frac{Q_{b,t}^B}{P_t^Y} = \mathrm{E}_t \frac{\beta\lambda_{t+1}^U}{\lambda_t^U}\left\{\frac{Q_{b,t+1}^B}{P_{t+1}^Y} - \left[\frac{\lambda_t^U}{\beta\lambda_{t+1}^U} - (1 + i_t^B)\right] - \mathcal{G}_{K^B}^{B,C}(b, t+1)\right\}. \tag{69}$$

Here $Q_{b,s}^B$ denotes the shadow price of bank capital, which is proportional to the Lagrange multiplier on the period $s$ bank capital accumulation function.

### 2.3.3 Credit Supply

In an adaptation of the model of nominal price rigidity proposed by Calvo (1983) to the banking sector along the lines of Hülsewig, Mayer, and Wollmershäuser (2009), each period a randomly selected fraction $1-\omega^B$ of intermediate banks adjust their gross mortgage and corporate loan rates optimally, where $0 \leq \omega^B < 1$. The remaining fraction $\omega^B$ of intermediate banks do not adjust their loan rates,

$$\alpha^Z + i_{b,t}^Z = \alpha^Z + i_{b,t-1}^Z, \tag{70}$$

where $Z \in \{H, F\}$. If the intermediate bank can adjust its gross mortgage and corporate loan rates in period $t$, then it does so to maximize pre-dividend stock market value (55) subject to balance sheet identity (59), intermediate loan demand function (53), and the assumed financial friction. We consider a symmetric equilibrium under which all bank-specific endogenous state variables are restricted to equal their aggregate counterparts. It follows that all intermediate banks that adjust their loan rates in period $t$ solve an identical value maximization problem, which implies that they all choose common loan rates $i_t^{Z,*}$ given by necessary first-order conditions:

$$\frac{\alpha^Z + i_t^{Z,*}}{\alpha^Z + i_t^Z} = \frac{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty} (\omega^B)^{s-t} \frac{\beta^{s-t}\lambda_s^U}{\lambda_t^U} \theta_s^Z \frac{(1+i_{s-1}^B)+\mathcal{G}_{A^{B,Z}}^{B,C}(b,s)}{\alpha^Z + i_{s-1}^Z} \\ \times \left(\frac{\alpha^Z + i_{s-1}^Z}{\alpha^Z + i_t^Z}\right)^{\theta_s^Z} \left(\frac{\alpha^Z + i_t^{Z,*}}{\alpha^Z + i_t^Z}\right)^{-\theta_s^Z} (\alpha^Z + i_{s-1}^Z) A_s^{B,Z} \end{array}}{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty} (\omega^B)^{s-t} \frac{\beta^{s-t}\lambda_s^U}{\lambda_t^U} \left[\theta_s^Z \left(\frac{1+i_t^{Z,*}}{\alpha^Z + i_t^{Z,*}} - \delta_s^{Z^E} \frac{Q_{b,s}^B}{P_s^Y}\right) \right. \\ \left. - \left(1 - \delta_s^{Z^E} \frac{Q_{b,s}^B}{P_s^Y}\right)\right] \left(\frac{\alpha^Z + i_{s-1}^Z}{\alpha^Z + i_t^Z}\right)^{\theta_s^Z - 1} \left(\frac{\alpha^Z + i_t^{Z,*}}{\alpha^Z + i_t^Z}\right)^{-\theta_s^Z} \\ \times (\alpha^Z + i_{s-1}^Z) A_s^{B,Z} \end{array}}. \tag{71}$$

Aggregate gross mortgage or corporate loan rate index (54) equals an average of the gross mortgage or corporate loan rate set by the fraction $1 - \omega^B$ of intermediate banks that adjust their loan rates in period $t$, and the average of the gross mortgage or corporate loan rates set by the remaining fraction $\omega^B$ of intermediate banks that do not adjust their loan rates:

$$\alpha^Z + i_t^Z = \left[(1-\omega^B)(\alpha^Z + i_t^{Z,*})^{1-\theta_{t+1}^Z} + \omega^B (\alpha^Z + i_{t-1}^Z)^{1-\theta_{t+1}^Z}\right]^{\frac{1}{1-\theta_{t+1}^Z}}. \tag{72}$$

Since those intermediate banks able to adjust their loan rates in period $t$ are selected randomly from among all intermediate banks, the average gross mortgage or corporate loan rate set by the remaining intermediate banks equals the value of the aggregate gross mortgage or corporate loan rate index that prevailed during period $t-1$.

### 2.3.4 Loan Defaults and Foreign Currency Liquidity

We define the financial gap as a weighted average of the contemporaneous deviations of real non-financial private-sector debt and the relative prices of housing and equity from their steady-state equilibrium values,

$$\ln F_t - \ln \bar{F}_t = \phi_B^F \left( \ln \frac{D_{t+1}^P}{P_t^Y} - \ln \frac{\bar{D}_{t+1}^P}{\bar{P}_t^Y} \right) + \phi_H^F \left( \ln \frac{V_t^H}{P_t^Y} - \ln \frac{\bar{V}_t^H}{\bar{P}_t^Y} \right) + \phi_F^F \left( \ln \frac{V_t^F}{P_t^Y} - \ln \frac{\bar{V}_t^F}{\bar{P}_t^Y} \right), \tag{73}$$

where $\phi_B^F > 0$, $\phi_H^F > 0$, $\phi_F^F > 0$, and $\phi_B^F + \phi_H^F + \phi_F^F = 1$. Non-financial private-sector debt $D_{t+1}^P$ satisfies $D_{t+1}^P = D_{t+1}^H + D_{t+1}^F$. The change in the financial gap reflects financial conditions, as well as other drivers of the financial cycle, while its level measures financial vulnerability.

The mortgage and corporate loan default rates satisfy loan default relationships exhibiting partial adjustment dynamics of the form

$$\delta_t^Z - \delta^Z = \rho^{\delta^C} (\delta_{t-1}^Z - \delta^Z) - (1 - \rho^{\delta^C}) \zeta^{\delta^Z} \times \left[ (\ln Y_t - \ln Y_t^P) + \zeta^F (\ln F_t - \ln \bar{F}_t) \right] + \nu_t^{\delta^Z}, \tag{74}$$

where $Z \in \{H, F\}$, while $0 < \delta^Z < 1$, $0 \leq \rho^{\delta^C} < 1$, $\zeta^{\delta^Z} > 0$, and $\zeta^F > 0$. As specified, the deviation of the mortgage or corporate loan default rate from its steady-state equilibrium value is inertially decreasing in the contemporaneous output and financial gaps. Deviations from these default rate relationships are captured by mean zero and serially correlated mortgage or corporate loan default shock $\nu_t^{\delta^Z}$.

The foreign currency liquidity shifter satisfies a foreign currency liquidity relationship that helps stabilize the net foreign asset ratio of the form

$$r(\gamma_t^B - \gamma^B) = -\zeta^{\mathcal{E}} \left( \frac{A_{t+1}}{P_t^Y Y_t} - \frac{\bar{A}_{t+1}}{P_t^Y Y_t} \right) + \nu_t^{\mathcal{E}}, \tag{75}$$

where $\zeta^{\mathcal{E}} > 0$. As specified, the deviation of the foreign currency liquidity shifter from its steady-state equilibrium value is decreasing in the contemporaneous deviation of the net foreign asset ratio from its steady-state equilibrium value. Deviations from this foreign currency liquidity relationship are captured by mean zero and serially correlated foreign currency liquidity shock $\nu_t^{\mathcal{E}}$.

## *2.4 The Trade Sector*

Let $\mathcal{Q}_t$ denote the real exchange rate, which measures the price of foreign output in terms of domestic output, that is, $\mathcal{Q}_t = \mathcal{E}_t P_t^{Y,f} / P_t^Y$.

### *2.4.1 The Export Sector*

The export sector transforms the final output good into a final export good under producer currency pricing, with partial indexation to contemporaneous domestic-currency-denominated foreign output price inflation. This partial indexation mechanism incorporates some degree of local currency pricing.

**Export Demand.** There exist a large number of perfectly competitive firms which combine differentiated intermediate export goods $\{X_{x,t}\}_{x=0}^1$ supplied by intermediate export good firms to produce final export good $X_t$ according to constant elasticity of substitution production function

$$X_t = \left[ \int_0^1 (X_{x,t})^{\frac{\theta_t^X - 1}{\theta_t^X}} dx \right]^{\frac{\theta_t^X}{\theta_t^X - 1}}. \tag{76}$$

The representative final export good firm maximizes profits from production of the final export good with respect to inputs of intermediate export goods, implying

$$X_{x,t} = \left( \frac{P_{x,t}^X}{P_t^X} \right)^{-\theta_t^X} X_t, \tag{77}$$

$$P_t^X = \left[ \int_0^1 (P_{x,t}^X)^{1-\theta_t^X} dx \right]^{\frac{1}{1-\theta_t^X}}. \tag{78}$$

Serially uncorrelated export price markup shock $\vartheta_t^X$ satisfies $\vartheta_t^X = \theta_t^X / (\theta_t^X - 1)$, where the price elasticity of demand for intermediate export goods $\theta_t^X$ satisfies $\theta_t^X > 1$.

**Export Supply.** There exists a continuum of monopolistically competitive intermediate export good firms indexed by $x \in [0,1]$. Intermediate export good firms supply differentiated intermediate export goods, but are otherwise identical.

Each intermediate good exporter $x$ sells shares to domestic credit-unconstrained households at price $V_{x,t}^X$. Acting in the interests of its shareholders, it maximizes its pre-dividend stock market value:

$$\Pi_{x,t}^X + V_{x,t}^X = \mathrm{E}_t \sum_{s=t}^{\infty} \frac{\beta^{s-t}\lambda_s^U}{\lambda_t^U} \Pi_{x,s}^X. \tag{79}$$

Shares entitle households to dividend payments equal to profits $\Pi_{x,s}^X$, defined as earnings less fixed cost $F_s^X$:

$$\Pi_{x,s}^X = P_{x,s}^X X_{x,s} - P_s^Y X_{x,s} - F_s^X. \tag{80}$$

Earnings are defined as revenues from sales of differentiated intermediate export good $X_{x,s}$ at price $P_{x,s}^X$ minus expenditures on final output good $X_{x,s}$. The representative intermediate export good firm purchases the final output good and differentiates it. Fixed cost $F_s^X$ ensures that $\int_0^1 \Pi_{x,s}^X dx = 0$.

In an adaptation of the model of nominal import price rigidity proposed by Monacelli (2005) to the export sector, each period a randomly selected fraction $1-\omega^X$ of intermediate export good firms adjust their price optimally, where $0 \leq \omega^X < 1$. The remaining fraction $\omega^X$ of intermediate export good firms adjust their price to account for past export price inflation, as well as contemporaneous domestic-currency-denominated foreign output price inflation, according to partial indexation rule

$$P_{x,t}^X = \left[\left(\frac{P_{t-1}^X}{P_{t-2}^X}\right)^{1-\mu^X}\left(\frac{\mathcal{E}_t P_t^{Y,f}}{\mathcal{E}_{t-1}P_{t-1}^{Y,f}}\right)^{\mu^X}\right]^{\gamma^X}$$

$$\times\left[\left(\frac{\bar{P}_{t-1}^X}{\bar{P}_{t-2}^X}\right)^{1-\mu^X}\left(\frac{\bar{\mathcal{E}}_t \bar{P}_t^{Y,f}}{\bar{\mathcal{E}}_{t-1}\bar{P}_{t-1}^{Y,f}}\right)^{\mu^X}\right]^{1-\gamma^X} P_{x,t-1}^X, \tag{81}$$

where $0 \leq \gamma^X \leq 1$ and $0 \leq \mu^X \leq 1$. If the representative intermediate export good firm can adjust its price optimally in period $t$, then it does so to maximize pre-dividend stock market value (79) subject to intermediate export good demand function (77), and the assumed form of nominal export price rigidity. Since all intermediate export good firms that adjust their price optimally in period $t$ solve an identical value maximization problem, in equilibrium they all choose a common price $P_t^{X,*}$ given by necessary first-order condition:

$$\frac{P_t^{X,*}}{P_t^X} = \frac{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty} (\omega^X)^{s-t} \frac{\beta^{s-t}\lambda_s^U}{\lambda_t^U} \theta_s^X \frac{P_s^Y}{P_s^X} \\ \times \left\{ \left[ \left( \frac{P_{t-1}^X}{P_{s-1}^X} \right)^{1-\mu^X} \left( \frac{\mathcal{E}_t P_t^{Y,f}}{\mathcal{E}_s P_s^{Y,f}} \right)^{\mu^X} \right]^{\gamma^X} \right. \\ \left. \times \left[ \left( \frac{\bar{P}_{t-1}^X}{\bar{P}_{s-1}^X} \right)^{1-\mu^X} \left( \frac{\bar{\mathcal{E}}_t \bar{P}_t^{Y,f}}{\bar{\mathcal{E}}_s \bar{P}_s^{Y,f}} \right)^{\mu^X} \right]^{1-\gamma^X} \frac{P_s^X}{P_t^X} \right\}^{\theta_s^X} \\ \times \left( \frac{P_t^{X,*}}{P_t^X} \right)^{-\theta_s^X} P_s^X X_s \end{array}}{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty} (\omega^X)^{s-t} \frac{\beta^{s-t}\lambda_s^U}{\lambda_t^U} (\theta_s^X - 1) \\ \times \left\{ \left[ \left( \frac{P_{t-1}^X}{P_{s-1}^X} \right)^{1-\mu^X} \left( \frac{\mathcal{E}_t P_t^{Y,f}}{\mathcal{E}_s P_s^{Y,f}} \right)^{\mu^X} \right]^{\gamma^X} \right. \\ \left. \times \left[ \left( \frac{\bar{P}_{t-1}^X}{\bar{P}_{s-1}^X} \right)^{1-\mu^X} \left( \frac{\bar{\mathcal{E}}_t \bar{P}_t^{Y,f}}{\bar{\mathcal{E}}_s \bar{P}_s^{Y,f}} \right)^{\mu^X} \right]^{1-\gamma^X} \frac{P_s^X}{P_t^X} \right\}^{\theta_s^X - 1} \\ \times \left( \frac{P_t^{X,*}}{P_t^X} \right)^{-\theta_s^X} P_s^X X_s \end{array}}. \quad (82)$$

Aggregate export price index (78) equals an average of the price set by the fraction $1-\omega^X$ of intermediate export good firms that adjust their price optimally in period $t$, and the average of the prices set by the remaining fraction $\omega^X$ of intermediate export good firms that adjust their price according to partial indexation rule (81):

$$P_t^X = \left\{ (1-\omega^X)(P_t^{X,*})^{1-\theta_t^X} + \omega^X \right. \\ \times \left\{ \left[ \left( \frac{P_{t-1}^X}{P_{t-2}^X} \right)^{1-\mu^X} \left( \frac{\mathcal{E}_t P_t^{Y,f}}{\mathcal{E}_{t-1} P_{t-1}^{Y,f}} \right)^{\mu^X} \right]^{\gamma^X} \right. \\ \left. \left. \times \left[ \left( \frac{\bar{P}_{t-1}^X}{\bar{P}_{t-2}^X} \right)^{1-\mu^X} \left( \frac{\bar{\mathcal{E}}_t \bar{P}_t^{Y,f}}{\bar{\mathcal{E}}_{t-1} \bar{P}_{t-1}^{Y,f}} \right)^{\mu^X} \right]^{1-\gamma^X} P_{t-1}^X \right\}^{1-\theta_t^X} \right\}^{\frac{1}{1-\theta_t^X}}. \tag{83}$$

Since those intermediate export good firms able to adjust their price optimally in period $t$ are selected randomly from among all intermediate export good firms, the average price set by the remaining intermediate export good firms equals the value of the aggregate export price index that prevailed during period $t-1$, rescaled to account for past export price inflation, as well as contemporaneous domestic-currency-denominated foreign output price inflation.

### *2.4.2 The Import Sector*

The import sector transforms the foreign final export good into a final import good under local currency pricing, with partial indexation to contemporaneous domestic-currency-denominated foreign output price inflation. This partial indexation mechanism incorporates some degree of producer currency pricing. The final import good is then combined with the final output good to produce goods for absorption by households, firms, and the government. Under this transformation, exchange rate pass-through to the prices of these absorption goods is incomplete in the short run but complete in the long run.

**Import Demand.** There exist a large number of perfectly competitive firms which combine the final output good $Z_t^h \in \{C_t^h, I_t^{H,h}, I_t^{K,h}, G_t^{C,h}, G_t^{I,h}\}$ with the final import good $Z_t^f \in$

$\{C_t^f, I_t^{H,f}, I_t^{K,f}, G_t^{C,f}, G_t^{I,f}\}$ to produce private consumption, residential investment, business investment, public consumption, or public investment good $Z_t \in \{C_t, I_t^H, I_t^K, G_t^C, G_t^I\}$ according to constant elasticity of substitution production function

$$Z_t = \left[ (1-\phi_Z^M)^{\frac{1}{\psi^M}} (Z_t^h)^{\frac{\psi^M-1}{\psi^M}} + (\phi_Z^M)^{\frac{1}{\psi^M}} (\vartheta^X \vartheta^M Z_t^f)^{\frac{\psi^M-1}{\psi^M}} \right]^{\frac{\psi^M}{\psi^M-1}}, \tag{84}$$

where $0 \leq \phi_Z^M < 1$ and $\psi^M > 0$, while $\phi_{I^H}^M = \phi_{I^K}^M = \phi_I^M$ and $\phi_{G^C}^M = \phi_{G^I}^M = \phi_G^M$. The representative absorption good firm maximizes profits from production of the private consumption, residential investment, business investment, public consumption, or public investment good, with respect to inputs of the final output and import goods, implying

$$Z_t^h = (1-\phi_Z^M) \left( \frac{P_t^Y}{P_t^Z} \right)^{-\psi^M} Z_t, \; Z_t^f = \phi_Z^M \left( \frac{1}{\vartheta^X \vartheta^M} \frac{P_t^M}{P_t^Z} \right)^{-\psi^M} \frac{Z_t}{\vartheta^X \vartheta^M}, \tag{85}$$

$$P_t^Z = \left[ (1-\phi_Z^M)(P_t^Y)^{1-\psi^M} + \phi_Z^M \left( \frac{P_t^M}{\vartheta^X \vartheta^M} \right)^{1-\psi^M} \right]^{\frac{1}{1-\psi^M}}. \tag{86}$$

The aggregate absorption price indices $P_t^Z$ equal the minimum cost of producing one unit of the absorption good, given the prices of the final output and import goods.

There exist a large number of perfectly competitive firms which combine differentiated intermediate import goods $\{M_{m,t}\}_{m=0}^1$ supplied by intermediate import good firms to produce final import good $M_t$ according to constant elasticity of substitution production function:

$$M_t = \left[ \int_0^1 (M_{m,t})^{\frac{\theta_t^M-1}{\theta_t^M}} dm \right]^{\frac{\theta_t^M}{\theta_t^M-1}}. \tag{87}$$

The representative final import good firm maximizes profits from production of the final import good with respect to inputs of intermediate import goods, implying

$$M_{m,t} = \left( \frac{P_{m,t}^M}{P_t^M} \right)^{-\theta_t^M} M_t, \tag{88}$$

$$P_t^M = \left[ \int_0^1 (P_{m,t}^M)^{1-\theta_t^M} dm \right]^{\frac{1}{1-\theta_t^M}}. \tag{89}$$

Serially uncorrelated import price markup shock $\vartheta_t^M$ satisfies $\vartheta_t^M = \theta_t^M/(\theta_t^M - 1)$, where the price elasticity of demand for intermediate import goods $\theta_t^M$ satisfies $\theta_t^M > 1$.

**Import Supply.** There exists a continuum of monopolistically competitive intermediate import good firms indexed by $m \in [0, 1]$. Intermediate import good firms supply differentiated intermediate import goods, but are otherwise identical.

Each intermediate good importer $m$ sells shares to domestic credit-unconstrained households at price $V_{m,t}^M$. Acting in the interests of its shareholders, it maximizes its pre-dividend stock market value:

$$\Pi_{m,t}^M + V_{m,t}^M = \mathrm{E}_t \sum_{s=t}^{\infty} \frac{\beta^{s-t} \lambda_s^U}{\lambda_t^U} \Pi_{m,s}^M. \tag{90}$$

Shares entitle households to dividend payments equal to profits $\Pi_{m,s}^M$, defined as earnings less fixed cost $F_s^M$:

$$\Pi_{m,s}^M = P_{m,s}^M M_{m,s} - \mathcal{E}_s P_s^{X,f} M_{m,s} - F_s^M. \tag{91}$$

Earnings are defined as revenues from sales of differentiated intermediate import good $M_{m,s}$ at price $P_{m,s}^M$ minus expenditures on foreign final export good $M_{m,s}$. The representative intermediate import good firm purchases the foreign final export good and differentiates it. Fixed cost $F_s^M$ ensures that $\int_0^1 \Pi_{m,s}^M dm = 0$.

In an extension of the model of nominal import price rigidity proposed by Monacelli (2005), each period a randomly selected fraction $1 - \omega^M$ of intermediate import good firms adjust their price optimally, where $0 \leq \omega^M < 1$. The remaining fraction $\omega^M$ of intermediate import good firms adjust their price to account for past import price inflation, as well as contemporaneous domestic-currency-denominated foreign output price inflation, according to partial indexation rule

$$P_{m,t}^{M} = \left[\left(\frac{P_{t-1}^{M}}{P_{t-2}^{M}}\right)^{1-\mu^M}\left(\frac{\mathcal{E}_t P_t^{Y,f}}{\mathcal{E}_{t-1}P_{t-1}^{Y,f}}\right)^{\mu^M}\right]^{\gamma^M} \times \left[\left(\frac{\bar{P}_{t-1}^{M}}{\bar{P}_{t-2}^{M}}\right)^{1-\mu^M}\left(\frac{\bar{\mathcal{E}}_t \bar{P}_t^{Y,f}}{\bar{\mathcal{E}}_{t-1}\bar{P}_{t-1}^{Y,f}}\right)^{\mu^M}\right]^{1-\gamma^M} P_{m,t-1}^{M}, \qquad (92)$$

where $0 \leq \gamma^M \leq 1$ and $0 \leq \mu^M \leq 1$. If the representative intermediate import good firm can adjust its price optimally in period $t$, then it does so to maximize pre-dividend stock market value (90) subject to intermediate import good demand function (88), and the assumed form of nominal import price rigidity. Since all intermediate import good firms that adjust their price optimally in period $t$ solve an identical value maximization problem, in equilibrium they all choose a common price $P_t^{M,*}$ given by necessary first-order condition

$$\frac{P_t^{M,*}}{P_t^M} = \frac{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty}(\omega^M)^{s-t}\frac{\beta^{s-t}\lambda_s^U}{\lambda_t^U}\theta_s^M\frac{\mathcal{E}_s P_s^{X,f}}{P_s^M} \\ \times\left\{\left[\left(\frac{P_{t-1}^M}{P_{s-1}^M}\right)^{1-\mu^M}\left(\frac{\mathcal{E}_t P_t^{Y,f}}{\mathcal{E}_s P_s^{Y,f}}\right)^{\mu^M}\right]^{\gamma^M} \times\left[\left(\frac{\bar{P}_{t-1}^M}{\bar{P}_{s-1}^M}\right)^{1-\mu^M}\left(\frac{\bar{\mathcal{E}}_t \bar{P}_t^{Y,f}}{\bar{\mathcal{E}}_s \bar{P}_s^{Y,f}}\right)^{\mu^M}\right]^{1-\gamma^M}\frac{P_s^M}{P_t^M}\right\}^{\theta_s^M} \\ \times\left(\frac{P_t^{M,*}}{P_t^M}\right)^{-\theta_s^M} P_s^M M_s \end{array}}{\begin{array}{l} \mathrm{E}_t \sum_{s=t}^{\infty}(\omega^M)^{s-t}\frac{\beta^{s-t}\lambda_s^U}{\lambda_t^U}(\theta_s^M - 1) \\ \times\left\{\left[\left(\frac{P_{t-1}^M}{P_{s-1}^M}\right)^{1-\mu^M}\left(\frac{\mathcal{E}_t P_t^{Y,f}}{\mathcal{E}_s P_s^{Y,f}}\right)^{\mu^M}\right]^{\gamma^M} \times\left[\left(\frac{\bar{P}_{t-1}^M}{\bar{P}_{s-1}^M}\right)^{1-\mu^M}\left(\frac{\bar{\mathcal{E}}_t \bar{P}_t^{Y,f}}{\bar{\mathcal{E}}_s \bar{P}_s^{Y,f}}\right)^{\mu^M}\right]^{1-\gamma^M}\frac{P_s^M}{P_t^M}\right\}^{\theta_s^M - 1} \\ \times\left(\frac{P_t^{M,*}}{P_t^M}\right)^{-\theta_s^M} P_s^M M_s \end{array}}. \qquad (93)$$

Aggregate import price index (89) equals an average of the price set by the fraction $1-\omega^M$ of intermediate import good firms that adjust their price optimally in period $t$, and the average of the prices set by the remaining fraction $\omega^M$ of intermediate import good firms that adjust their price according to partial indexation rule (92):

$$P_t^M = \Bigg\{ (1-\omega^M)(P_t^{M,*})^{1-\theta_t^M} + \omega^M \Bigg\{ \left[ \left(\frac{P_{t-1}^M}{P_{t-2}^M}\right)^{1-\mu^M} \left(\frac{\mathcal{E}_t P_t^{Y,f}}{\mathcal{E}_{t-1} P_{t-1}^{Y,f}}\right)^{\mu^M} \right]^{\gamma^M} \times \left[ \left(\frac{\bar{P}_{t-1}^M}{\bar{P}_{t-2}^M}\right)^{1-\mu^M} \left(\frac{\bar{\mathcal{E}}_t \bar{P}_t^{Y,f}}{\bar{\mathcal{E}}_{t-1} \bar{P}_{t-1}^{Y,f}}\right)^{\mu^M} \right]^{1-\gamma^M} P_{t-1}^M \Bigg\}^{1-\theta_t^M} \Bigg\}^{\frac{1}{1-\theta_t^M}}. \tag{94}$$

Since those intermediate import good firms able to adjust their price optimally in period $t$ are selected randomly from among all intermediate import good firms, the average price set by the remaining intermediate import good firms equals the value of the aggregate import price index that prevailed during period $t-1$, rescaled to account for past import price inflation, as well as contemporaneous domestic-currency-denominated foreign output price inflation.

## 2.5 The Monetary, Fiscal, and Macroprudential Authorities

The government consists of a monetary authority, a fiscal authority, and a macroprudential authority. The monetary authority conducts monetary policy and executes foreign exchange intervention. The fiscal authority conducts fiscal policy and administers capital controls. The macroprudential authority conducts macroprudential policy.

### 2.5.1 The Monetary Authority

The monetary authority takes offsetting positions in the domestic and foreign interbank markets, transferring profits $\Pi_t^C$ to the fiscal authority,

$$\Pi_t^C = (B_{t+1}^{C,B^h} - (1+i_{t-1}^B)B_t^{C,B^h}) + \mathcal{E}_t(B_{t+1}^{C,B^f} - (1+i_{t-1}^{B,f})B_t^{C,B^f}), \tag{95}$$

where $B_{t+1}^{C,B^h} + \mathcal{E}_t B_{t+1}^{C,B^f} = 0$. Profits are defined as the increase in net loans $B_{t+1}^{C,B^h}$ from the domestic interbank market net of interest payments at the domestic interbank rate $i_{t-1}^B$, plus the domestic-currency-denominated increase in net loans $B_{t+1}^{C,B^f}$ from the foreign interbank market net of interest payments at the foreign interbank rate $i_{t-1}^{B,f}$. The stock of foreign exchange reserves $R_{t+1}$ satisfies $R_{t+1} = -B_{t+1}^{C,B^f}$, while the foreign exchange reserve ratio $r_{t+1}$ satisfies $r_{t+1} = \mathcal{E}_t R_{t+1}/P_t^Y Y_t$, and foreign exchange intervention $FXI_t$ satisfies $FXI_t = \Delta r_{t+1}$. Changes in foreign exchange reserves are fully sterilized since $\Delta \mathcal{E}_t R_{t+1} = \Delta B_{t+1}^{C,B^h}$.

**Monetary Policy.** The monetary authority implements monetary policy through control of the interbank rate according to a monetary policy rule exhibiting partial adjustment dynamics of the form

$$i_t^B - \bar{i}_t^B = \rho^{i^B}(i_{t-1}^B - \bar{i}_{t-1}^B) + (1-\rho^{i^B}) \times \left[\xi^{\pi^C} \mathrm{E}_t(\pi_{t+1}^C - \bar{\pi}_{t+1}^C) + \xi^{Y^G}(\ln Y_t - \ln Y_t^P)\right] + \nu_t^{i^B}, \tag{96}$$

where $0 \leq \rho^{i^B} < 1$, $\xi^{\pi^C} > 1$, and $\xi^{Y^G} \geq 0$. As specified, the deviation of the interbank rate from its steady-state equilibrium value is inertially increasing in the expected future deviation of consumption price inflation from its target value, as well as the contemporaneous output gap. We define the output gap as the deviation of output from its potential value, which we define as that output level consistent with full utilization of private physical capital and effective labor, given the private physical capital stock and effective labor force. Deviations from this monetary policy rule are captured by mean zero and serially uncorrelated monetary policy shock $\nu_t^{i^B}$.

**Foreign Exchange Intervention.** The foreign exchange reserve ratio satisfies a foreign exchange intervention rule that helps stabilize the real exchange rate of the form

$$r_{t+1} - r = -\xi^r(\ln \mathcal{Q}_t - \ln \bar{\mathcal{Q}}_t) + \nu_t^r, \tag{97}$$

where $r > 0$, $0 \leq \rho^r < 1$, and $\xi^r \geq 0$. As specified, the deviation of the foreign exchange reserve ratio from its steady-state equilibrium value is decreasing in the contemporaneous deviation of the real exchange rate from its steady-state equilibrium value. Deviations from this foreign exchange intervention rule are captured by mean zero and serially correlated foreign exchange intervention shock $\nu_t^r$.

### 2.5.2 The Fiscal Authority

The fiscal authority issues domestic-currency-denominated government bonds to domestic households, securing new government borrowing $B_t^{G,G}$. It also levies taxes on corporate earnings at rate $\tau_t^K$, on household labor income at rate $\tau_t^L$, on household consumption expenditures at rate $\tau_t^C$, on cross-border mortgage borrowing at rate $\tau_t^H$, and on cross-border corporate borrowing at rate $\tau_t^F$, generating tax revenues $T_t$. In addition, the fiscal authority receives profit transfer $\Pi_t^C$ from the monetary authority. These sources of funds are summed in government dynamic budget constraint:

$$
\begin{aligned}
C_t^{G,G} + P_t^{G^C} G_t^C + P_t^{G^I} G_t^I + \int_0^1 T_{h,t}^Z dh = B_t^{G,G} \\
+ \int_0^1 \tau_t^K (P_{f,t}^Y Y_{f,t} - W_t L_{f,t} - \Phi_{f,t}^F) df + \int_0^1 \tau_t^L \int_0^1 W_{i,t} L_{h,i,t} di dh \\
+ \int_0^1 \tau_t^C P_t^C C_{h,t} dh + \tau_{t-1}^H (1 - \delta_t^H)(\alpha^H + i_{t-1}^{H,f}) \mathcal{E}_t D_t^{H,f} \\
+ \tau_{t-1}^F (1 - \delta_t^F)(\alpha^F + i_{t-1}^{F,f}) \mathcal{E}_t D_t^{F,f} + \Pi_t^C. \qquad (98)
\end{aligned}
$$

According to this dynamic budget constraint, the fiscal authority services its debt at cost $C_t^{G,G}$. It also purchases public consumption good $G_t^C$ at price $P_t^{G^C}$, and public investment good $G_t^I$ at price $P_t^{G^I}$, accumulating the public capital stock $K_{t+1}^G$ according to $K_{t+1}^G = (1 - \delta_G) K_t^G + G_t^I$ where $0 \leq \delta_G \leq 1$. Finally, the fiscal authority remits household type specific lump-sum transfer payments $\{T_{h,t}^Z\}_{h=0}^1$, which it allocates across non-discretionary transfers $\{T_{h,t}^{Z,N}\}_{h=0}^1$ and discretionary transfers $\{T_{h,t}^{Z,D}\}_{h=0}^1$, that is, $T_{h,t}^Z = T_{h,t}^{Z,N} + T_{h,t}^{Z,D}$. Non-discretionary transfers sum to zero across households, that is, $\int_0^1 T_{h,t}^{Z,N} dh = 0$, while discretionary transfers are targeted at credit-constrained households, that is,

$T_{h,t}^{U,D} = 0$. In steady-state equilibrium, non-discretionary transfers equate consumption across credit-unconstrained and credit-constrained households.

The fiscal authority enters period $t$ with previously accumulated public debt $D_t^G$, which subsequently evolves according to accumulation function

$$D_{t+1}^G = (1-\alpha^G)D_t^G + B_t^{G,G}, \tag{99}$$

where $\alpha^G = 1-\omega^G$, which implies that $0 \leq \alpha^G < 1$. Its debt service cost satisfies $C_t^{G,G} = (\alpha^G + i_{t-1}^{G^E})D_t^G$, reflecting an amortization payment at rate $\alpha^G$ and an interest payment at effective rate $i_{t-1}^{G^E}$ on the outstanding stock of public debt. This effective government rate evolves according to

$$i_t^{G^E} = \left(1 - \frac{B_{t-1}^{G,G}}{D_t^G}\right) i_{t-1}^{G^E} + \frac{B_{t-1}^{G,G}}{D_t^G} i_{t-1}^G, \tag{100}$$

as a weighted average of the interest rates applicable to outstanding and new public debt, the latter given by the past government bond yield.

**Fiscal Policy.** Public consumption and investment satisfy countercyclical fiscal expenditure rules exhibiting partial adjustment dynamics of the form

$$\ln \frac{G_t^Z}{\bar{G}_t^Z} = \rho^G \ln \frac{G_{t-1}^Z}{\bar{G}_{t-1}^Z} - (1-\rho^G)\xi^{G^Z}(\ln Y_t - \ln Y_t^P) + \nu_t^{G^Z}, \tag{101}$$

where $Z \in \{C, I\}$, while $0 \leq \rho^G < 1$ and $\xi^{G^Z} \geq 0$. As specified, the deviation of public consumption or investment from its steady-state equilibrium value is inertially decreasing in the contemporaneous output gap. Deviations from these fiscal expenditure rules are captured by mean zero and serially correlated public consumption or investment shock $\nu_t^{G^Z}$.

The tax rates applicable to corporate earnings, household labor income, and household consumption expenditures satisfy acyclical fiscal revenue rules of the form

$$\tau_t^Z - \tau^Z = \rho^\tau(\tau_{t-1}^Z - \tau^Z) + \nu_t^{\tau^Z}, \tag{102}$$

where $Z \in \{K, L, C\}$, while $0 < \tau^Z < 1$ and $0 \leq \rho^\tau < 1$. Deviations from these fiscal revenue rules are captured by mean zero and serially correlated corporate, labor income, or consumption tax rate shock $\nu_t^{\tau^Z}$.

Non-discretionary transfers to credit-constrained households satisfy a transfer payment rule that gradually stabilizes the net foreign asset ratio of the form

$$\frac{T_t^{C,N}}{P_t^Y Y_t} - \frac{\bar{T}_t^{C,N}}{\bar{P}_t^Y \bar{Y}_t} = \xi^{T^N} \left( \frac{A_{t+1}}{P_t^Y Y_t} - \frac{\bar{A}_{t+1}}{P_t^Y Y_t} \right), \tag{103}$$

where $\xi^{T^N} > 0$. As specified, the deviation of the non-discretionary transfer payment ratio from its steady-state equilibrium value is increasing in the contemporaneous deviation of the net foreign asset ratio from its steady-state equilibrium value. Discretionary transfers to credit-constrained households satisfy a transfer payment rule that gradually stabilizes the public debt ratio of the form

$$\frac{T_t^{C,D}}{P_t^Y Y_t} - \frac{\bar{T}_t^{C,D}}{\bar{P}_t^Y \bar{Y}_t} = -\xi^{T^D} \left( \frac{D_{t+1}^G}{P_t^Y Y_t} - \frac{\bar{D}_{t+1}^G}{P_t^Y Y_t} \right) + \nu_t^T, \tag{104}$$

where $\xi^{T^D} > 0$. As specified, the deviation of the discretionary transfer payment ratio from its steady-state equilibrium value is decreasing in the contemporaneous deviation of the public debt ratio from its target value. Deviations from this transfer payment rule are captured by mean zero and serially correlated transfer payment shock $\nu_t^T$.

**Capital Flow Management.** The tax rates applicable to cross-border mortgage and corporate borrowing satisfy capital flow management rules exhibiting partial adjustment dynamics of the form

$$\tau_t^Z = \rho^{\tau^C} \tau_{t-1}^Z + (1 - \rho^{\tau^C}) \xi^{\tau^Z} \left( \ln \frac{\mathcal{E}_t D_{t+1}^{Z,f}}{P_t^Y} - \ln \frac{\bar{\mathcal{E}}_t \bar{D}_{t+1}^{Z,f}}{\bar{P}_t^Y} \right) + \nu_t^{\tau^Z}, \tag{105}$$

where $Z \in \{H, F\}$, while $\tau^Z = 0$, $0 \leq \rho^{\tau^C} < 1$ and $\xi^{\tau^Z} \geq 0$. As specified, the mortgage or corporate capital control tax rate is inertially increasing in the contemporaneous deviation of the real domestic-currency-denominated value of external mortgage or corporate debt from its steady-state equilibrium value. Deviations from these capital flow management rules are captured by mean zero and serially correlated mortgage or corporate capital control shock $\nu_t^{\tau^Z}$.[1]

### 2.5.3 The Macroprudential Authority

The regulatory bank capital ratio requirement satisfies a countercyclical capital buffer rule exhibiting partial adjustment dynamics of the form

$$\kappa_{t+1}^R - \kappa^R = \rho^{\kappa^R}(\kappa_t^R - \kappa^R) + (1 - \rho^{\kappa^R})\xi^{\kappa^R} \times \left(\ln \frac{A_{t+1}^B}{P_t^Y} - \ln \frac{\bar{A}_{t+1}^B}{\bar{P}_t^Y}\right) + \nu_t^{\kappa^R}, \tag{106}$$

where $0 < \kappa^R < 1$, $0 \leq \rho^{\kappa^R} < 1$, and $\xi^{\kappa^R} \geq 0$. As specified, the deviation of the bank capital requirement from its steady-state equilibrium value is inertially increasing in the contemporaneous deviation of real bank credit from its steady-state equilibrium value. Deviations from this countercyclical capital buffer rule are captured by mean zero and serially correlated bank capital requirement shock $\nu_t^{\kappa^R}$.

The regulatory mortgage and corporate loan-to-value ratio limits satisfy loan-to-value limit rules exhibiting partial adjustment dynamics of the form

$$\phi_t^Z - \phi^Z = \rho^\phi(\phi_{t-1}^Z - \phi^Z) - (1 - \rho^\phi)\xi^{\phi^Z} \times \left(\ln \frac{D_{t+1}^Z}{P_t^Y} - \ln \frac{\bar{D}_{t+1}^Z}{\bar{P}_t^Y}\right) + \nu_t^{\phi^Z}, \tag{107}$$

where $Z \in \{H, F\}$, while $0 < \phi^Z < 1$, $0 \leq \rho^\phi < 1$, and $\xi^{\phi^Z} \geq 0$. As specified, the deviation of the mortgage or corporate loan-to-value limit from its steady-state equilibrium value is inertially decreasing in the contemporaneous deviation of real mortgage or corporate debt from its steady-state equilibrium value. Deviations from these loan-to-value limit rules are captured by mean zero and serially correlated mortgage or corporate loan-to-value limit shock $\nu_t^{\phi^Z}$.

[1] These capital controls may be classified as both capital flow management and macroprudential policy measures, as they limit both capital inflows and systemic risk arising from them.

### *2.6 Market Clearing Conditions*

A rational expectations equilibrium in this DSGE model of the world economy consists of state-contingent sequences of allocations for domestic and foreign households, firms, and banks that solve their constrained optimization problems given prices and policies, together with state-contingent sequences of allocations for the domestic and foreign governments that satisfy their policy rules and constraints given prices, with supporting prices such that all markets clear.

Clearing of the final output good market requires that the value of exports $X_t$ equal the value of final output good supply minus demand from households, firms, and the government,

$$P_t^X X_t = P_t^Y (Y_t - C_t^h - I_t^{H,h} - I_t^{K,h} - G_t^{C,h} - G_t^{I,h}), \tag{108}$$

where $X_t = M_t^f$. Clearing of the final import good market requires that the volume of imports $M_t$ equal the volume of demand from households, firms, and the government,

$$M_t = C_t^f + I_t^{H,f} + I_t^{K,f} + G_t^{C,f} + G_t^{I,f}, \tag{109}$$

where $M_t = X_t^f$. In equilibrium, combination of these final output and import good market clearing conditions yields output expenditure decomposition,

$$P_t^Y Y_t = P_t^C C_t + P_t^I I_t + P_t^G G_t + P_t^X X_t - P_t^M M_t, \tag{110}$$

where the price of investment satisfies $P_t^I = P_t^{I^H} = P_t^{I^K}$ while investment satisfies $I_t = I_t^H + I_t^K$, and the price of public demand satisfies $P_t^G = P_t^{G^C} = P_t^{G^I}$ while public demand satisfies $G_t = G_t^C + G_t^I$.

Clearing of the final mortgage or corporate loan market requires that bank credit supply equal bank credit demand, ultimately from domestic and foreign households or firms,

$$A_{t+1}^{B,Z} = D_{t+1}^{Z,h} + D_{t+1}^{Z,f,f}, \tag{111}$$

where $Z \in \{H, F\}$. In equilibrium, clearing of the final mortgage or corporate loan payment system implies that the mortgage or corporate credit loss rate satisfies

$$\delta_t^{Z^E} A_t^{B,Z} = \delta_t^Z D_t^{Z,h} + \delta_t^{Z,f} D_t^{Z,f,f}. \tag{112}$$

The derivation of this result equates the debt service receipts of domestic banks to the debt service payments of domestic and foreign households or firms. To close the model, we assume that the economy has zero net exposure to the foreign interbank market, that is, $B_{t+1}^{B,B^f} + B_{t+1}^{C,B^f} = 0$.

Let $A_{t+1}$ denote the net foreign asset position, which equals the sum of the assets less liabilities of households, firms, banks, and the government:

$$A_{t+1} = \int_0^1 A_{b,t+1}^{B,H} db + \int_0^1 A_{b,t+1}^{B,F} db - D_{t+1}^H - D_{t+1}^F. \tag{113}$$

Imposing equilibrium conditions on government dynamic budget constraint (98) reveals that the fiscal deficit $FD_t = D_{t+1}^G - D_t^G$ equals the sum of interest expenditures, the primary fiscal deficit $PD_t = P_t^G G_t + T_t^{C,D} - T_t$, and the cost of holding foreign exchange reserves,

$$\begin{aligned} D_{t+1}^G - D_t^G &= i_{t-1}^{G^E} D_t^G + P_t^G G_t + T_t^{C,D} - \tau_t^K (P_t^Y Y_t - W_t L_t) \\ &\quad - \tau_t^L W_t L_t - \tau_t^C P_t^C C_t - \sum_Z \tau_{t-1}^Z (1 - \delta_t^Z)(\alpha^Z + i_{t-1}^{Z,f}) \mathcal{E}_t D_t^{Z,f} \\ &\quad + \left[ (1 + i_{t-1}^B) - (1 + i_{t-1}^{B,f}) \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \right] \mathcal{E}_{t-1} R_t, \end{aligned} \tag{114}$$

where $Z \in \{H, F\}$. Imposing equilibrium conditions on household dynamic budget constraint (5), and combining it with government dynamic budget constraint (114), firm dividend payment definition (32), bank dividend payment definition (56), output expenditure decomposition (110), and mortgage or corporate credit loss rate decomposition (112) reveals that the current account balance $CA_t = A_{t+1} - A_t$ equals the sum of net international investment income and the trade balance $TB_t = P_t^X X_t - P_t^M M_t$,

$$\begin{aligned} A_{t+1} - A_t = \sum_Z \Big[ &(1 - \delta_t^{Z,f})(\alpha^Z + i_{t-1}^Z)(A_t^{B,Z} - D_t^{Z,h}) \\ &- (1 - \delta_t^Z)(\alpha^Z + i_{t-1}^{Z,f}) \mathcal{E}_t D_t^{Z,f} - \alpha^Z \left( \int_0^1 A_{b,t}^{B,Z} db - D_t^Z \right) \Big] \\ &+ P_t^X X_t - P_t^M M_t, \end{aligned} \tag{115}$$

where $Z \in \{H, F\}$. The derivation of this result imposes deposit market clearing condition $B_{t+1}^{H,D} = B_{t+1}^{B,D}$, government bond market clearing conditions $D_{t+1}^{G} = \sum_{v=1}^{t} V_{v,t}^{G} S_{v,t+1}^{G}$ and $(1 + i_{t-1}^{G^E}) D_t^G = \sum_{v=1}^{t-1} (\Pi_{v,t}^{G} + V_{v,t}^{G}) S_{v,t}^{G}$, stock market clearing conditions $S_{f,t+1}^{F} = 1$ for all $f \in [0,1]$ and $S_{b,t+1}^{B} = 1$ for all $b \in [0,1]$, and domestic interbank market clearing condition $B_{t+1}^{B,B^h} + B_{t+1}^{C,B^h} = 0$.

## 3. The Empirical Framework

Estimation, inference, and forecasting are based on an augmented linear state-space representation of an approximate multivariate linear rational expectations representation of this DSGE model of the world economy, expressed as a function of its potentially heteroskedastic structural shocks. This multivariate linear rational expectations representation is derived by analytically linearizing the equilibrium conditions of the DSGE model around a stationary deterministic steady-state equilibrium that abstracts from long-run balanced growth, and consolidating them by substituting out intermediate variables.[2] Its linear state-space representation is augmented with empirically flexible trend component specifications for observed endogenous variables that account for long-run balanced growth while absorbing intermittent structural breaks. It is also augmented with state-dependent conditional heteroskedasticity specifications for structural shocks that generate endogenous risk, by parsimoniously capturing intertemporal dependence of the conditional variances of endogenous variables on their conditional means, yielding a non-linear empirical framework.

### *3.1 Endogenous Variables*

In what follows, $\hat{x}_t$ denotes the cyclical component of variable $x_t$, while $\bar{x}_t$ denotes its trend component, where $x_t = \hat{x}_t + \bar{x}_t$. The relative sizes of the domestic and foreign economies are measured by

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[2]In steady-state equilibrium $\nu^C = \nu^{I^H} = \nu^{I^K} = 1$, $\nu^B = \nu^H = \nu^S = \nu^{\delta^H} = \nu^{\delta^F} = \nu^{\mathcal{E}} = \nu^{i^B} = \nu^r = \nu^{G^C} = \nu^{G^I} = \nu^{\tau^K} = \nu^{\tau^L} = \nu^{\tau^C} = \nu^T = \nu^{\kappa^R} = \nu^{\phi^H} = \nu^{\phi^F} = \nu^{\tau^H} = \nu^{\tau^F} = 0$, $\tilde{\nu}^Z = \nu^Z$ for $Z \in \{A, B, S\}$, and $A^{B,Z}/P^Y Y = D^Z/P^Y Y$ for $Z \in \{H, F\}$.

their steady-state equilibrium world output shares $w^Y$ and $w^{Y,f}$, where $w^Y + w^{Y,f} = 1$.

### *3.1.1 Cyclical Components*

Credit-unconstrained consumption $\ln \hat{C}_t^U$ depends on its past and expected future values, and is driven by the real interbank rate adjusted by the housing, duration, and equity risk premiums, according to Euler equation

$$\begin{aligned}\ln \hat{C}_t^U &= \frac{\alpha^C}{1+\alpha^C}\ln \hat{C}_{t-1}^U + \frac{1}{1+\alpha^C}\mathrm{E}_t \ln \hat{C}_{t+1}^U \\ &\quad - \sigma\frac{1-\alpha^C}{1+\alpha^C}\mathrm{E}_t\Bigg[(\hat{i}_t^B + \phi_H^C \hat{\nu}_t^H + \phi_B^C \hat{\tilde{\nu}}_t^B + \phi_S^C \hat{\tilde{\nu}}_t^S - \hat{\pi}_{t+1}^C) \\ &\quad - \frac{1}{1+\tau^C}\Delta\hat{\tau}_{t+1}^C + \Delta \ln \hat{\nu}_{t+1}^C\Bigg]. \qquad (116)\end{aligned}$$

Credit-unconstrained consumption is also driven by the change in the consumption tax rate. Credit-constrained consumption $\ln \hat{C}_t^C$ satisfies static budget constraint

$$\begin{aligned}&(1+\tau^C)\frac{C}{Y}\left(\ln \frac{\hat{P}_t^C \hat{C}_t^C}{\hat{P}_t^Y \hat{Y}_t} + \frac{1}{1+\tau^C}\hat{\tau}_t^C\right) \\ &\quad = (1-\tau^L)\frac{WL}{P^Y Y}\left(\ln \frac{\hat{W}_t \hat{L}_t}{\hat{P}_t^Y \hat{Y}_t} - \frac{1}{1-\tau^L}\hat{\tau}_t^L\right) + \frac{1}{\phi^C}\frac{\hat{T}_t^C}{P_t^Y Y_t}, \qquad (117)\end{aligned}$$

which equates credit-constrained consumption expenditures to household disposable labor income plus transfers.

The unemployment rate depends on its past value, and is driven by employment and the real effective wage, determining the labor force $\ln \hat{N}_t$ according to supply function

$$\begin{aligned}\hat{u}_t^L &= \alpha^L \hat{u}_{t-1}^L - (1-\alpha^L) \\ &\quad \times \left\{\mu \ln \frac{\hat{L}_t}{\hat{\nu}_t^N} - \eta\left[\ln \frac{\hat{W}_t}{\hat{P}_t^C \hat{A}_t^T} - \frac{1}{1-\tau^L}\hat{\tau}_t^L - \frac{1}{1+\tau^C}\hat{\tau}_t^C\right]\right\}. \qquad (118)\end{aligned}$$

The unemployment rate also depends on the labor income and consumption tax rates. The unemployment rate $\hat{u}_t^L$ satisfies $\hat{u}_t^L = \ln \hat{N}_t - \ln \hat{L}_t$.

The deviation of wage inflation $\hat{\pi}_t^W$ from its partially indexed value depends on its expected future value, and is driven by the contemporaneous and past unemployment rate, according to Phillips curve

$$\begin{aligned}
&\hat{\pi}_t^W - \gamma^L((1-\mu^L)\hat{\pi}_{t-1}^W + \mu^L(\hat{\pi}_{t-1}^C + \hat{g}_{t-1}^{A^T})) \\
&\quad = \beta \mathrm{E}_t \left[\hat{\pi}_{t+1}^W - \gamma^L((1-\mu^L)\hat{\pi}_t^W + \mu^L(\hat{\pi}_t^C + \hat{g}_t^{A^T}))\right] \\
&\qquad - \frac{(1-\omega^L)(1-\omega^L\beta)}{\omega^L}\left[\frac{1}{\eta}\frac{1}{1-\alpha^L}(\hat{u}_t^L - \alpha^L \hat{u}_{t-1}^L) - \ln \hat{\vartheta}_t^L\right].
\end{aligned} \tag{119}$$

The partially indexed value of wage inflation depends on its past value, as well as past consumption price inflation and trend productivity growth. The wage $\ln \hat{W}_t$ satisfies $\hat{\pi}_t^W = \ln \hat{W}_t - \ln \hat{W}_{t-1}$.

The price of housing $\ln \hat{V}_t^H$ depends on its expected future value, and is driven by the user cost of housing, according to asset pricing relationship:

$$\ln \hat{V}_t^H = \beta \mathrm{E}_t \ln \hat{V}_{t+1}^H + (1-\beta)\mathrm{E}_t \ln \hat{\Pi}_{t+1}^H - (\hat{i}_t^B + \hat{\nu}_t^B + \hat{\nu}_t^H). \tag{120}$$

The price of housing is also driven by the interbank rate adjusted by the duration and housing risk premiums. The user cost of housing $\ln \hat{\Pi}_t^H$ satisfies

$$\begin{aligned}
\frac{\Pi^H}{P^Y Y}\ln \hat{\Pi}_t^H = \ln(\hat{P}_t^H \hat{H}_t) &+ \frac{A^{B,H}}{P^Y Y} \\
&\times \left[\alpha^H \ln \hat{B}_t^{H,H} - (1-\delta^H)(\alpha^H + i^H)\ln \hat{C}_t^{H,H}\right] \\
&- \frac{I^H}{Y}\ln(\hat{P}_t^I \hat{I}_t^H),
\end{aligned} \tag{121}$$

where $\frac{\Pi^H}{P^Y Y} = 1 - \left[1 - \frac{\phi^H}{1+\phi^H(1+R^H)}\left(1-(1-\delta^H)\frac{\alpha^H + i^H}{\alpha^H}\right)\right]\frac{I^H}{Y}$. New mortgage borrowing $\ln \hat{B}_t^{H,H}$ satisfies $\ln \hat{B}_t^{H,H} = \frac{\hat{\phi}_t^H}{\phi^H} + \ln(\hat{Q}_t^H \hat{I}_t^H)$, while mortgage debt service cost $\ln \hat{C}_t^{H,H}$ satisfies

$$\ln \hat{C}_t^{H,H} = \frac{1+i^H}{\alpha^H + i^H}\hat{i}_{t-1}^{H^E} - \hat{\delta}_t^H + \ln \hat{D}_t^H. \tag{122}$$

Mortgage debt $\ln \hat{D}^H_{t+1}$ is accumulated from new mortgage borrowing according to $\ln \hat{D}^H_{t+1} = (1-\alpha^H)\ln \hat{D}^H_t + \alpha^H \ln \hat{B}^{H,H}_t$.

The deviation of residential investment expenditures from nominal output depends on its past and expected future values, and is driven by the relative shadow price of housing, shadow price of mortgage debt, and regulatory mortgage loan-to-value ratio limit, determining residential investment $\ln \hat{I}^H_t$ according to demand function

$$\ln \frac{\hat{P}^I_t \hat{I}^H_t}{\hat{P}^Y_t \hat{Y}_t} = \frac{1}{1+\beta} \ln \frac{\hat{P}^I_{t-1} \hat{I}^H_{t-1}}{\hat{P}^Y_{t-1} \hat{Y}_{t-1}} + \frac{\beta}{1+\beta} \mathrm{E}_t \ln \frac{\hat{P}^I_{t+1} \hat{I}^H_{t+1}}{\hat{P}^Y_{t+1} \hat{Y}_{t+1}} + \frac{1}{\chi^H(1+\beta)} \times \left[ \ln \left( \hat{\nu}^{I^H}_t \frac{\hat{Q}^H_t}{\hat{P}^I_t} \right) + \phi^H (1+R^H) \left( \ln \frac{\hat{Q}^H_t}{\hat{P}^I_t} - \frac{\hat{\phi}^H_t}{\phi^H} \right) + \phi^H \hat{R}^H_t \right]. \tag{123}$$

The relative shadow price of housing depends on its expected future value, and is driven by the real interbank rate adjusted by the duration and housing risk premiums, determining the shadow price of housing $\ln \hat{Q}^H_t$ according to Euler equation

$$\ln \frac{\hat{Q}^H_t}{\hat{P}^I_t} = \mathrm{E}_t \left[ \beta(1-\delta_H) \ln \frac{\hat{Q}^H_{t+1}}{\hat{P}^I_{t+1}} - (\hat{\imath}^B_t + \hat{\nu}^B_t + \hat{\nu}^H_t - \hat{\pi}^I_{t+1}) + (1-\beta(1-\delta_H)) \ln \frac{\hat{P}^H_{t+1}}{\hat{P}^I_{t+1}} \right]. \tag{124}$$

The relative shadow price of housing is also driven by the relative implicit rental price of housing. The implicit rental price of housing $\ln \hat{P}^H_t$ satisfies

$$\ln \frac{\hat{P}^H_t}{\hat{P}^C_t} - \frac{1}{1+\tau^C} \hat{\tau}^C_t = -\frac{1}{\varsigma} \ln \frac{\hat{H}_t}{\hat{C}_t}. \tag{125}$$

The shadow price of mortgage debt $\hat{R}^H_t$ depends on its expected future value, and is driven by the interbank rate adjusted by the duration and housing risk premiums, according to Euler equation

$$\frac{\hat{R}_t^H}{R^H} = \mathrm{E}_t\Bigg[\beta(1-\alpha^H)\frac{\hat{R}_{t+1}^H}{R^H} - (\hat{i}_t^B + \hat{\tilde{\nu}}_t^B + \hat{\nu}_t^H)$$
$$+ (1-\beta(1-\alpha^H))\frac{1+i^H}{\alpha^H+i^H}\hat{i}_t^{H^E}\Bigg], \tag{126}$$

where $R^H = -\frac{\beta(1-\delta^H)(\alpha^H+i^H)}{1-\beta(1-\alpha^H)}$. The shadow price of mortgage debt is also driven by the effective mortgage loan rate. The housing stock $\ln \hat{H}_{t+1}$ is accumulated from residential investment according to $\ln \hat{H}_{t+1} = (1-\delta_H)\ln \hat{H}_t + \delta_H \ln(\hat{\nu}_t^{I^H}\hat{I}_t^H)$.[3]

The government bond yield $\hat{i}_t^G$ depends on its expected future value, and is driven by the interbank rate adjusted by the duration risk premium, according to asset pricing relationship

$$\hat{i}_t^G = \omega^G\beta\mathrm{E}_t\hat{i}_{t+1}^G + \frac{1-\omega^G\beta}{1-\omega^G(1-\omega^G)\beta}(\hat{i}_t^B + \hat{\tilde{\nu}}_t^B). \tag{127}$$

The term premium $\hat{\mu}_t^B$ depends on its expected future value, and is driven by the duration risk premium, according to

$$\hat{\mu}_t^B = \omega^G\beta\mathrm{E}_t\hat{\mu}_{t+1}^B + \frac{1-\omega^G\beta}{1-\omega^G(1-\omega^G)\beta}\hat{\tilde{\nu}}_t^B. \tag{128}$$

The duration risk premium $\hat{\tilde{\nu}}_t^B$ may be internationally correlated given $\hat{\tilde{\nu}}_t^B = \lambda^B\hat{\nu}_t^{B,f} + (1-\lambda^B)\hat{\nu}_t^B$ where $0 \leq \lambda^B \leq 1$, capturing international bond market contagion.

Output depends on utilized private physical capital and effective employment, determining employment $\ln \hat{L}_t$ according to production function

$$\ln \hat{Y}_t = \left(1 - \vartheta^Y\frac{WL}{P^YY}\right)\ln(\hat{u}_t^K\hat{K}_t) + \vartheta^Y\frac{WL}{P^YY}\ln(\hat{A}_t\hat{L}_t). \tag{129}$$

Potential output $\ln \hat{Y}_t^P$ depends on the private physical capital stock and effective labor force according to

$$\ln \hat{Y}_t^P = \left(1 - \vartheta^Y\frac{WL}{P^YY}\right)\ln \hat{K}_t + \vartheta^Y\frac{WL}{P^YY}\ln(\hat{A}_t\hat{N}_t). \tag{130}$$

[3]The inclusion of asset risk premiums, exclusion of the mortgage loan default rate, and sign on the mortgage loan-to-value ratio limit in these equations are not microfounded.

The output gap $\ln \hat{Y}_t^G$ satisfies $\ln \hat{Y}_t^G = \ln \hat{Y}_t - \ln \hat{Y}_t^P$. Productivity $\ln \hat{A}_t$ depends on the productivity shifter and public capital intensity according to

$$\ln \hat{A}_t = \phi^A \ln \hat{\tilde{\nu}}_t^A + (1 - \phi^A) \ln \frac{\hat{K}_t^G}{\hat{N}_t}. \tag{131}$$

The productivity shifter $\ln \hat{\tilde{\nu}}_t^A$ may be internationally correlated given $\ln \hat{\tilde{\nu}}_t^A = \lambda^A \ln \hat{\nu}_t^{A,f} + (1 - \lambda^A) \ln \hat{\nu}_t^A$, where $0 \leq \lambda^A \leq 1$. Trend productivity $\ln \hat{A}_t^T$ satisfies $\ln \hat{A}_t^T = \rho^{A^T} \ln \hat{A}_{t-1}^T + (1 - \rho^{A^T}) \ln \hat{A}_t$, while trend productivity growth $\hat{g}_t^{A^T}$ satisfies $\hat{g}_t^{A^T} = \ln \hat{A}_t^T - \ln \hat{A}_{t-1}^T$.

The price of equity $\ln \hat{V}_t^F$ depends on its expected future value, and is driven by corporate profit, according to asset pricing relationship

$$\ln \hat{V}_t^F = \beta \mathrm{E}_t \ln \hat{V}_{t+1}^F + (1 - \beta) \mathrm{E}_t \ln \hat{\Pi}_{t+1}^F - (\hat{i}_t^B + \hat{\tilde{\nu}}_t^B + \hat{\tilde{\nu}}_t^S). \tag{132}$$

The price of equity is also driven by the interbank rate adjusted by the duration and equity risk premiums. The equity risk premium $\hat{\tilde{\nu}}_t^S$ may be internationally correlated given $\hat{\tilde{\nu}}_t^S = \lambda^S \hat{\nu}_t^{S,f} + (1 - \lambda^S) \hat{\nu}_t^S$ where $0 \leq \lambda^S \leq 1$, capturing international stock market contagion. Corporate profit $\ln \hat{\Pi}_t^F$ satisfies

$$\begin{aligned} &\frac{\Pi^F}{P^Y Y} \ln \hat{\Pi}_t^F = \\ &(1 - \tau^K) \left[ \ln(\hat{P}_t^Y \hat{Y}_t) - \frac{WL}{P^Y Y} \ln(\hat{W}_t \hat{L}_t) \right] - \left( 1 - \frac{WL}{P^Y Y} \right) \hat{\tau}_t^K + \frac{A^{B,F}}{P^Y Y} \\ &\times \left[ \alpha^F \ln \hat{B}_t^{F,F} - (1 - \delta^F)(\alpha^F + i^F) \ln \hat{C}_t^{F,F} \right] - \frac{I^K}{Y} \ln(\hat{P}_t^I \hat{I}_t^K), \end{aligned} \tag{133}$$

where $\frac{\Pi^F}{P^Y Y} = (1 - \tau^K) \left(1 - \frac{WL}{P^Y Y}\right) - \left[1 - \frac{\phi^F}{1 + \phi^F (1 + R^K)} \left(1 - (1 - \delta^F) \frac{\alpha^F + i^F}{\alpha^F}\right)\right] \frac{I^K}{Y}$. New corporate borrowing $\ln \hat{B}_t^{F,F}$ satisfies $\ln \hat{B}_t^{F,F} = \frac{\hat{\phi}_t^F}{\phi^F} + \ln(\hat{Q}_t^K \hat{I}_t^K)$, while corporate debt service cost $\ln \hat{C}_t^{F,F}$ satisfies

$$\ln \hat{C}_t^{F,F} = \frac{1 + i^F}{\alpha^F + i^F} \hat{i}_{t-1}^{F^E} - \hat{\delta}_t^F + \ln \hat{D}_t^F. \tag{134}$$

Corporate debt $\ln \hat{D}^F_{t+1}$ is accumulated from new corporate borrowing according to $\ln \hat{D}^F_{t+1} = (1-\alpha^F) \ln \hat{D}^F_t + \alpha^F \ln \hat{B}^{F,F}_t$.

The deviation of business investment expenditures from nominal output depends on its past and expected future values, and is driven by the relative shadow price of private physical capital, shadow price of corporate debt, and regulatory corporate loan-to-value ratio limit, determining business investment $\ln \hat{I}^K_t$ according to demand function

$$\ln \frac{\hat{P}^I_t \hat{I}^K_t}{\hat{P}^Y_t \hat{Y}_t} = \frac{1}{1+\beta} \ln \frac{\hat{P}^I_{t-1} \hat{I}^K_{t-1}}{\hat{P}^Y_{t-1} \hat{Y}_{t-1}} + \frac{\beta}{1+\beta} \mathrm{E}_t \ln \frac{\hat{P}^I_{t+1} \hat{I}^K_{t+1}}{\hat{P}^Y_{t+1} \hat{Y}_{t+1}} + \frac{1}{\chi^K (1+\beta)} \times \left[ \ln \left( \hat{\nu}^{I^K}_t \frac{\hat{Q}^K_t}{\hat{P}^I_t} \right) + \phi^F (1+R^K) \left( \ln \frac{\hat{Q}^K_t}{\hat{P}^I_t} - \frac{\hat{\phi}^F_t}{\phi^F} \right) + \phi^F \hat{R}^K_t \right]. \tag{135}$$

The relative shadow price of private physical capital depends on its expected future value, and is driven by the real interbank rate adjusted by the duration and equity risk premiums, determining the shadow price of private physical capital $\ln \hat{Q}^K_t$ according to Euler equation

$$\ln \frac{\hat{Q}^K_t}{\hat{P}^I_t} = \mathrm{E}_t \left[ \beta(1-\delta_K) \ln \frac{\hat{Q}^K_{t+1}}{\hat{P}^I_{t+1}} - (\hat{i}^B_t + \hat{\nu}^B_t + \hat{\nu}^S_t - \hat{\pi}^I_{t+1}) + (1-\beta(1-\delta_K)) \left( \eta^K \ln \hat{u}^K_{t+1} - \frac{1}{1-\tau^K} \hat{\tau}^K_{t+1} \right) \right]. \tag{136}$$

The relative shadow price of private physical capital is also driven by the capital utilization and corporate tax rates. The capital utilization rate $\ln \hat{u}^K_t$ satisfies

$$\ln \hat{u}^K_t = \frac{1}{1+\eta^K} \ln \frac{\hat{W}_t \hat{L}_t}{\hat{P}^I_t \hat{K}_t}. \tag{137}$$

The shadow price of corporate debt $\hat{R}^K_t$ depends on its expected future value, and is driven by the interbank rate adjusted by the duration and equity risk premiums, according to Euler equation

$$\frac{\hat{R}_t^K}{R^K} = \mathrm{E}_t\Bigg[\beta(1-\alpha^F)\frac{\hat{R}_{t+1}^K}{R^K} - (\hat{i}_t^B + \hat{\nu}_t^B + \hat{\nu}_t^S) + (1-\beta(1-\alpha^F))\frac{1+i^F}{\alpha^F+i^F}\hat{i}_t^{F^E}\Bigg], \tag{138}$$

where $R^K = -\frac{\beta(1-\delta^F)(\alpha^F+i^F)}{1-\beta(1-\alpha^F)}$. The shadow price of corporate debt is also driven by the effective corporate loan rate. The private physical capital stock $\ln \hat{K}_{t+1}$ is accumulated from business investment according to $\ln \hat{K}_{t+1} = (1-\delta_K)\ln \hat{K}_t + \delta_K \ln(\hat{\nu}_t^{I^K}\hat{I}_t^K)$.[4]

The deviation of output price inflation $\hat{\pi}_t^Y$ from its partially indexed value depends on its expected future value, and is driven by the labor income share, according to Phillips curve

$$\hat{\pi}_t^Y - \gamma^Y\hat{\pi}_{t-1}^Y = \beta\mathrm{E}_t(\hat{\pi}_{t+1}^Y - \gamma^Y\hat{\pi}_t^Y) + \frac{(1-\omega^Y)(1-\omega^Y\beta)}{\omega^Y} \times \left(\ln\frac{\hat{W}_t\hat{L}_t}{\hat{P}_t^Y\hat{Y}_t} + \ln\hat{\vartheta}_t^Y\right). \tag{139}$$

The partially indexed value of output price inflation depends on its past value. The price of output $\ln \hat{P}_t^Y$ satisfies $\hat{\pi}_t^Y = \ln\hat{P}_t^Y - \ln\hat{P}_{t-1}^Y$.

Domestic mortgage or corporate debt $\ln \hat{D}_{t+1}^{Z,h}$ depends on total mortgage or corporate debt, as well as the deviation of the mortgage or corporate loan rate from its effective value, according to demand function

$$\ln\hat{D}_{t+1}^{Z,h} = \ln\hat{D}_{t+1}^Z - \psi^B\frac{1+i^Z}{\alpha^Z+i^Z}(\hat{i}_t^Z - \hat{i}_t^{Z^E}), \tag{140}$$

where $Z \in \{H, F\}$. The domestic-currency-denominated value of external mortgage or corporate debt depends on total mortgage or corporate debt, determining external mortgage or corporate debt $\ln\hat{D}_{t+1}^{Z,f}$ according to demand function

$$\ln(\hat{\mathcal{E}}_t\hat{D}_{t+1}^{Z,f}) = \ln\hat{D}_{t+1}^Z - \psi^B \times \left[\hat{\tau}_t^Z + \frac{1+i^Z}{\alpha^Z+i^Z}\hat{i}_t^{Z,f} + \mathrm{E}_t\Delta\ln\hat{\mathcal{E}}_{t+1} - \frac{1+i^Z}{\alpha^Z+i^Z}\hat{i}_t^{Z^E}\right]. \tag{141}$$

[4]The exclusion of the corporate loan default rate and sign on the corporate loan-to-value ratio limit in these equations are not microfounded.

The domestic-currency-denominated value of external mortgage or corporate debt also depends on the deviation of the foreign mortgage or corporate loan rate from its effective value, adjusted by the mortgage or corporate capital control tax and nominal currency depreciation rates. The effective mortgage or corporate loan rate $\hat{i}_t^{Z^E}$ depends on the mortgage or corporate loan rate according to

$$\frac{1+i^Z}{\alpha^Z+i^Z}\hat{i}_t^{Z^E} = \\ (1-\phi_Z^B)\frac{1+i^Z}{\alpha^Z+i^Z}\hat{i}_t^Z + \phi_Z^B\left[\hat{\tau}_t^Z + \frac{1+i^Z}{\alpha^Z+i^Z}\hat{i}_t^{Z,f} + \mathrm{E}_t\Delta\ln\hat{\mathcal{E}}_{t+1}\right], \quad (142)$$

where $\phi_Z^B = \frac{\mathcal{E}D^{Z,f}}{D^Z}$ with $\phi_Z^B w^Y \frac{A^{B,Z}}{P^Y Y} = \phi_Z^{B,f} w^{Y,f} \frac{A^{B,Z,f}}{P^{Y,f}Y^f}$. The effective mortgage or corporate loan rate also depends on the foreign mortgage or corporate loan rate, adjusted by the mortgage or corporate capital control tax and nominal currency depreciation rates.

The money stock $\ln\hat{M}_{t+1}^S$ satisfies $\ln\hat{A}_{t+1}^B = (1-\kappa^R)\ln\hat{M}_{t+1}^S + \kappa^R\ln\hat{K}_{t+1}^B$, while bank credit $\ln\hat{A}_{t+1}^B$ depends on contemporaneous mortgage and corporate credit according to

$$\frac{A^B}{P^Y Y}\ln\hat{A}_{t+1}^B = \frac{A^{B,H}}{P^Y Y}\ln\hat{A}_{t+1}^{B,H} + \frac{A^{B,F}}{P^Y Y}\ln\hat{A}_{t+1}^{B,F}, \quad (143)$$

where $\frac{A^B}{P^Y Y} = \frac{A^{B,H}}{P^Y Y} + \frac{A^{B,F}}{P^Y Y}$ with $\frac{A^{B,H}}{P^Y Y} = \frac{1}{\alpha^H}\frac{\phi^H}{1+\phi^H(1+R^H)}\frac{I^H}{Y}$ and $\frac{A^{B,F}}{P^Y Y} = \frac{1}{\alpha^F}\frac{\phi^F}{1+\phi^F(1+R^K)}\frac{I^K}{Y}$. New mortgage or corporate lending $\ln\hat{B}_t^{B,Z}$ satisfies $\ln\hat{A}_{t+1}^{B,Z} = (1-\alpha^Z)\ln\hat{A}_t^{B,Z} + \alpha^Z\ln\hat{B}_t^{B,Z}$, while mortgage or corporate loan income $\ln\hat{C}_t^{B,Z}$ satisfies

$$\ln\hat{C}_t^{B,Z} = \frac{1+i^Z}{\alpha^Z+i^Z}\hat{i}_{t-1}^Z + \ln\hat{A}_t^{B,Z}, \quad (144)$$

where $Z \in \{H, F\}$. Mortgage or corporate credit $\ln\hat{A}_{t+1}^{B,Z}$ depends on domestic and foreign external mortgage or corporate debt according to $\ln\hat{A}_{t+1}^{B,Z} = (1-\phi_Z^B)\ln\hat{D}_{t+1}^{Z,h} + \phi_Z^B\ln\hat{D}_{t+1}^{Z,f,f}$.

Bank-retained earnings $\ln\hat{I}_t^B$ depends on its past and expected future values, and is driven by the relative shadow price of bank capital, according to

$$\ln\hat{I}_t^B = \frac{1}{1+\beta}\ln\hat{I}_{t-1}^B + \frac{\beta}{1+\beta}\mathrm{E}_t\ln\hat{I}_{t+1}^B + \frac{1}{\chi^B(1+\beta)}\ln\frac{\hat{Q}_t^B}{\hat{P}_t^Y}. \quad (145)$$

The relative shadow price of bank capital depends on its expected future value, and is driven by the interbank rate, determining the shadow price of bank capital $\ln \hat{Q}_t^B$ according to Euler equation

$$\ln \frac{\hat{Q}_t^B}{\hat{P}_t^Y} = \beta \mathrm{E}_t \ln \frac{\hat{Q}_{t+1}^B}{\hat{P}_{t+1}^Y} - \hat{i}_t^B - (1-\beta)\frac{\eta^B}{\kappa^R}(\hat{\kappa}_{t+1} - \hat{\kappa}_{t+1}^R). \tag{146}$$

The relative shadow price of bank capital is also driven by the deviation of the bank capital ratio from its required value. The bank capital ratio $\hat{\kappa}_{t+1}$ satisfies $\hat{\kappa}_{t+1} = \kappa^R(\ln \hat{K}_{t+1}^B - \ln \hat{A}_{t+1}^B)$. The bank capital stock $\ln \hat{K}_{t+1}^B$ is accumulated from retained earnings given credit losses according to $\ln \hat{K}_{t+1}^B = (1-\delta^B)(\ln \hat{K}_t^B - \hat{\delta}_t^B) + \delta^B \ln \hat{I}_t^B$.

The financial gap $\ln \hat{F}_t$ depends on real non-financial private-sector debt, as well as the relative prices of housing and equity, according to

$$\ln \hat{F}_t = \phi_B^F \ln \frac{\hat{D}_{t+1}^P}{\hat{P}_t^Y} + \phi_H^F \ln \frac{\hat{V}_t^H}{\hat{P}_t^Y} + \phi_F^F \ln \frac{\hat{V}_t^F}{\hat{P}_t^Y}, \tag{147}$$

where non-financial private-sector debt $\ln \hat{D}_{t+1}^P$ satisfies $\frac{A^B}{P^Y Y} \ln \hat{D}_{t+1}^P = \frac{A^{B,H}}{P^Y Y} \ln \hat{D}_{t+1}^H + \frac{A^{B,F}}{P^Y Y} \ln \hat{D}_{t+1}^F$. The mortgage or corporate loan default rate $\hat{\delta}_t^Z$ responds inertially to the output and financial gaps according to

$$\hat{\delta}_t^Z = \rho^{\delta^C} \hat{\delta}_{t-1}^Z - (1-\rho^{\delta^C})\zeta^{\delta^Z}(\ln \hat{Y}_t^G + \zeta^F \ln \hat{F}_t) + \hat{\nu}_t^{\delta^Z}. \tag{148}$$

The effective mortgage or corporate loan default rate $\hat{\delta}_t^{Z^E}$ satisfies $\hat{\delta}_t^{Z^E} = (1-\phi_Z^B)\hat{\delta}_t^Z + \phi_Z^B \hat{\delta}_t^{Z,f}$. The bank capital destruction rate $\hat{\delta}_t^B$ depends on the effective mortgage and corporate loan default rates according to

$$\delta^B \kappa^R \frac{A^B}{P^Y Y}\left[\frac{1-\delta^B}{\delta^B}\hat{\delta}_t^B + \ln \hat{K}_t^B\right] =$$

$$\sum_Z \delta^Z(\alpha^Z + i^Z)\frac{A^{B,Z}}{P^Y Y}\left[\frac{1+i^Z}{\alpha^Z + i^Z}\hat{i}_{t-1}^Z + \frac{1-\delta^Z}{\delta^Z}\hat{\delta}_t^{Z^E} + \ln \hat{A}_t^{B,Z}\right], \tag{149}$$

where $\delta^B \kappa^R \frac{A^B}{P^Y Y} = \delta^H(\alpha^H + i^H)\frac{A^{B,H}}{P^Y Y} + \delta^F(\alpha^F + i^F)\frac{A^{B,F}}{P^Y Y}$. The bank capital destruction rate also depends on the bank capital buffer and credit risk exposures.

The change in the mortgage or corporate loan rate $\hat{i}_t^Z$ depends on its expected future value, and is driven by the interbank rate and mortgage or corporate loan rate, according to Phillips curves

$$\Delta\hat{i}_t^Z = \beta \mathrm{E}_t \Delta\hat{i}_{t+1}^Z + \frac{(1-\omega^C)(1-\omega^C\beta)}{\omega^C} \times \left\{ \frac{\vartheta^Z}{\beta(1-\delta^Z)(1+i^Z)} \left[ \hat{i}_{t-1}^B - \eta^B(1-\beta)\left(\hat{\kappa}_t - \frac{1+\eta^B}{\eta^B}\hat{\kappa}_t^R\right)\right] + \frac{\alpha^Z + i^Z}{1+i^Z}\left[\hat{\delta}_t^{Z^E} + \frac{\delta^Z}{1-\delta^Z}\ln\frac{\hat{Q}_t^B}{\hat{P}_t^Y} + \ln\hat{\vartheta}_t^Z\right] - \hat{i}_t^Z \right\}, \quad (150)$$

where $\vartheta^Z = \frac{\beta(1-\delta^Z)(\alpha^Z+i^Z)}{1+\kappa^R(1-\beta)-\beta(1-\alpha^Z)}$. The change in the mortgage or corporate loan rate is also driven by the bank capital ratio and its required value, as well as the effective mortgage or corporate loan default rate and relative shadow price of bank capital.

The interbank rate $\hat{i}_t^B$ responds inertially to consumption price inflation and the output gap according to monetary policy rule

$$\hat{i}_t^B = \rho^{i^B}\hat{i}_{t-1}^B + (1-\rho^{i^B})(\xi^{\pi^C}\mathrm{E}_t\hat{\pi}_{t+1}^C + \xi^{Y^G}\ln\hat{Y}_t^G) + \hat{\nu}_t^{i^B}. \quad (151)$$

The foreign exchange reserve ratio $\hat{r}_{t+1}$ responds to the real exchange rate according to foreign exchange intervention rule

$$\hat{r}_{t+1} = -\xi^r \ln\hat{\mathcal{Q}}_t + \hat{\nu}_t^r. \quad (152)$$

Foreign exchange intervention $\widehat{FXI_t}$ satisfies $\widehat{FXI_t} = \Delta\hat{r}_{t+1}$, while the foreign exchange reserve stock $\ln\hat{R}_{t+1}$ satisfies $\hat{r}_{t+1} = r(\ln\hat{\mathcal{E}}_t + \ln\hat{R}_{t+1} - \ln\hat{P}_t^Y - \ln\hat{Y}_t)$.

Public consumption or investment $\ln\hat{G}_t^Z$ responds inertially to the output gap according to fiscal expenditure rule

$$\ln\hat{G}_t^Z = \rho^G\ln\hat{G}_{t-1}^Z - (1-\rho^G)\xi^{G^Z}\ln\hat{Y}_t^G + \hat{\nu}_t^{G^Z}, \quad (153)$$

where $Z \in \{C, I\}$. The public capital stock $\ln\hat{K}_{t+1}^G$ is accumulated from public investment according to $\ln\hat{K}_{t+1}^G = (1-\delta_G)\ln\hat{K}_t^G + \delta_G\ln\hat{G}_t^I$. The corporate, labor income, or consumption tax rate $\hat{\tau}_t^Z$ satisfies fiscal revenue rule

$$\hat{\tau}_t^Z = \rho^\tau\hat{\tau}_{t-1}^Z + \hat{\nu}_t^{\tau^Z}, \quad (154)$$

where $Z \in \{K, L, C\}$. The mortgage or corporate capital control tax rate $\hat{\tau}_t^Z$ responds inertially to the real domestic-currency-denominated value of external mortgage or corporate debt according to capital flow management rule

$$\hat{\tau}_t^Z = \rho^{\tau^C} \hat{\tau}_{t-1}^Z + (1 - \rho^{\tau^C}) \xi^{\tau^Z} \ln \frac{\hat{\mathcal{E}}_t \hat{D}_{t+1}^{Z,f}}{\hat{P}_t^Y} + \nu_t^{\tau^Z}, \tag{155}$$

where $Z \in \{H, F\}$. The non-discretionary transfer payment ratio $\frac{\hat{T}_t^{C,N}}{P_t^Y Y_t}$ satisfies $\frac{\hat{T}_t^{C,N}}{P_t^Y Y_t} = \xi^{T^N} \frac{\hat{A}_{t+1}}{P_t^Y Y_t}$, while the discretionary transfer payment ratio $\frac{\hat{T}_t^{C,D}}{P_t^Y Y_t}$ satisfies $\frac{\hat{T}_t^{C,D}}{P_t^Y Y_t} = -\xi^{T^D} \frac{\hat{D}_{t+1}^G}{P_t^Y Y_t} + \hat{\nu}_t^T$.

The regulatory bank capital ratio requirement $\hat{\kappa}_{t+1}^R$ responds inertially to real bank credit according to countercyclical capital buffer rule

$$\hat{\kappa}_{t+1}^R = \rho^{\kappa^R} \hat{\kappa}_t^R + (1 - \rho^{\kappa^R}) \xi^{\kappa^R} \ln \frac{\hat{A}_{t+1}^B}{\hat{P}_t^Y} + \hat{\nu}_t^{\kappa^R}. \tag{156}$$

The regulatory mortgage or corporate loan-to-value ratio limit $\hat{\phi}_t^Z$ responds inertially to real mortgage or corporate debt according to loan-to-value limit rule

$$\hat{\phi}_t^Z = \rho^{\phi} \hat{\phi}_{t-1}^Z - (1 - \rho^{\phi}) \xi^{\phi^Z} \ln \frac{\hat{D}_{t+1}^Z}{\hat{P}_t^Y} + \hat{\nu}_t^{\phi^Z}, \tag{157}$$

where $Z \in \{H, F\}$.

The nominal exchange rate $\ln \hat{\mathcal{E}}_t$ depends on its expected future value, and is driven by the international interbank rate differential, according to uncovered interest parity condition

$$\ln \hat{\mathcal{E}}_t = \mathrm{E}_t \ln \hat{\mathcal{E}}_{t+1} - (\hat{i}_t^B - \hat{i}_t^{B,f}) + \gamma^B \hat{r}_{t+1} - \zeta^{\mathcal{E}} \frac{\hat{A}_{t+1}}{P_t^Y Y_t} + \hat{\nu}_t^{\mathcal{E}}. \tag{158}$$

The nominal exchange rate is also driven by the foreign exchange reserve and net foreign asset ratios. The real exchange rate $\ln \hat{\mathcal{Q}}_t$ satisfies $\ln \hat{\mathcal{Q}}_t = \ln \hat{\mathcal{E}}_t + \ln \hat{P}_t^{Y,f} - \ln \hat{P}_t^Y$.

The deviation of export price inflation $\hat{\pi}_t^X$ from its partially indexed value depends on its expected future value, and is driven by the price of output relative to exports, according to Phillips curve

$$\begin{aligned}&\hat{\pi}_t^X - \gamma^X((1-\mu^X)\hat{\pi}_{t-1}^X + \mu^X \Delta \ln(\hat{\mathcal{E}}_t \hat{P}_t^{Y,f}))\\&\quad = \beta \mathrm{E}_t \left[\hat{\pi}_{t+1}^X - \gamma^X((1-\mu^X)\hat{\pi}_t^X + \mu^X \Delta \ln(\hat{\mathcal{E}}_{t+1} \hat{P}_{t+1}^{Y,f}))\right]\\&\qquad + \frac{(1-\omega^X)(1-\omega^X\beta)}{\omega^X}\left(\ln \frac{\hat{P}_t^Y}{\hat{P}_t^X} + \ln \hat{\vartheta}_t^X\right). \qquad (159)\end{aligned}$$

The partially indexed value of export price inflation depends on its past value, as well as contemporaneous domestic-currency-denominated foreign output price inflation. The price of exports $\ln \hat{P}_t^X$ satisfies $\hat{\pi}_t^X = \ln \hat{P}_t^X - \ln \hat{P}_{t-1}^X$.

The deviation of import price inflation $\hat{\pi}_t^M$ from its partially indexed value depends on its expected future value, and is driven by the domestic-currency-denominated foreign price of exports relative to imports, according to Phillips curve

$$\begin{aligned}&\hat{\pi}_t^M - \gamma^M((1-\mu^M)\hat{\pi}_{t-1}^M + \mu^M \Delta \ln(\hat{\mathcal{E}}_t \hat{P}_t^{Y,f}))\\&\quad = \beta \mathrm{E}_t \left[\hat{\pi}_{t+1}^M - \gamma^M((1-\mu^M)\hat{\pi}_t^M + \mu^M \Delta \ln(\hat{\mathcal{E}}_{t+1} \hat{P}_{t+1}^{Y,f}))\right]\\&\qquad + \frac{(1-\omega^M)(1-\omega^M\beta)}{\omega^M}\left(\ln \frac{\hat{\mathcal{E}}_t \hat{P}_t^{X,f}}{\hat{P}_t^M} + \ln \hat{\vartheta}_t^M\right). \qquad (160)\end{aligned}$$

The partially indexed value of import price inflation depends on its past value, as well as contemporaneous domestic-currency-denominated foreign output price inflation. The price of imports $\ln \hat{P}_t^M$ satisfies $\hat{\pi}_t^M = \ln \hat{P}_t^M - \ln \hat{P}_{t-1}^M$.

The price of absorption $\ln \hat{P}_t^Z$ depends on the price of output, as well as the relative price of imports, according to

$$\ln \frac{\hat{P}_t^Z}{\hat{\nu}_t^P} = \ln \hat{P}_t^Y + \phi_Z^M \ln \frac{\hat{P}_t^M}{\hat{P}_t^Y}, \qquad (161)$$

where $Z \in \{C, I, G\}$. Absorption price inflation $\hat{\pi}_t^Z$ satisfies $\hat{\pi}_t^Z = \ln \hat{P}_t^Z - \ln \hat{P}_{t-1}^Z$. Imports $\ln \hat{M}_t$ depend on private consumption, private investment, and public demand according to demand function

$$\vartheta^X \vartheta^M \frac{M}{Y} \ln \frac{\hat{M}_t}{\hat{\nu}_t^M} = \phi_C^M \frac{C}{Y} \left( \ln \hat{C}_t - \psi^M \ln \frac{\hat{P}_t^M}{\hat{P}_t^C} \right) + \phi_I^M \frac{I}{Y} \left( \ln \hat{I}_t - \psi^M \ln \frac{\hat{P}_t^M}{\hat{P}_t^I} \right) + \phi_G^M \frac{G}{Y} \left( \ln \hat{G}_t - \psi^M \ln \frac{\hat{P}_t^M}{\hat{P}_t^G} \right), \tag{162}$$

where $\vartheta^X \vartheta^M \frac{M}{Y} = \phi_C^M \frac{C}{Y} + \phi_I^M \frac{I}{Y} + \phi_G^M \frac{G}{Y}$ with $w^Y \vartheta^M \frac{M}{Y} = w^{Y,f} \frac{M^f}{Y^f}$. Imports also depend on the corresponding relative prices of imports. Exports $\ln \hat{X}_t$ satisfy $\ln \hat{X}_t = \ln(\hat{\nu}_t^X \hat{M}_t^f)$.[5]

Nominal output depends on consumption expenditures, investment expenditures, government expenditures, export revenues, and import expenditures, determining output $\ln \hat{Y}_t$ according to market clearing condition

$$\ln(\hat{P}_t^Y \hat{Y}_t) = \frac{C}{Y} \ln(\hat{P}_t^C \hat{C}_t) + \frac{I}{Y} \ln(\hat{P}_t^I \hat{I}_t) + \frac{G}{Y} \ln(\hat{P}_t^G \hat{G}_t) + \vartheta^X \vartheta^M \frac{M}{Y} \ln \frac{\hat{P}_t^X \hat{X}_t}{\hat{P}_t^M \hat{M}_t}, \tag{163}$$

where $\frac{C}{Y} + \frac{I}{Y} + \frac{G}{Y} = 1$. Private consumption $\ln \hat{C}_t$ satisfies $\ln \hat{C}_t = (1 - \phi^C) \ln \hat{C}_t^U + \phi^C \ln \hat{C}_t^C$, while private investment $\ln \hat{I}_t$ satisfies $\frac{I}{Y} \ln \hat{I}_t = \frac{I^H}{Y} \ln \hat{I}_t^H + \frac{I^K}{Y} \ln \hat{I}_t^K$ with $\frac{I}{Y} = \frac{I^H}{Y} + \frac{I^K}{Y}$, and public demand $\ln \hat{G}_t$ satisfies $\frac{G}{Y} \ln \hat{G}_t = \frac{G^C}{Y} \ln \hat{G}_t^C + \frac{G^I}{Y} \ln \hat{G}_t^I$ with $\frac{G}{Y} = \frac{G^C}{Y} + \frac{G^I}{Y}$.

The fiscal deficit ratio $\frac{\widehat{FD}_t}{P_t^Y Y_t}$ depends on public debt service cost, the primary fiscal deficit ratio, and the central bank profit transfer according to dynamic budget constraint

$$\frac{\widehat{FD}_t}{P_t^Y Y_t} = \frac{1 - \omega^G (1 - \omega^G) \beta}{\omega^G \beta} \frac{D^G}{P^Y Y} \hat{i}_{t-1}^{G^E} + \left( \frac{1 - \omega^G (1 - \omega^G) \beta}{\omega^G \beta} - 1 \right) \left( \frac{\hat{D}_t^G}{P_{t-1}^Y Y_{t-1}} - \frac{D^G}{P^Y Y} \ln \frac{\hat{P}_t^Y \hat{Y}_t}{\hat{P}_{t-1}^Y \hat{Y}_{t-1}} \right) + \frac{\widehat{PD}_t}{P_t^Y Y_t} + \frac{r}{\beta} \left( \hat{i}_{t-1}^B - \hat{i}_{t-1}^{B,f} - \ln \frac{\hat{\mathcal{E}}_t}{\hat{\mathcal{E}}_{t-1}} \right). \tag{164}$$

[5]The inclusion of shocks in these equations is not microfounded.

The effective government rate $\hat{i}_t^{G^E}$ satisfies $\hat{i}_t^{G^E} = \omega^G \hat{i}_{t-1}^{G^E} + (1-\omega^G)\hat{i}_{t-1}^G$. The primary fiscal deficit ratio $\frac{\widehat{PD}_t}{P_t^Y Y_t}$ depends on the government expenditure, discretionary transfer payment, and tax revenue ratios according to

$$\frac{\widehat{PD}_t}{P_t^Y Y_t} = \frac{G}{Y} \ln \frac{\hat{P}_t^G \hat{G}_t}{\hat{P}_t^Y \hat{Y}_t} + \frac{\hat{T}_t^{C,D}}{P_t^Y Y_t} - \frac{\hat{T}_t}{P_t^Y Y_t}. \tag{165}$$

The transfer payment ratio $\frac{\hat{T}_t^C}{P_t^Y Y_t}$ satisfies $\frac{\hat{T}_t^C}{P_t^Y Y_t} = \frac{\hat{T}_t^{C,N}}{P_t^Y Y_t} + \frac{\hat{T}_t^{C,D}}{P_t^Y Y_t}$. The tax revenue ratio $\frac{\hat{T}_t}{P_t^Y Y_t}$ depends on the corporate, labor income, and consumption tax rates, as well as the mortgage and corporate capital control tax rates, according to

$$\begin{aligned}\frac{\hat{T}_t}{P_t^Y Y_t} &= \hat{\tau}_t^K - \frac{WL}{P^Y Y}\left(\hat{\tau}_t^K + \tau^K \ln \frac{\hat{W}_t \hat{L}_t}{\hat{P}_t^Y \hat{Y}_t}\right) \\ &\quad + \frac{WL}{P^Y Y}\left(\hat{\tau}_t^L + \tau^L \ln \frac{\hat{W}_t \hat{L}_t}{\hat{P}_t^Y \hat{Y}_t}\right) + \frac{C}{Y}\left(\hat{\tau}_t^C + \tau^C \ln \frac{\hat{P}_t^C \hat{C}_t}{\hat{P}_t^Y \hat{Y}_t}\right) \\ &\quad + \sum_Z \phi_Z^B (1-\delta^Z)(\alpha^Z + i^Z) \frac{A^{B,Z}}{P^Y Y} \hat{\tau}_{t-1}^Z. \end{aligned} \tag{166}$$

The tax revenue ratio also depends on the corporate, labor income, and consumption tax bases. The public debt ratio $\frac{\hat{D}_{t+1}^G}{P_t^Y Y_t}$ satisfies $\frac{\widehat{FD}_t}{P_t^Y Y_t} = \frac{\hat{D}_{t+1}^G}{P_t^Y Y_t} - \left(\frac{\hat{D}_t^G}{P_{t-1}^Y Y_{t-1}} - \frac{D^G}{P^Y Y} \ln \frac{\hat{P}_t^Y \hat{Y}_t}{\hat{P}_{t-1}^Y \hat{Y}_{t-1}}\right)$.

The current account balance ratio $\frac{\widehat{CA}_t}{P_t^Y Y_t}$ depends on net international investment income and the trade balance ratio according to dynamic budget constraint

$$\begin{aligned}\frac{\widehat{CA}_t}{P_t^Y Y_t} &= \sum_Z \frac{A^{B,Z}}{P^Y Y}\Bigg\{(1-\delta^Z)(\alpha^Z + i^Z) \\ &\quad \times \Bigg\{\phi_Z^B \Bigg[\left(\frac{1+i^Z}{\alpha^Z + i^Z}\hat{i}_{t-1}^Z - \hat{\delta}_t^{Z,f} + \ln \hat{D}_t^{Z,h}\right)\end{aligned}$$

$$-\left(\frac{1+i^Z}{\alpha^Z+i^Z}\hat{i}_{t-1}^{Z,f}-\hat{\delta}_t^Z+\ln(\hat{\mathcal{E}}_t\hat{D}_t^{Z,f})\right)\Bigg]+\ln\frac{\hat{A}_t^{B,Z}}{\hat{D}_t^{Z,h}}\Bigg\}$$

$$-\alpha^Z\ln\frac{\hat{A}_t^{B,Z}}{\hat{D}_t^Z}\Bigg\}+\frac{\widehat{TB}_t}{P_t^YY_t}, \tag{167}$$

where $Z\in\{H,F\}$. The trade balance ratio $\frac{\widehat{TB}_t}{P_t^YY_t}$ satisfies $\frac{\widehat{TB}_t}{P_t^YY_t}=\vartheta^X\vartheta^M\frac{M}{Y}\ln\frac{\hat{P}_t^X\hat{X}_t}{\hat{P}_t^M\hat{M}_t}$, while the net foreign asset ratio $\frac{\hat{A}_{t+1}}{P_t^YY_t}$ satisfies $\frac{\widehat{CA}_t}{P_t^YY_t}=\frac{\hat{A}_{t+1}}{P_t^YY_t}-\frac{\hat{A}_t}{P_{t-1}^YY_{t-1}}$.

### *3.1.2 Trend Components*

The changes in the trend components of the price of output $\ln\bar{P}_t^Y$, output $\ln\bar{Y}_t$, price of consumption $\ln\bar{P}_t^C$, consumption $\ln\bar{C}_t$, investment $\ln\bar{I}_t$, exports $\ln\bar{X}_t$, imports $\ln\bar{M}_t$, price of housing $\ln\bar{V}_t^H$, price of equity $\ln\bar{V}_t^F$, bank credit $\ln\bar{A}_t^B$, nominal exchange rate $\ln\bar{\mathcal{E}}_t$, wage $\ln\bar{W}_t$, and employment $\ln\bar{L}_t$ follow stationary first-order autoregressive processes

$$\Delta\bar{x}_t=(1-\rho)\mu_x+\rho\Delta\bar{x}_{t-1}+\bar{\varepsilon}_t^x,\ \bar{\varepsilon}_t^x|\mathcal{I}_{t-1}\sim\mathcal{N}(0,\bar{h}^x), \tag{168}$$

where $\bar{x}_t\in\{\ln\bar{P}_t^Y,\ln\bar{Y}_t,\ln\bar{P}_t^C,\ln\bar{C}_t,\ln\bar{I}_t,\ln\bar{X}_t,\ln\bar{M}_t,\ln\bar{V}_t^H,\ln\bar{V}_t^F,\ln\bar{A}_t^B,\ln\bar{\mathcal{E}}_t,\ln\bar{W}_t,\ln\bar{L}_t\}$, with corresponding unconditional means $\mu_x\in\{\pi,g+n,\pi,g+n,g+n,g+n,g+n,\pi+g,\pi+g+n,\pi+g+n,\pi-\pi^f,\pi+g,n\}$ and innovations $\bar{\varepsilon}_t^x\in\{\bar{\varepsilon}_t^{P^Y},\bar{\varepsilon}_t^Y,\bar{\varepsilon}_t^{P^C},\bar{\varepsilon}_t^C,\bar{\varepsilon}_t^I,\bar{\varepsilon}_t^X,\bar{\varepsilon}_t^M,\bar{\varepsilon}_t^{V^H},\bar{\varepsilon}_t^{V^F},\bar{\varepsilon}_t^{A^B},\bar{\varepsilon}_t^{\mathcal{E}},\bar{\varepsilon}_t^W,\bar{\varepsilon}_t^L\}$ having unconditional variances $\bar{h}^x\in\{\bar{\sigma}_{P^Y}^2,\bar{\sigma}_Y^2,\bar{\sigma}_{P^C}^2,\bar{\sigma}_C^2,\bar{\sigma}_I^2,\bar{\sigma}_X^2,\bar{\sigma}_M^2,\bar{\sigma}_{V^H}^2,\bar{\sigma}_{V^F}^2,\bar{\sigma}_{A^B}^2,\bar{\sigma}_{\mathcal{E}}^2,\bar{\sigma}_W^2,\bar{\sigma}_L^2\}$. These trend components converge asymptotically at a common speed determined by $\rho$ to a long-run balanced-growth path featuring constant inflation at rate $\pi$, productivity growth at rate $g$, and population growth at rate $n$. In parallel, the changes in the trend components of the interbank rate $\bar{i}_t^B$, government bond yield $\bar{i}_t^G$, and unemployment rate $\bar{u}_t^L$ follow stationary first-order autoregressive processes with zero unconditional means

$$\Delta\bar{x}_t=\rho\Delta\bar{x}_{t-1}+\bar{\varepsilon}_t^x,\ \bar{\varepsilon}_t^x|\mathcal{I}_{t-1}\sim\mathcal{N}(0,\bar{h}^x), \tag{169}$$

where $\bar{x}_t\in\{\bar{i}_t^B,\bar{i}_t^G,\bar{u}_t^L\}$, with corresponding innovations $\bar{\varepsilon}_t^x\in\{\bar{\varepsilon}_t^{i^B},\bar{\varepsilon}_t^{i^G},\bar{\varepsilon}_t^{u^L}\}$ having unconditional variances $\bar{h}^x\in\{\bar{\sigma}_{i^B}^2,\bar{\sigma}_{i^G}^2,\bar{\sigma}_{u^L}^2\}$.

These trend components converge asymptotically at the same speed to a long-run balanced-growth path featuring constant interest and unemployment rates. As an identifying restriction, all innovations are assumed to be contemporaneously uncorrelated.

## *3.2 Exogenous Variables*

All structural shocks follow stationary first-order autoregressive or serially uncorrelated processes, driven by conditionally normally distributed heteroskedastic or homoskedastic innovations.

### *3.2.1 Conditional Means*

The productivity $\ln \hat{\nu}_t^A$, labor supply $\ln \hat{\nu}_t^N$, private consumption demand $\ln \hat{\nu}_t^C$, residential investment demand $\ln \hat{\nu}_t^{I^H}$, business investment demand $\ln \hat{\nu}_t^{I^K}$, export demand $\ln \hat{\nu}_t^X$, import demand $\ln \hat{\nu}_t^M$, duration risk premium $\hat{\nu}_t^B$, housing risk premium $\hat{\nu}_t^H$, equity risk premium $\hat{\nu}_t^S$, and foreign currency liquidity $\hat{\nu}_t^{\mathcal{E}}$ shocks follow stationary first-order autoregressive processes driven by conditionally normally distributed heteroskedastic innovations

$$\hat{\nu}_t^Z = \rho_Z \hat{\nu}_{t-1}^Z + \hat{\varepsilon}_t^Z,\ \hat{\varepsilon}_t^Z | \mathcal{I}_{t-1} \sim \mathcal{N}(0, \hat{h}_t^Z), \tag{170}$$

where $\hat{\nu}_t^Z \in \{\ln \hat{\nu}_t^A, \ln \hat{\nu}_t^N, \ln \hat{\nu}_t^C, \ln \hat{\nu}_t^{I^H}, \ln \hat{\nu}_t^{I^K}, \ln \hat{\nu}_t^X, \ln \hat{\nu}_t^M, \hat{\nu}_t^B, \hat{\nu}_t^H, \hat{\nu}_t^S, \hat{\nu}_t^{\mathcal{E}}\}$, with corresponding autoregressive coefficients $\rho_Z \in \{\rho_A, \rho_N, \rho_C, \rho_I, \rho_I, \rho_X, \rho_M, \rho_B, \rho_H, \rho_S, \rho_{\mathcal{E}}\}$ and innovations $\hat{\varepsilon}_t^Z \in \{\hat{\varepsilon}_t^A, \hat{\varepsilon}_t^N, \hat{\varepsilon}_t^C, \hat{\varepsilon}_t^{I^H}, \hat{\varepsilon}_t^{I^K}, \hat{\varepsilon}_t^X, \hat{\varepsilon}_t^M, \hat{\varepsilon}_t^B, \hat{\varepsilon}_t^H, \hat{\varepsilon}_t^S, \hat{\varepsilon}_t^{\mathcal{E}}\}$ having conditional variances $\hat{h}_t^Z \in \{\hat{h}_t^A, \hat{h}_t^N, \hat{h}_t^C, \hat{h}_t^I, \hat{h}_t^I, \hat{h}_t^X, \hat{h}_t^M, \hat{h}_t^B, \hat{h}_t^H, \hat{h}_t^S, \hat{h}_t^{\mathcal{E}}\}$. Furthermore, the output price markup $\ln \hat{\vartheta}_t^Y$, wage markup $\ln \hat{\vartheta}_t^L$, export price markup $\ln \hat{\vartheta}_t^X$, import price markup $\ln \hat{\vartheta}_t^M$, and monetary policy $\hat{\nu}_t^{i^B}$ shocks follow serially uncorrelated processes driven by conditionally normally distributed homoskedastic innovations

$$\hat{\nu}_t^Z = \hat{\varepsilon}_t^Z,\ \hat{\varepsilon}_t^Z | \mathcal{I}_{t-1} \sim \mathcal{N}(0, \hat{h}^Z), \tag{171}$$

where $\hat{\nu}_t^Z \in \{\ln \hat{\vartheta}_t^Y, \ln \hat{\vartheta}_t^L, \ln \hat{\vartheta}_t^X, \ln \hat{\vartheta}_t^M, \hat{\nu}_t^{i^B}\}$, with corresponding innovations $\hat{\varepsilon}_t^Z \in \{\hat{\varepsilon}_t^{\vartheta^Y}, \hat{\varepsilon}_t^{\vartheta^L}, \hat{\varepsilon}_t^{\vartheta^X}, \hat{\varepsilon}_t^{\vartheta^M}, \hat{\varepsilon}_t^{i^B}\}$ having unconditional variances $\hat{h}_t^Z \in \{\hat{\sigma}_{\vartheta^Y}^2, \hat{\sigma}_{\vartheta^L}^2, \hat{\sigma}_{\vartheta^X}^2, \hat{\sigma}_{\vartheta^M}^2, \hat{\sigma}_{i^B}^2\}$. Finally, the mortgage loan markup $\ln \hat{\vartheta}_t^H$, corporate loan markup $\ln \hat{\vartheta}_t^F$, mortgage loan default $\hat{\nu}_t^{\delta^H}$, corporate loan default $\hat{\nu}_t^{\delta^F}$, absorption price $\ln \hat{\nu}_t^P$, foreign exchange intervention $\hat{\nu}_t^r$, public consumption demand $\hat{\nu}_t^{G^C}$, public investment demand $\hat{\nu}_t^{G^I}$, corporate tax rate $\hat{\nu}_t^{\tau^K}$, labor income tax rate $\hat{\nu}_t^{\tau^L}$, consumption tax rate $\hat{\nu}_t^{\tau^C}$, transfer payment $\hat{\nu}_t^T$, bank capital requirement $\hat{\nu}_t^{\kappa^R}$, mortgage loan-to-value limit $\hat{\nu}_t^{\phi^H}$, corporate loan-to-value limit $\hat{\nu}_t^{\phi^F}$, mortgage capital control $\hat{\nu}_t^{\tau^H}$, and corporate capital control $\hat{\nu}_t^{\tau^F}$ shocks follow stationary first-order autoregressive processes driven by conditionally normally distributed homoskedastic innovations

$$\hat{\nu}_t^Z = \rho_Z \hat{\nu}_{t-1}^Z + \hat{\varepsilon}_t^Z,\ \hat{\varepsilon}_t^Z | \mathcal{I}_{t-1} \sim \mathcal{N}(0, \hat{h}^Z), \tag{172}$$

where $\hat{\nu}_t^Z \in \{\ln \hat{\vartheta}_t^H, \ln \hat{\vartheta}_t^F, \hat{\nu}_t^{\delta^H}, \hat{\nu}_t^{\delta^F}, \ln \hat{\nu}_t^P, \hat{\nu}_t^r, \hat{\nu}_t^{G^C}, \hat{\nu}_t^{G^I}, \hat{\nu}_t^{\tau^K}, \hat{\nu}_t^{\tau^L}, \hat{\nu}_t^{\tau^C}, \hat{\nu}_t^T, \hat{\nu}_t^{\kappa^R}, \hat{\nu}_t^{\phi^H}, \hat{\nu}_t^{\phi^F}, \hat{\nu}_t^{\tau^H}, \hat{\nu}_t^{\tau^F}\}$, with corresponding autoregressive coefficients $\rho_Z \in \{\rho_{\vartheta^C}, \rho_{\vartheta^C}, \rho_{\delta^C}, \rho_{\delta^C}, \rho_P, \rho_r, \rho_G, \rho_G, \rho_\tau, \rho_\tau, \rho_\tau, \rho_T, \rho_\kappa, \rho_\phi, \rho_\phi, \rho_{\tau^C}, \rho_{\tau^C}\}$ and innovations $\hat{\varepsilon}_t^Z \in \{\hat{\varepsilon}_t^{\vartheta^H}, \hat{\varepsilon}_t^{\vartheta^F}, \hat{\varepsilon}_t^{\delta^H}, \hat{\varepsilon}_t^{\delta^F}, \hat{\varepsilon}_t^P, \hat{\varepsilon}_t^r, \hat{\varepsilon}_t^{G^C}, \hat{\varepsilon}_t^{G^I}, \hat{\varepsilon}_t^{\tau^K}, \hat{\varepsilon}_t^{\tau^L}, \hat{\varepsilon}_t^{\tau^C}, \hat{\varepsilon}_t^T, \hat{\varepsilon}_t^{\kappa^R}, \hat{\varepsilon}_t^{\phi^H}, \hat{\varepsilon}_t^{\phi^F}, \hat{\varepsilon}_t^{\tau^H}, \hat{\varepsilon}_t^{\tau^F}\}$ having unconditional variances $\hat{h}^Z \in \{\hat{\sigma}_{\vartheta^C}^2, \hat{\sigma}_{\vartheta^C}^2, \hat{\sigma}_{\delta^C}^2, \hat{\sigma}_{\delta^C}^2, \hat{\sigma}_P^2, \hat{\sigma}_r^2, \hat{\sigma}_G^2, \hat{\sigma}_G^2, \hat{\sigma}_\tau^2, \hat{\sigma}_\tau^2, \hat{\sigma}_\tau^2, \hat{\sigma}_T^2, \hat{\sigma}_\kappa^2, \hat{\sigma}_\phi^2, \hat{\sigma}_\phi^2, \hat{\sigma}_{\tau^C}^2, \hat{\sigma}_{\tau^C}^2\}$. As an identifying restriction, all innovations are assumed to be contemporaneously uncorrelated.

### *3.2.2 Conditional Variances*

The conditional variances of the productivity $\hat{h}_t^A$, labor supply $\hat{h}_t^N$, consumption demand $\hat{h}_t^C$, investment demand $\hat{h}_t^I$, export demand $\hat{h}_t^X$, and import demand $\hat{h}_t^M$ shocks are log-linear functions of the past changes in and levels of the domestic and foreign output gaps

$$\begin{aligned}\ln \hat{h}_t^Z = \ln \hat{\sigma}_Z^2 &- \lambda^M (\psi_{\Delta Y} \Delta \ln \hat{Y}_{t-1}^{G,f} - \psi_Y \ln \hat{Y}_{t-1}^{G,f}) \\ &- (1-\lambda^M)(\psi_{\Delta Y} \Delta \ln \hat{Y}_{t-1}^G - \psi_Y \ln \hat{Y}_{t-1}^G),\end{aligned} \tag{173}$$

where $Z \in \{A, N, C, I, X, M\}$, while $0 \leq \lambda^M \leq 1$. If $\psi_{\Delta Y} > 0$, then the conditional variances of these macroeconomic shocks are higher during a domestic or foreign business cycle contraction than during an expansion, while if $\psi_Y > 0$, then they are higher when domestic or foreign capacity pressures are elevated than when they are subdued. In parallel, the conditional variances of the duration risk premium $\hat{h}_t^B$, housing risk premium $\hat{h}_t^H$, equity risk premium $\hat{h}_t^S$, and foreign currency liquidity $\hat{h}_t^{\mathcal{E}}$ shocks are log-linear functions of the past changes in and levels of the domestic and foreign financial gaps

$$\ln \hat{h}_t^Z = \ln \hat{\sigma}_Z^2 - \lambda^F(\psi_{\Delta F}\Delta \ln \hat{F}_{t-1}^f - \psi_F \ln \hat{F}_{t-1}^f) \\ - (1-\lambda^F)(\psi_{\Delta F}\Delta \ln \hat{F}_{t-1} - \psi_F \ln \hat{F}_{t-1}), \tag{174}$$

where $Z \in \{B, H, S, \mathcal{E}\}$, while $0 \leq \lambda^F \leq 1$. If $\psi_{\Delta F} > 0$, then the conditional variances of these financial shocks are higher during a domestic or foreign financial cycle downturn than during an upturn, while if $\psi_F > 0$, then they are higher when domestic or foreign financial vulnerabilities are elevated than when they are subdued. These log-linear functional forms ensure positive conditional variances $\hat{h}_t^Z$, which converge asymptotically to unconditional variances of $\hat{\sigma}_Z^2$, given that the lagged output and financial gaps are stationary predetermined endogenous variables with zero unconditional means.

## 4. Estimation, Inference, and Forecasting

We interpret our linearized DSGE model with state-dependent conditional heteroskedasticity as a representation of the joint probability distribution of the data, and estimate a restricted version of it using the Bayesian maximum-likelihood procedure documented in Adrian and Vitek (2020). This restricted version of the model consolidates or eliminates those structural shocks that are weakly identified by our macrofinancial time-series data sets. Given the parameter estimates, we then conduct scenario analysis using the unrestricted version of the model.

### *4.1 Estimation*

The set of parameters associated with our heteroskedastic linearized DSGE model is partitioned into two subsets. Those parameters that enter into the conditional mean function of its augmented linear state-space representation are calibrated, whereas those that enter into its conditional variance function are estimated. Most calibrated and all estimated parameters are subject to cross-economy equality restrictions.[6]

#### *4.1.1 Calibrated Parameters*

The calibrated values of steady-state equilibrium parameters are set to match observed data, or lie within the range of existing empirical estimates. All steady-state equilibrium great ratios are set to their sample average values for the economy under consideration, or are derived from these given steady-state equilibrium relationships. In steady-state equilibrium, the import share of private investment $\phi_I^M$ is set to 1.25 times that of private consumption $\phi_C^M$ and public demand $\phi_G^M$. The steady-state equilibrium annualized depreciation rate of the housing stock $\delta_H$ is set to 5.0 percent, while that of the private physical capital stock $\delta_K$ is set to 10.0 percent, and that of the public capital stock $\delta_G$ is set to 7.5 percent. In steady-state equilibrium, the annualized mortgage $i^H$ and corporate $i^F$ loan rates are set to 4.0 and 6.0 percent, while the annualized mortgage $\alpha^H$ and corporate $\alpha^F$ loan amortization rates are set to 2.5 and 5.0 percent, and the annualized mortgage $\delta^H$ and corporate $\delta^F$ loan default rates are set to 1.0 and 2.0 percent, respectively. Finally, the output $\vartheta^Y$, export $\vartheta^X$, and import $\vartheta^M$ price markup parameters are all set to imply steady-state equilibrium price markups of 25 percent.

The calibrated values of behavioral parameters lie within the range of estimates reported in the existing empirical literature where available, and are differentiated across the advanced versus emerging market economies under consideration where appropriate. For example, the habit persistence in consumption $\alpha^C$ and labor supply $\alpha^L$ parameters are both set to 0.8, while the subjective discount factor $\beta$ is set to imply a steady-state equilibrium annualized interbank rate of 2.0 percent. The intertemporal elasticity of substitution in consumption $\sigma$ is set to 1.0, while the intratemporal elasticity of substitution in labor supply $\eta$ is set to 0.5. In addition, the share of credit-constrained households $\phi^C$ is set to 20 percent in the advanced economies under consideration, versus 25 percent in the emerging market economies. Furthermore, the adjustment cost parameters for

[6]For a complete statement of the parameter values, see Adrian, Gaspar, and Vitek (2022).

residential $\chi^H$ and business $\chi^K$ investment are both set to 3.0. The partial indexation parameters for output price $\gamma^Y$, wage $\gamma^L$, export price $\gamma^X$, and import price $\gamma^M$ determination are all set to 0.8. In addition, the nominal rigidity parameters for output price $\omega^Y$ and wage $\omega^L$ determination are both set to imply average reoptimization intervals of eight quarters in the advanced economies under consideration, versus six quarters in the emerging market economies. Furthermore, the nominal rigidity parameters for export $\omega^X$ and import $\omega^M$ price determination are both set to imply average reoptimization intervals of six quarters, while the financial friction parameter for nominal mortgage and corporate loan rate determination $\omega^B$ is set to imply an average adjustment interval of four quarters. The intratemporal elasticities of substitution in import $\psi^M$ and external bank credit $\psi^B$ demand are both set to 0.5. Finally, the international bond and stock market contagion coefficients $\lambda^B$ and $\lambda^S$ are set to 40 and 50 percent in the advanced economies under consideration, versus 60 and 75 percent in the emerging market economies, respectively.

The calibrated values of policy rule parameters also lie within the range of estimates reported in the existing empirical literature where available. In the monetary policy rule, the response coefficient on consumption price inflation $\xi^{\pi^C}$ is set to 2.0, while that on the output gap $\xi^{Y^G}$ is set to 0.5 at the annual frequency. In the foreign exchange intervention rule, the steady-state equilibrium foreign exchange reserve ratio $r$ is set to its sample average value for the economy under consideration, while the response coefficient on the real exchange rate $\xi^r$ is set to 0.1 at the annual frequency. In the fiscal expenditure rules, the response coefficients for public consumption $\xi^{G^C}$ and investment $\xi^{G^I}$ with respect to the output gap are both set to 1.0. In the fiscal revenue rules, the steady-state equilibrium corporate $\tau^K$, labor income $\tau^L$, and consumption $\tau^C$ tax rates are set to their sample average values for the economy under consideration. In the countercyclical capital buffer rule, the steady-state equilibrium bank capital ratio $\kappa^R$ is set to 5.0 percent, while the response coefficient on real bank credit $\xi^{\kappa^R}$ is set to 0.1. In the loan-to-value limit rules, the steady-state equilibrium mortgage $\phi^H$ and corporate $\phi^F$ loan-to-value ratio limits are both set to 80 percent, while the response coefficients on real mortgage $\xi^{\phi^H}$ and corporate $\xi^{\phi^F}$ debt are both set to 0.5. Finally, in the capital flow management rules, the response coefficients on the real domestic-currency-denominated value of external mortgage $\xi^{\tau^H}$ and corporate $\xi^{\tau^F}$ debt are both set to 0.1 at the annual frequency.

The calibrated values of trend component parameters are set to match observed data, or lie within a plausible range. The common speed of convergence parameter $\rho$ is set to imply a half-life of deviations from the long-run balanced growth path of 10 years. Along this balanced-growth path, the constant inflation $\pi$, productivity growth $g$, and population growth $n$ rates are set to their sample average values for the economy under consideration.

#### *4.1.2 Estimated Parameters*

Estimation of the restricted version of our heteroskedastic linearized DSGE model is based on the levels of a total of 31 endogenous variables observed for four pairs of economies over the sample period 2001:Q1 to 2019:Q4. Each pair of economies combines a small open advanced or emerging market economy with the United States, which is taken to represent the rest of the world. This choice is motivated by our focus on the global financial cycle, but the rest of the world could alternatively be represented by another systemic economy such as the euro area, depending on the application. The small open advanced economies under consideration are Korea and Switzerland, while the small open emerging market economies are South Africa and Thailand. These economies have experienced volatile capital flows, span a wide range of structural characteristics, and satisfy our data availability requirements.

The observed macroeconomic and financial market variables under consideration are the gross domestic product price deflator, real gross domestic product, the headline consumer price index, real private consumption, real private investment, real exports, real imports, the nominal policy interest rate, a benchmark long-term nominal government bond yield, a house price index, an equity price index, credit to the non-financial private sector, the nominal bilateral exchange rate, a nominal wage index, the unemployment rate, and employment. The macroeconomic variables are all seasonally adjusted. The nominal wage index is derived from observed labor income and employment. For Switzerland and the United States, the estimated shadow nominal policy interest rate substitutes for the observed nominal policy interest rate, to account for the effects of unconventional monetary policy at the effective lower bound. All data were obtained from the Global Data Source (GDS) database compiled by the International Monetary Fund (IMF) where available, and from databases produced by the Bank for International Settlements (BIS) or Haver Analytics otherwise.

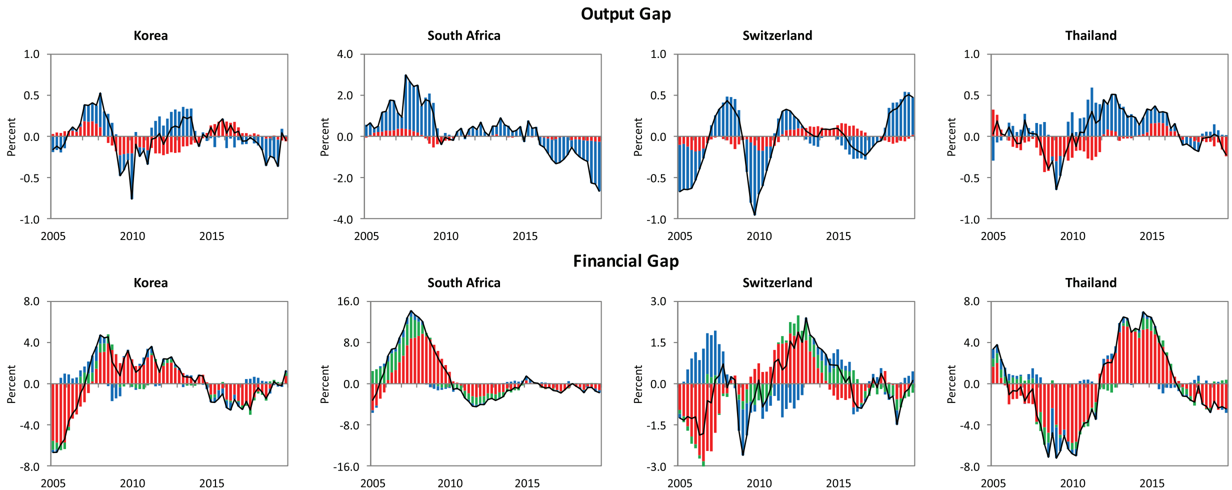
The restricted version of our model consolidates or eliminates those structural shocks that are weakly identified by our macrofinancial time-series data sets. In particular, we consolidate the residential and business investment demand shocks into an investment demand shock, the public consumption and investment demand shocks into a public demand shock, and the mortgage and corporate loan-to-value limit shocks into a loan-to-value limit shock. In addition, we eliminate the mortgage and corporate loan markup shocks; the mortgage and corporate loan default shocks; the export and import price markup shocks; the foreign exchange intervention shock; the corporate, labor income, and consumption tax rate shocks; the transfer payment shock; the bank capital requirement shock; and the mortgage and corporate capital control shocks.

We estimate this restricted version of our model based on effective sample period 2001:Q3 to 2019:Q4. The data are very informative regarding many of the estimated parameters that enter into the conditional variance function, as evidenced by substantial updates from prior to posterior. The prior means of the slope parameters associated with our state-dependent conditional heteroskedasticity mechanism are aligned with the estimated posterior modes reported for different economies in Adrian and Vitek (2020). The posterior modes of these slope parameters exhibit substantial economy-specific deviations around these common prior means.

### *4.2 Inference*

Our estimated DSGE model generates output and financial gap estimates, which summarize the business and financial cycles. As shown in Figure 1, our output gap estimates indicate abrupt synchronized business cycle contractions during the global financial crisis (GFC) in all of the economies under consideration, followed by recoveries of varying intensity. These business cycle dynamics reflect reinforcing

## Figure 1. Business and Financial Cycles




**Note:** Decomposes smoothed estimates of the output gap ■ into contributions from the capital utilization ■ and unemployment ■ rate gaps. Also decomposes smoothed estimates of the financial gap ■ into contributions from the debt ■, house price ■, and equity price ■ gaps.

fluctuations in capital and labor utilization.[7] In parallel, our financial gap estimates indicate synchronized financial cycle downturns during the GFC, followed by upturns that lag behind the business cycle recoveries. These financial cycle dynamics reflect reinforcing credit cycle dynamics and asset price adjustments.

Our historical decompositions of consumption price inflation and output growth yield economically plausible explanations of their evolution over time, as shown in Figure 2. Those of consumption price inflation attribute deviations from trend rates primarily to macroeconomic shocks—in particular, to price and wage markup shocks. In parallel, our historical decompositions of output growth attribute business cycle dynamics around trend growth rates primarily to macroeconomic and financial shocks—in particular, to demand and risk premium shocks. Consistent with conventional views, these historical decompositions identify adverse demand and risk premium shocks in the United States as the primary drivers of the business cycle contractions that occurred during the GFC. Finally, they identify policy shocks as countercyclical mitigants of these business cycle contractions, particularly in the advanced economies under consideration.

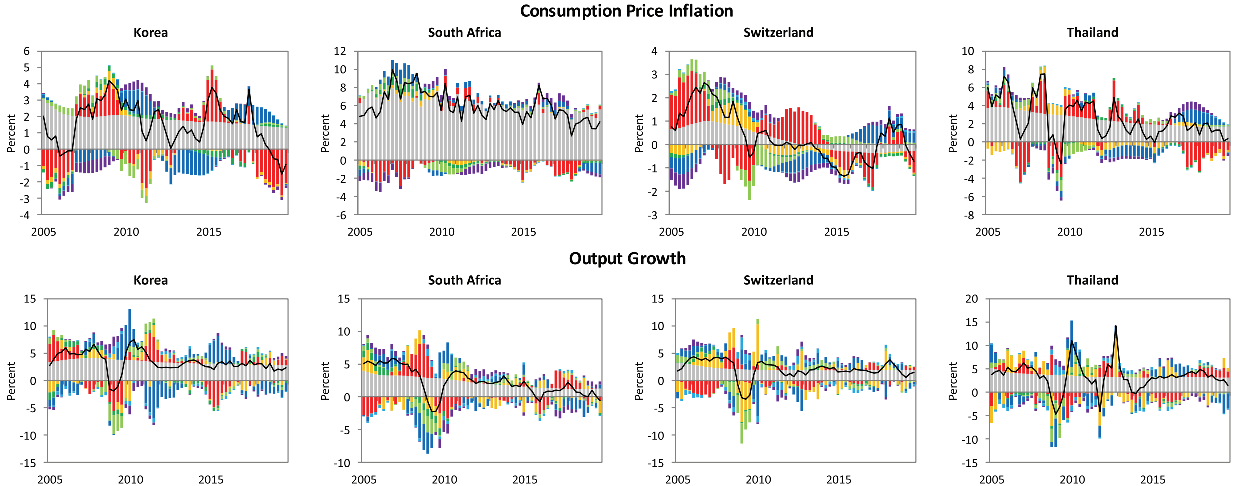
### *4.3 Forecasting*

Our sequential dynamic forecasts of consumption price inflation and output growth track their observed realizations reasonably accurately, as shown in Figure 3. We measure the dynamic forecasting performance of our estimated DSGE model relative to that of a random walk in sample at the 1- to 12-quarter horizons on the basis of the logarithm of the $U$ statistic due to Theil (1966), which equals the ratio of root mean squared prediction errors. We find that the model dominates a random walk in terms of predictive accuracy for consumption price inflation and output growth, for all of the economies under consideration. Indeed, over the holdout sample period 2005:Q2 to 2019:Q4, the root mean squared prediction error is 19 to 40 percent lower for consumption price inflation, and 40 to 46 percent lower for output growth, on average across horizons.

Policymakers are often concerned with the risks surrounding their central forecasts. In our model, these risks vary systematically

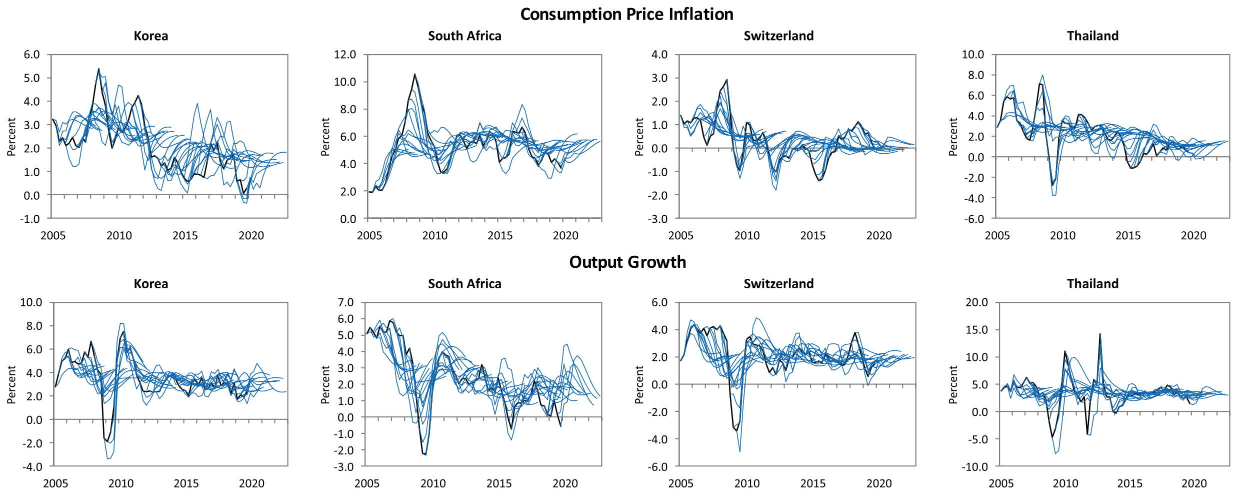
[7] The output gap satisfies $\ln \hat{Y}_t^G = \left(1 - \vartheta^Y \frac{WL}{P^Y Y}\right) \ln \hat{u}_t^K - \vartheta^Y \frac{WL}{P^Y Y} \hat{u}_t^L$.

## Figure 2. Historical Decompositions




**Note:** Decomposes observed consumption price inflation or output growth ■ as measured by the seasonal logarithmic difference of the consumption price level or output into the sum of a trend component ■ and contributions from domestic macroeconomic ■, foreign macroeconomic ■, domestic financial ■, foreign financial ■, domestic policy ■, foreign policy ■, and world terms of trade ■ shocks.

## Figure 3. Sequential Dynamic Forecasts




**Note:** Depicts observed consumption price inflation or output growth ■ as measured by the seasonal difference of the logarithm of the consumption price level or output versus sequential dynamic forecasts ■.

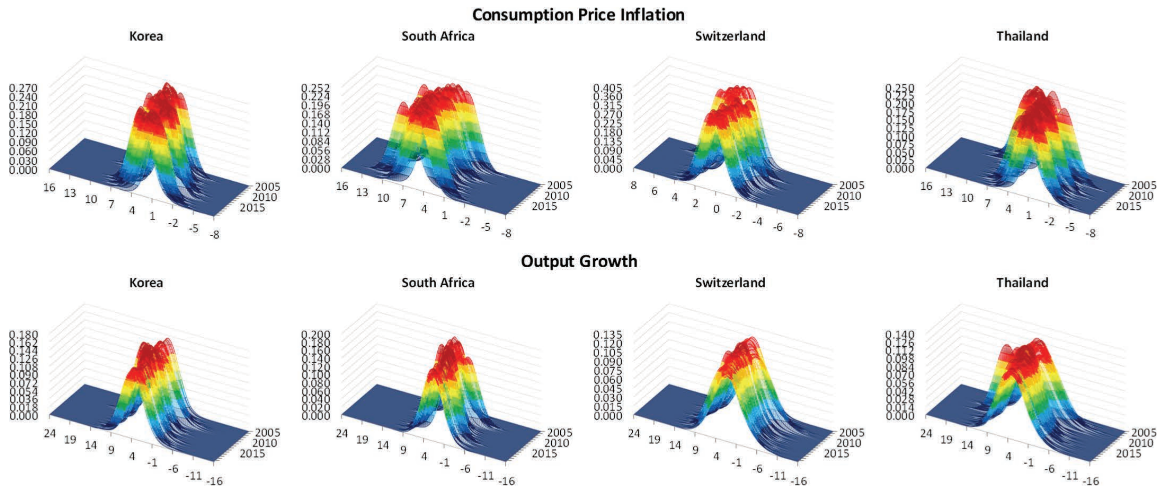
with respect to the phase and position of the domestic and global business and financial cycles. As shown in Figure 4, the entire conditional distribution of output growth, and not just its central tendency, evolves over time. Indeed, both the location and scale of the conditional distribution of output growth shift in response to changes in domestic and global macroeconomic and financial conditions and vulnerabilities. Moreover, these shifts are negatively correlated, generating conditional distributions that are skewed to the downside, particularly at times of domestic or global macrofinancial stress. In contrast, the conditional distribution of consumption price inflation is roughly symmetric.

Consistent with the key stylized facts of growth at risk documented in Adrian and Vitek (2020), in our model the conditional lower quantile of output growth is more volatile than its conditional mean, which in turn is more volatile than its conditional upper quantile, as shown in Figure 5. This reflects the strong dependence of output growth dynamics on demand and risk premium shocks, which are conditionally heteroskedastic. Given the specification of our state-dependent conditional heteroskedasticity mechanism, adverse demand and risk premium shocks not only reduce the conditional mean of output growth but also raise its conditional variance, and vice versa. This generates a negative correlation between the conditional mean and variance of output growth, which ranges from –0.14 to –0.49 across the economies under consideration. In contrast, for consumption price inflation the conditional lower and upper quantiles are roughly equally volatile in our model. This reflects the strong dependence of consumption price inflation dynamics on price and wage markup shocks, which are conditionally homoskedastic.

## 5. Policy Analysis

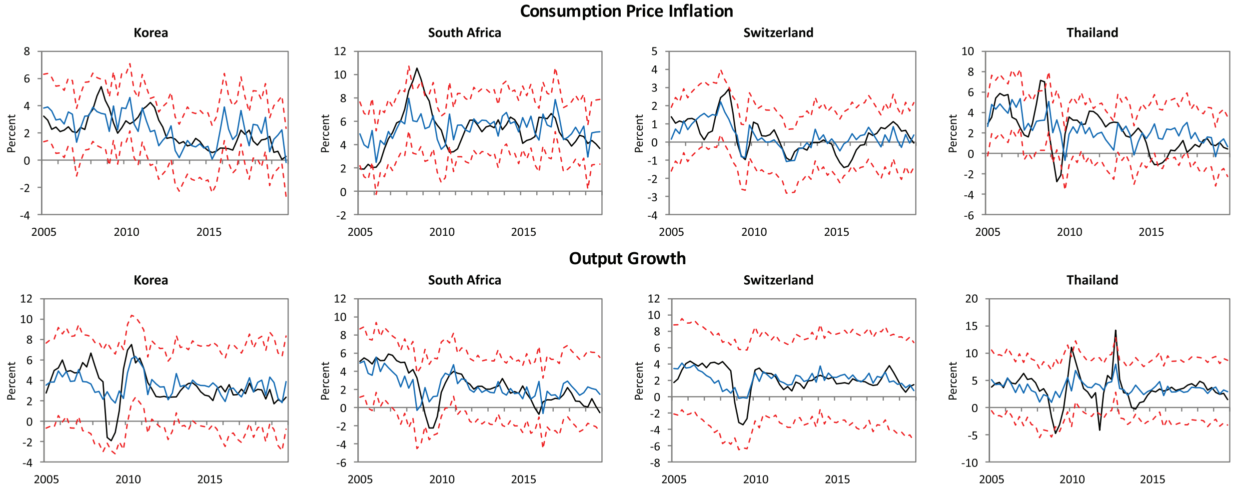
Having verified that our estimated DSGE model yields economically plausible historical decompositions and reasonably accurate sequential dynamic forecasts of consumption price inflation and output growth, we proceed to conduct policy analysis using it. In particular, we quantify its monetary policy, foreign exchange intervention, fiscal policy, macroprudential policy, and capital flow management transmission mechanisms with impulse responses. We then jointly

## Figure 4. Conditional Distributions




**Note:** Depicts the one-year-ahead predicted probability density function of consumption price inflation or output growth, estimated using a normal kernel based on a Monte Carlo simulation with 100,000 replications.

# Figure 5. Conditional Quantiles




**Note:** Depicts observed consumption price inflation or output growth ■ as measured by the seasonal difference of the logarithm of the consumption price level or output versus the one-year-ahead predicted mean ■ and 0.05 and 0.95 quantiles ■. The quantiles are estimated based on a Monte Carlo simulation with 100,000 replications.

optimize the response coefficients of the simple instrument rules governing the conduct of these policies. Finally, we examine the jointly optimized responses of these policies under global financial cycle upturn and downturn scenarios, with and without policy space constraints.

In what follows, note that under the parameterization of our model, Korea and Switzerland have well-anchored inflation expectations, whereas South Africa and Thailand have less well-anchored inflation expectations, as reflected in the values of the nominal rigidity parameters for output price $\omega^Y$ and wage $\omega^L$ determination. Furthermore, Switzerland and Thailand have relatively high trade openness, whereas Korea and South Africa have relatively low trade openness, as reflected in the value of the steady-state equilibrium import ratio $M/Y$. Finally, Switzerland and South Africa have the largest unhedged foreign-currency-denominated mortgage and corporate external debt exposures, while Korea and Thailand have the smallest, as reflected in the values of the steady-state equilibrium external debt ratios $\mathcal{E}D^{H,f}/P^YY$ and $\mathcal{E}D^{F,f}/P^YY$, respectively.[8]

## 5.1 Policy Transmission Mechanisms

Our estimated DSGE model features extensive interactions among its monetary policy, foreign exchange intervention, fiscal policy, macroprudential policy, and capital flow management transmission mechanisms. We quantify these policy transmission mechanisms and interactions with impulse responses.

### 5.1.1 Monetary Policy

A monetary easing through an interbank rate cut lowers bank lending rates and raises asset prices, as shown in Figure A.1 of Appendix

[8]Calibration of the mortgage and corporate external debt exposures is based on the Locational Banking Statistics and Debt Securities Statistics databases compiled by the BIS. The mortgage external debt exposures capture cross-border bank credit to households, while the corporate external debt exposures capture cross-border bank credit to and international debt securities issued by non-financial firms. We assume that these observed non-financial private-sector external debt exposures are entirely foreign currency denominated, and that they are 75 percent currency hedged for Switzerland versus 25 percent for the other small open economies under consideration, motivated by Du and Schreger (2021).

A. The resultant loosening of financial conditions stimulates private domestic demand—in particular, residential and business investment. The currency depreciates in nominal and real terms, slightly increasing exports and moderately offsetting the rise in imports. Output expands more than potential, and the output gap rises while the unemployment rate falls, associated with higher price and wage inflation. The currency depreciation also increases import price inflation, amplifying and accelerating the rise in consumption price inflation. Quantitatively, lowering the interbank rate by 1 percentage point boosts consumption price inflation by 0.2 to 0.3 percentage point peak after two to four quarters, and output by 0.3 to 0.4 percent peak after three to four quarters, across the economies under consideration. Bank credit rises with mortgage and corporate debt. The fiscal deficit ratio of the consolidated public sector initially falls, reflecting a valuation gain on foreign exchange reserves held by the central bank, contributing to the reduction in the public debt ratio. The current account balance ratio also falls, reflecting higher import expenditures, reducing the net foreign asset ratio.

#### *5.1.2 Foreign Exchange Intervention*

A foreign exchange intervention through reserve sales appreciates the currency, slightly decreasing exports and moderately raising imports, as shown in Figure A.2 of Appendix A. Quantitatively, lowering the foreign exchange reserve ratio by 1 percentage point appreciates the currency by 1.5 percent on impact in nominal and real terms, consistent with the empirical estimates of Adler, Lisack, and Mano (2019).[9] Output contracts more than potential, and the output gap falls while the unemployment rate rises, associated with lower price and wage inflation. The currency appreciation also reduces import price inflation, amplifying and accelerating the fall in consumption price inflation. The central bank cuts the interbank rate to mitigate the falls in consumption price inflation and the output gap, stimulating private domestic demand—in particular, residential and business investment. Bank credit eventually rises

[9]The panel regression on which these empirical estimates are based covers a wide sample of advanced and emerging market economies, including all of the small open economies under consideration in this paper.

with mortgage and corporate debt, while external debt falls due to a valuation effect. The fiscal deficit ratio of the consolidated public sector initially increases, reflecting a valuation loss on foreign exchange reserves held by the central bank, contributing to the rise in the public debt ratio. The current account balance ratio eventually falls, reflecting lower export receipts and higher import expenditures, reducing the net foreign asset ratio.

#### *5.1.3 Fiscal Policy*

A public consumption or investment based fiscal stimulus boosts public demand, while raising the fiscal deficit and public debt ratios, as shown in Figure A.3 or Figure A.4 of Appendix A. Output expands more than potential, and the output gap rises while the unemployment rate falls, associated with higher price and wage inflation. Quantitatively, the peak output multiplier for a public-consumption-based fiscal stimulus ranges from 0.7 to 1.0, while that for a public-investment-based fiscal stimulus ranges from 0.7 to 1.1, across the economies under consideration. But the expansionary effects of the public-investment-based fiscal stimulus are far more persistent, reflecting the productivity gains from building up the public capital stock. To stabilize consumption price inflation and output, the central bank hikes the interbank rate, and the currency appreciates in real terms. Private domestic demand initially rises as output expands, then falls as financial conditions tighten. Substitution from domestic to external mortgage and corporate debt occurs. The current account balance ratio falls, reflecting higher import expenditures, reducing the net foreign asset ratio.

#### *5.1.4 Macroprudential Policy*

A macroprudential tightening through a countercyclical capital buffer increase widens bank lending spreads, enabling banks to accumulate capital through retained earnings, as shown in Figure A.5 of Appendix A. The increases in real mortgage and corporate loan rates reduce residential and business investment. Output contracts more than potential, and the output gap falls while the unemployment rate rises, associated with lower price and wage inflation. The central bank cuts the interbank rate to mitigate the falls in consumption price inflation and the output gap. Bank credit falls with mortgage and corporate debt, while substitution from domestic to external debt occurs. The fiscal deficit ratio increases, reflecting lower nominal output, raising the public debt ratio. The current account balance ratio also increases, reflecting lower import expenditures, raising the net foreign asset ratio.

In response to a macroprudential tightening through a mortgage or corporate loan-to-value limit reduction, residential or business investment falls, as shown in Figure A.6 or Figure A.7 of Appendix A. The associated reduction in mortgage or corporate debt lowers bank credit. Output contracts more than potential, and the output gap falls while the unemployment rate rises, associated with lower price and wage inflation. The central bank cuts the interbank rate to mitigate the falls in consumption price inflation and the output gap. The fiscal deficit ratio increases, reflecting lower nominal output, raising the public debt ratio. The current account balance ratio also increases, reflecting lower import expenditures, raising the net foreign asset ratio.

#### *5.1.5 Capital Flow Management*

Capital flow management through a mortgage or corporate capital control tightening raises the cost of cross-border mortgage or corporate borrowing, as shown in Figure A.8 or Figure A.9 of Appendix A. Bank credit rises as households or firms substitute from external to domestic mortgage or corporate debt, whereas residential or business investment falls. Output contracts more than potential, and the output gap falls while the unemployment rate rises, associated with lower price and wage inflation. The central bank cuts the interbank rate to mitigate the falls in consumption price inflation and the output gap. The currency depreciates only slightly in real terms, because raising the tax rate applicable to cross-border mortgage or corporate borrowing alters the composition of capital inflows without reducing the total much, consistent with the empirical findings of Magud, Reinhart, and Rogoff (2018). The fiscal deficit ratio falls, reflecting higher capital control revenues, reducing the public debt ratio. The current account balance ratio increases, reflecting lower import expenditures, raising the net foreign asset ratio.

### 5.2 Optimized Policy Rules

Suppose that the government has preferences defined over inflation and output stabilization objectives, as well as instrument smoothing objectives, represented by intertemporal loss function

$$\mathcal{L}_t = (1-\beta)\mathrm{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \ell(\hat{\pi}_s^C, \ln \hat{Y}_s^G, \hat{z}_s), \tag{175}$$

where $\hat{z}_s = (\hat{i}_s^B, \hat{r}_{s+1}, \ln \hat{G}_s^C, \ln \hat{G}_s^I, \hat{\kappa}_{s+1}^R, \hat{\phi}_s^H, \hat{\phi}_s^F, \hat{\tau}_s^H, \hat{\tau}_s^F)$. The $N$ policy instruments under consideration are the interbank rate, the foreign exchange reserve ratio, public consumption and investment, the bank capital ratio requirement, the mortgage and corporate loan-to-value ratio limits, and the mortgage and corporate capital control tax rates. For fiscal policy, we abstract from the tax rates and transfer payments, because in practice these policy instruments are linked to automatic fiscal stabilizers, and are rarely used to provide fiscal stimulus.

The intratemporal loss function quadratically penalizes the deviations of consumption price inflation from target and output from potential, as well as the deviations of the policy instruments from their steady-state equilibrium values,

$$\ell(\hat{\pi}_s^C, \ln \hat{Y}_s^G, \hat{z}_s) = (\hat{\pi}_s^C)^2 + \lambda_0 (\ln \hat{Y}_s^G)^2 + \sum_{i=1}^{N} \lambda_i (\hat{z}_{i,s})^2, \tag{176}$$

where $\lambda_i \geq 0$ for all $i = 0, \ldots, N$. As specified, this intratemporal loss function does not represent an independent financial stability objective, which is instead internalized in the inflation and output stabilization objectives. Note that its conditional mean depends on the conditional means and variances of its arguments:

$$\begin{aligned} \mathrm{E}_t \ell(\hat{\pi}_s^C, \ln \hat{Y}_s^G, \hat{z}_s) &= \left[(\mathrm{E}_t \hat{\pi}_s^C)^2 + Var_t(\hat{\pi}_s^C)\right] \\ &+ \lambda_0 \left[(\mathrm{E}_t \ln \hat{Y}_s^G)^2 + Var_t(\ln \hat{Y}_s^G)\right] + \sum_{i=1}^{N} \lambda_i \left[(\mathrm{E}_t \hat{z}_{i,s})^2 + Var_t(\hat{z}_{i,s})\right]. \end{aligned} \tag{177}$$

By making the conditional variances of all endogenous variables state dependent, our endogenous risk mechanism has the potential to alter the optimal conduct of policy under quadratic loss, by capturing intertemporal risk-return policy trade-offs. For example, stimulating the economy with monetary easing builds up financial vulnerabilities in our framework, which makes drawing large shocks more likely under our state-dependent conditional heteroskedasticity mechanism, which further puts growth at risk if such shocks tighten financial conditions. As shown in Adrian and Vitek (2020), accounting for this macrofinancial feedback loop calls for accompanying monetary easing with more aggressive macroprudential tightening, to enhance the resilience of the banking sector to financial vulnerabilities while leaning against their buildup.

Suppose that the government minimizes its intertemporal loss function under long-run commitment to its policy rules with respect to their response coefficients, subject to the structure of the world economy as represented by the rest of our estimated DSGE model. Note that this constrained minimization problem takes as given our postulated functional dependence of policy instruments on intermediate targets. We consider a flexible inflation-targeting regime with a dual mandate, and set the weight on output fluctuations $\lambda_0$ to 0.50. To account for instrument smoothing, we set the weights on the policy instruments under consideration $\lambda_i$ to 1.00 for all $i = 1, \ldots, N$. We evaluate the intertemporal loss function by forecasting the means and variances of its annualized arguments out 25 years, conditional on the estimated state of the world economy. Under long-run commitment, we then average this intertemporal loss function across all historical states, to eliminate its dependence on initial conditions. Finally, we numerically minimize this average intertemporal loss function, jointly with respect to the response coefficients of the relevant policy rules, subject to inequality constraints on them.

The optimized policy rule response coefficients are all positive, as shown in Table 1. This absence of corner solutions implies that all of the policies under consideration should be systematically used to help stabilize inflation and output in our framework, on average across states of the world economy. Across the economies under consideration, monetary policy should respond aggressively to expected future consumption price inflation and moderately to the output gap. Indeed, our optimized monetary policy rules are similar to that advocated by Taylor (1993). In the pursuit of inflation and output stabilization objectives, foreign exchange intervention should

**Table 1. Optimized Policy Rule Response Coefficients**

| | Korea | South Africa | Switzerland | Thailand |
|---|---|---|---|---|
| Monetary Policy | | | | |
| $\xi^{\pi^C}$ | 1.6663 | 1.5050 | 1.4337 | 1.7387 |
| $\xi^{Y^G}$ | 0.8447 / $S$ | 0.1787 / $S$ | 0.6652 / $S$ | 0.3137 / $S$ |
| Foreign Exchange Intervention | | | | |
| $\xi^{r}$ | $0.0258S$ | $0.0036S$ | $0.0481S$ | $0.0032S$ |
| Fiscal Policy | | | | |
| $\xi^{G^C}$ | 1.6330 | 0.9694 | 1.6255 | 1.3297 |
| $\xi^{G^I}$ | 1.5909 | 0.9079 | 1.6179 | 1.2938 |
| Macroprudential Policy | | | | |
| $\xi^{\kappa^R}$ | 0.0166 | 0.0094 | 0.0161 | 0.0100 |
| $\xi^{\phi^H}$ | 0.0854 | 0.0438 | 0.0481 | 0.0439 |
| $\xi^{\phi^F}$ | 0.0723 | 0.0560 | 0.0889 | 0.0503 |
| Capital Flow Management | | | | |
| $\xi^{\tau^H}$ | $0.0182\ f(\alpha^H, i^H)$ | $0.0124\ f(\alpha^H, i^H)$ | $0.0171\ f(\alpha^H, i^H)$ | $0.0109\ f(\alpha^H, i^H)$ |
| $\xi^{\tau^F}$ | $0.0205\ f(\alpha^F, i^F)$ | $0.0189\ f(\alpha^F, i^F)$ | $0.0178\ f(\alpha^F, i^F)$ | $0.0111\ f(\alpha^F, i^F)$ |

**Note:** The parameterization is a function of the seasonal frequency $S$, evaluated at $S = 4$. Also, $f(\alpha^Z, i^Z) = \frac{1+i^Z}{\alpha^Z+i^Z}\frac{1}{S}$ for $Z \in \{H, F\}$.

respond mildly to the change in the real exchange rate, by adjusting the foreign exchange reserve ratio in response to its level. This finding is consistent with Lama and Medina (2020), who also rationalize leaning against real exchange rate changes through foreign exchange intervention under a flexible inflation-targeting regime. Fiscal policy should respond moderately to the output gap, by adjusting public consumption and investment over the business cycle. Macroprudential policy should respond mildly to real bank credit, by adjusting the countercyclical capital buffer over the credit cycle. It should also respond mildly to real mortgage and corporate debt, by adjusting the mortgage and corporate loan-to-value ratio limits. Finally, capital flow management should respond mildly to real external mortgage and corporate debt, by adjusting the mortgage and corporate capital control tax rates.

While the absence of corner solutions implies in principle that all of the policies under consideration should systematically respond to all shocks in our continuous framework, in practice the prescribed adjustments to policy instrument settings will often fall short of conventional discrete response thresholds. For example, monetary policy responses through interbank rate adjustments are conventionally measured in 25 basis point increments. If comparable thresholds are applied to the other policy instruments under consideration, then the magnitudes of our optimized policy rule response coefficients imply that foreign exchange intervention, macroprudential policy, and capital flow management responses will rarely be warranted in practice. Indeed, they will only be warranted in response to large changes in the relevant intermediate targets, which tend to arise from sequences of large mutually reinforcing shocks.

The substantial variation in the optimized policy rule response coefficients across economies reflects differences in their calibrated structural characteristics and estimated shock exposures. A general principle that emerges from examining these patterns is that economies with larger international trade and financial exposures should more actively use foreign exchange intervention and capital flow management. Intuitively, foreign exchange intervention tends to be more effective at stabilizing inflation and output in economies with higher trade openness due to stronger exchange rate pass-through and expenditure switching. In parallel, capital flow management tends to be more effective at stabilizing economies with larger unhedged external foreign-currency-denominated debt exposures due to more sensitive financial conditions and vulnerabilities, which influence growth at risk. Indeed, this calibrated structural characteristic is strongly associated with the optimized intensity of capital flow management in our framework.

This general principle is conditional on foreign exchange intervention and capital flow management being effective. Its application in practice is also conditional on their response thresholds being crossed. In our model, foreign exchange intervention affects the real exchange rate under our assumption that $\gamma^B > 0$, which ensures that the foreign currency liquidity regulation cost drives a wedge into the uncovered interest parity condition, indicative of a shallow foreign exchange market. Capital flow management affects capital inflows if non-financial private-sector external debt exposures exist, which in our model are foreign currency denominated and unhedged. If foreign exchange intervention or capital flow management do not affect these intermediate targets, then the intertemporal loss function does not trade off inflation and output stabilization benefits from using

**Table 2. Global Financial Cycle Upturn Scenario Assumptions**

| | |
|---|---|
| Layer 1: Asset Prices | |
| Term Premium, Duration Risk Premium Shocks | −50 Basis Points |
| Relative Price of Housing, Housing Risk Premium Shocks | +5 Percent |
| Relative Price of Equity, Equity Risk Premium Shocks | +10 Percent |
| Real Exchange Rate, Foreign Currency Liquidity Shocks | + 5 Percent |
| Layer 2: Bank Credit | |
| Mortgage Loan Spread, Mortgage Loan Markup Shocks | −50 Basis Points |
| Corporate Loan Spread, Corporate Loan Markup Shocks | −100 Basis Points |
| Layer 3: Confidence | |
| Private Consumption, Private Consumption Demand Shocks | +0.5 Percent |
| Residential Investment, Residential Investment Demand Shocks | +2.0 Percent |
| Business Investment, Business Investment Demand Shocks | +2.0 Percent |

**Note:** All scenario assumptions apply to the rest of the world and are expressed as deviations from baseline at the annual frequency, with effects phased in over two years.

them against instrument smoothing costs, driving the corresponding optimized policy rule response coefficients to zero.

## *5.3 Optimized Policy Responses*

We now examine how the policy mix should be adjusted in response to global financial cycle upturns and downturns, with and without policy space constraints. This scenario analysis is conditional on our jointly optimized monetary policy, foreign exchange intervention, fiscal policy, macroprudential policy, and capital flow management rules. To focus on differences in the optimized policy responses across the small open economies under consideration, we consider stylized scenarios based on harmonized assumptions. In reality, greater differentiation across the advanced versus emerging market economies may be expected, reflecting phenomena that we abstract from such as safe-haven capital inflows to government bond markets in the former group at times of stress.

### *5.3.1 Global Financial Cycle Upturn Scenario*

Our global financial cycle upturn scenario assumes a gradual loosening of financial conditions and rise in confidence in the rest of the world, as detailed in Table 2. In particular, the compression of duration, housing, and equity risk premiums reduces the government bond yield and raises the prices of housing and equity. In addition, higher foreign currency liquidity appreciates the currency of the small open economy. Furthermore, the compression of mortgage and corporate loan markups narrows the mortgage and corporate loan spreads. Finally, higher confidence among households and firms further raises private domestic demand.

Under our global financial cycle upturn scenario, looser financial conditions and higher confidence stimulate private domestic demand, in particular residential and business investment, as shown in Figure B.1 of Appendix B. This gradual loosening of financial conditions mainly reflects a lower government bond yield and higher price of equity. These asset price adjustments are transmitted from the rest of the world to the small open economy under consideration via international bond and stock market contagion effects, which are stronger for the emerging market economies. Output initially expands more than potential, and the output gap rises while the unemployment rate falls, associated with higher output price and wage inflation. But consumption price inflation falls due to appreciation of the currency, which reduces import price inflation. It also induces expenditure switching from exports to imports, mitigating the output expansion. Nevertheless, exports rise substantially, driven by higher private domestic demand in the rest of the world. Finally, financial vulnerabilities build up, reflected in higher bank credit, as well as higher mortgage and corporate debt, in particular external corporate debt.

Under this global financial cycle upturn scenario, if the economy under consideration has well-anchored inflation expectations and relatively low trade openness, then the central bank can look through the temporary fall in consumption price inflation, and hikes the interbank rate to stabilize output. In contrast, if the economy has less well-anchored inflation expectations and relatively high trade openness, then the central bank initially cuts the interbank rate to raise consumption price inflation to target, amplifying the output expansion. Nevertheless, foreign exchange intervention limits the need for a procyclical interbank rate cut, with the central bank leaning against the currency appreciation through reserve purchases, mitigating the fall in consumption price inflation. In addition, countercyclical fiscal consolidation by the government helps stabilize output, through lower public consumption and investment expenditures. Furthermore, macroprudential tightening leans against the buildup of financial vulnerabilities, through a higher countercyclical capital buffer, as well as lower mortgage and corporate loan-to-value limits. Finally, capital flow management leans against the buildup of external corporate debt, through a corporate capital control tightening.

Quantitatively, monetary policy plays the primary role in stabilizing consumption price inflation and output under this global financial cycle upturn scenario.[10] Foreign exchange intervention plays a supporting role in raising consumption price inflation to target, through reserve purchases to depreciate the currency. The destabilizing effect of foreign exchange intervention on output is offset by fiscal policy, through expenditure-based fiscal consolidation which reinforces expenditure switching from imports to exports. In addition, automatic fiscal stabilizers are allowed to operate fully, further mitigating the output expansion. While macroprudential policy and capital flow management have much smaller effects on the conditional means of consumption price inflation and the output gap, they help maintain macroeconomic stability by safeguarding financial stability, by leaning against the buildup of financial vulnerabilities that put growth at risk. In economies with relatively large financial exposures, this significantly mitigates the buildup of bank credit, as well as mortgage and corporate debt—in particular, external corporate debt.

#### *5.3.2 Global Financial Cycle Downturn Scenario*

Our global financial cycle downturn scenario is qualitatively symmetric to our global financial cycle upturn scenario, but is quantitatively more severe. It assumes an abrupt tightening of financial conditions and fall in confidence in the rest of the world, as detailed in Table 3. In particular, the decompression of duration, housing, and equity risk premiums raises the government bond yield and reduces the prices of housing and equity. In addition, lower foreign currency liquidity depreciates the currency of the small open economy.

[10] For the constrained scenario simulation results, see Adrian, Gaspar, and Vitek (2022).

**Table 3. Global Financial Cycle Downturn Scenario Assumptions**

| | |
|---|---|
| Layer 1: Asset Prices | |
| Term Premium, Duration Risk Premium Shocks | +100 Basis Points |
| Relative Price of Housing, Housing Risk Premium Shocks | −10 Percent |
| Relative Price of Equity, Equity Risk Premium Shocks | −20 Percent |
| Real Exchange Rate, Foreign Currency Liquidity Shocks | −10 Percent |
| Layer 2: Bank Credit | |
| Mortgage Loan Spread, Mortgage Loan Markup Shocks | +100 Basis Points |
| Corporate Loan Spread, Corporate Loan Markup Shocks | +200 Basis Points |
| Layer 3: Confidence | |
| Private Consumption, Private Consumption Demand Shocks | −1.0 Percent |
| Residential Investment, Residential Investment Demand Shocks | −4.0 Percent |
| Business Investment, Business Investment Demand Shocks | −4.0 Percent |

**Note:** All scenario assumptions apply to the rest of the world and are expressed as deviations from baseline at the annual frequency, with effects phased in over one year.

Furthermore, the decompression of mortgage and corporate loan markups widens the mortgage and corporate loan spreads. Finally, lower confidence among households and firms further reduces private domestic demand.

Under our global financial cycle downturn scenario, tighter financial conditions and lower confidence depress private domestic demand, in particular residential and business investment, as shown in Figure B.2 of Appendix B. This abrupt tightening of financial conditions mainly reflects a higher government bond yield and lower price of equity, transmitted via international bond and stock market contagion effects. Output initially contracts more than potential, and the output gap falls while the unemployment rate rises, associated with lower output price and wage inflation. But consumption price inflation rises due to depreciation of the currency, while expenditure switching from imports to exports mitigates the output contraction. Nevertheless, exports fall substantially, driven by lower private domestic demand in the rest of the world. Finally, financial vulnerabilities unwind, reflected in lower bank credit, as well as lower mortgage and corporate debt, in particular external corporate debt.

Under this global financial cycle downturn scenario, if the economy under consideration has well-anchored inflation expectations and relatively low trade openness, then the central bank can look through the temporary rise in consumption price inflation, and cuts the interbank rate to stabilize output. In contrast, if the economy has less well-anchored inflation expectations and relatively high trade openness, then the central bank initially hikes the interbank rate to reduce consumption price inflation to target, amplifying the output contraction. This prediction is consistent with the empirical finding of Vegh and Vuletin (2013), that many emerging market economies tend to respond to capital outflow surges with procyclical monetary policy tightening. Nevertheless, foreign exchange intervention limits the need for a procyclical interbank rate hike, with the central bank leaning against the currency depreciation through reserve sales, mitigating the rise in consumption price inflation. This use of foreign exchange intervention during a financial cycle downturn parallels Adrian et al. (2021), who emphasize the resultant monetary autonomy gain. In addition, countercyclical fiscal stimulus by the government helps stabilize output, through higher public consumption and investment expenditures. Furthermore, macroprudential easing helps support bank credit supply through a lower countercyclical capital buffer, as well as bank credit demand through higher mortgage and corporate loan-to-value limits. Finally, capital flow management limits the retrenchment of cross-border corporate borrowing, through a corporate capital control easing.

Quantitatively, monetary policy plays the primary role in stabilizing consumption price inflation and output under this global financial cycle downturn scenario.[11] Foreign exchange intervention plays a supporting role in reducing consumption price inflation to target, through reserve sales to appreciate the currency. The destabilizing effect of foreign exchange intervention on output is offset by fiscal policy, through expenditure-based fiscal stimulus. In addition, automatic fiscal stabilizers are allowed to operate fully, further mitigating the output contraction. While macroprudential policy and capital flow management have much smaller effects on the conditional means of consumption price inflation and the output gap, they help maintain macroeconomic stability by safeguarding financial stability, by supporting domestic bank credit supply, as well as domestic and cross-border bank credit demand.

[11]For the constrained scenario simulation results, see Adrian, Gaspar, and Vitek (2022).

## 6. Conclusion

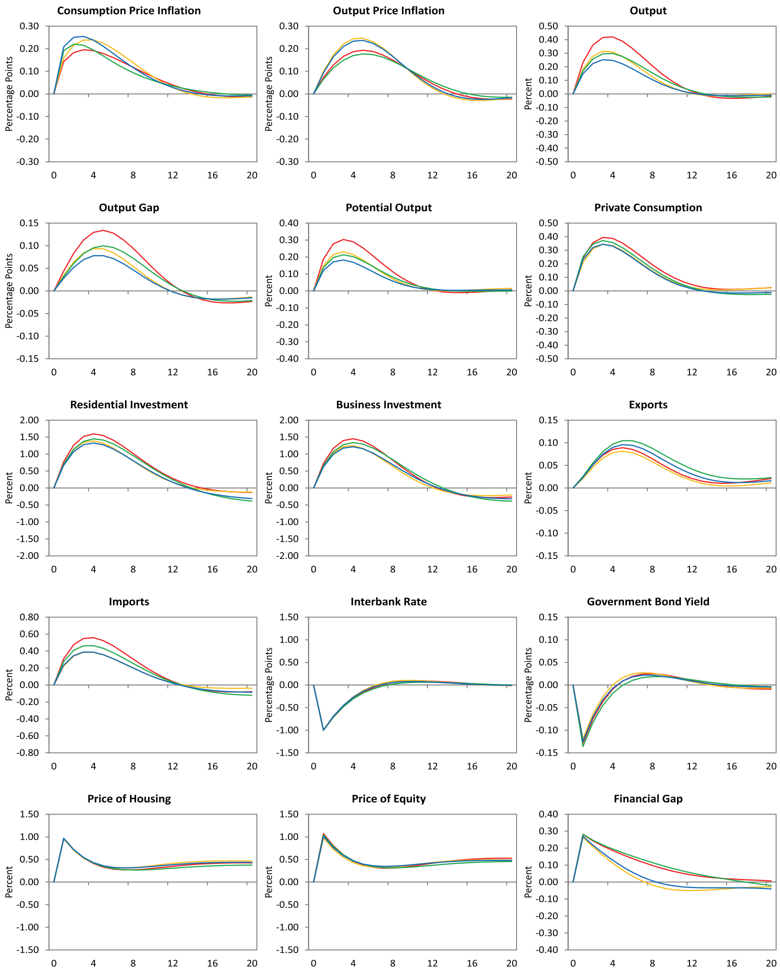
Recurrent capital inflow and outflow surges—often associated with global financial cycle upturns and downturns—confront policymakers in small open advanced and emerging market economies with complex policy trade-offs. To maintain macroeconomic and financial stability amid volatile capital flows, these policymakers have developed toolkits spanning some combination of monetary policy, foreign exchange intervention, fiscal policy, macroprudential policy, or capital flow management. Optimally adjusting such a high-dimensional policy mix in response to shocks while internalizing trade-offs requires an IPF.

This paper develops and estimates a medium-scale heteroskedastic linearized DSGE model of the world economy, disaggregated into a pair of asymmetric economies, to help support the IPF. Our model integrates the full range of policies used to cope with recurrent capital inflow and outflow surges. Applying it to four small open advanced and emerging market economies, our optimal policy analysis broadly supports their observed tendency to respond to global financial cycle upturns and downturns with eclectic policy mix adjustments. We find that economies with larger international trade and financial exposures should more actively use foreign exchange intervention and capital flow management, under some conditions. We illustrate this general principle by simulating global financial cycle upturn and downturn scenarios using our model, conditional on our optimized policy rules. When unconstrained, monetary policy plays the primary role in stabilizing consumption price inflation and output. Foreign exchange intervention enhances monetary autonomy through a supporting role in stabilizing consumption price inflation, while its destabilizing effect on output under these scenarios is offset by fiscal policy. Finally, macroprudential policy and capital flow management lean against financial developments that put growth at risk.

Our policy analysis framework is subject to important caveats. Notably, the specification of our endogenous risk mechanism is not derived from microeconomic foundations, so its slope coefficients may not be invariant to policy rule changes, exposing our policy analysis to the critique due to Lucas (1976). In addition, the frequent use of foreign exchange intervention and capital flow management can change structural characteristics of the financial markets on which these policies operate, altering their transmission mechanisms. While adopted from the inflation-targeting literature, the loss function that we use is inconsistent with our model, as choosing the response coefficients of our policy rules to minimize it does not maximize the welfare of the representative household. Furthermore, these policy rules restrict the functional dependence of policy instruments on intermediate targets to postulated simple linear relationships, so their policy prescriptions may depart from the unconstrained optimum. Finally, jointly optimizing these policy rules disregards institutional realities that may preclude such a high degree of policy coordination in practice. Despite these caveats, we view our model as a useful approximation to reality—and our policy analysis framework as a powerful tool—to help guide policymakers in adjusting their policy mix to cope with capital flow surges in an integrated way.

## Appendix A. Transmission Mechanisms

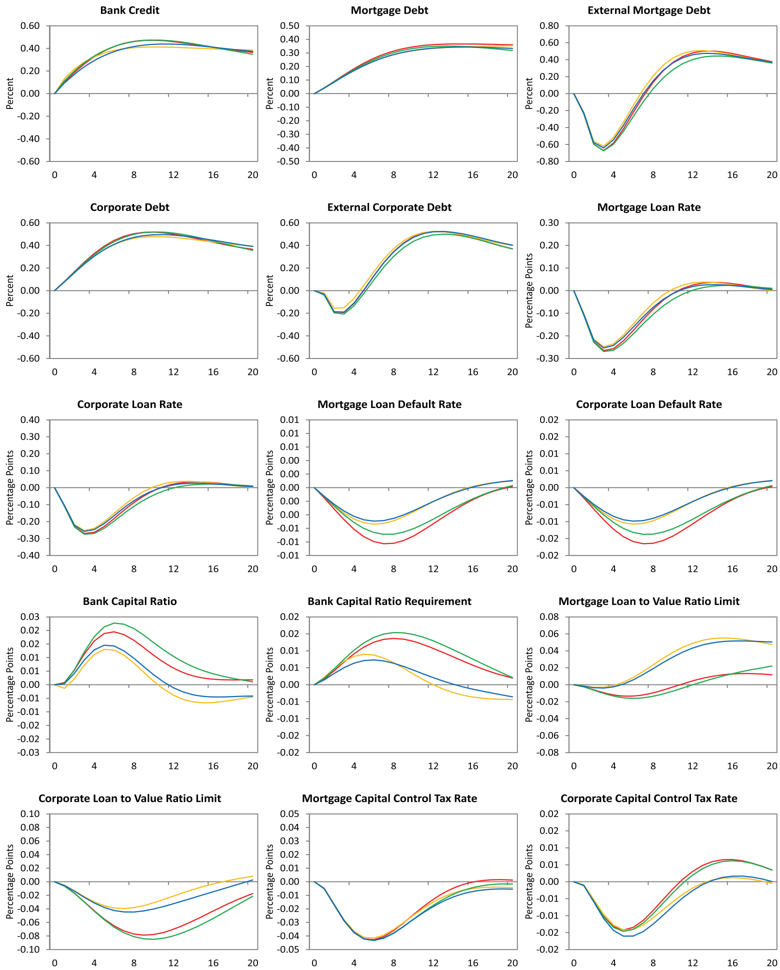
### Figure A.1. Monetary Easing: Interbank Rate Cut




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a monetary policy shock that reduces the interbank rate by 1 percentage point. All variables are annualized, where applicable.

*(continued)*

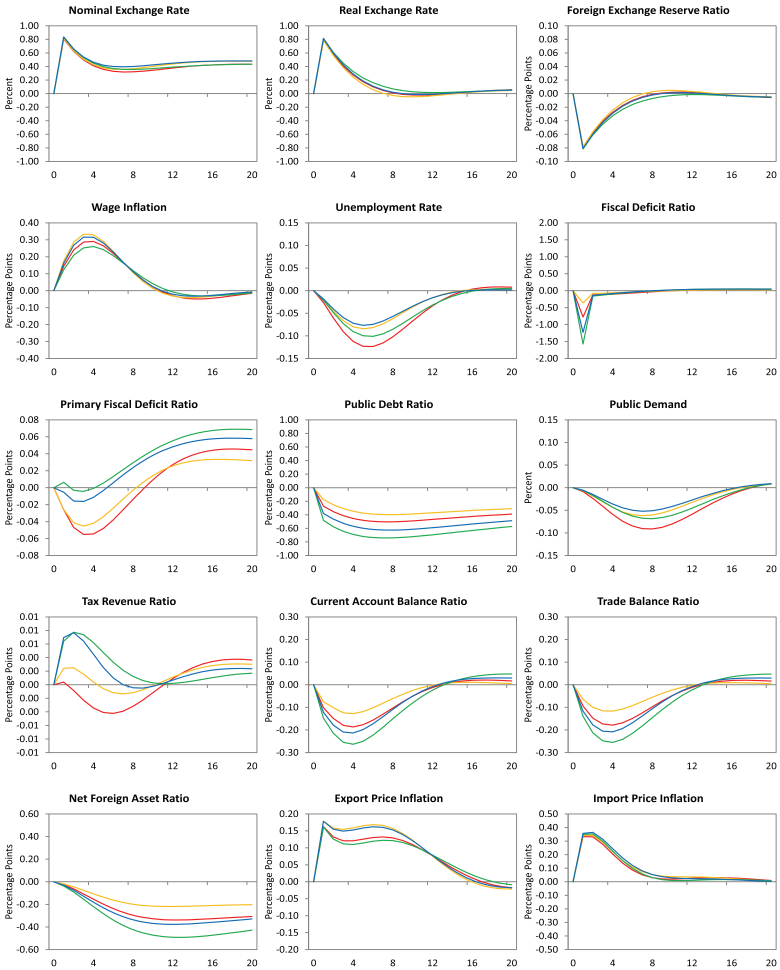
## Figure A.1. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a monetary policy shock that reduces the interbank rate by 1 percentage point. All variables are annualized, where applicable.

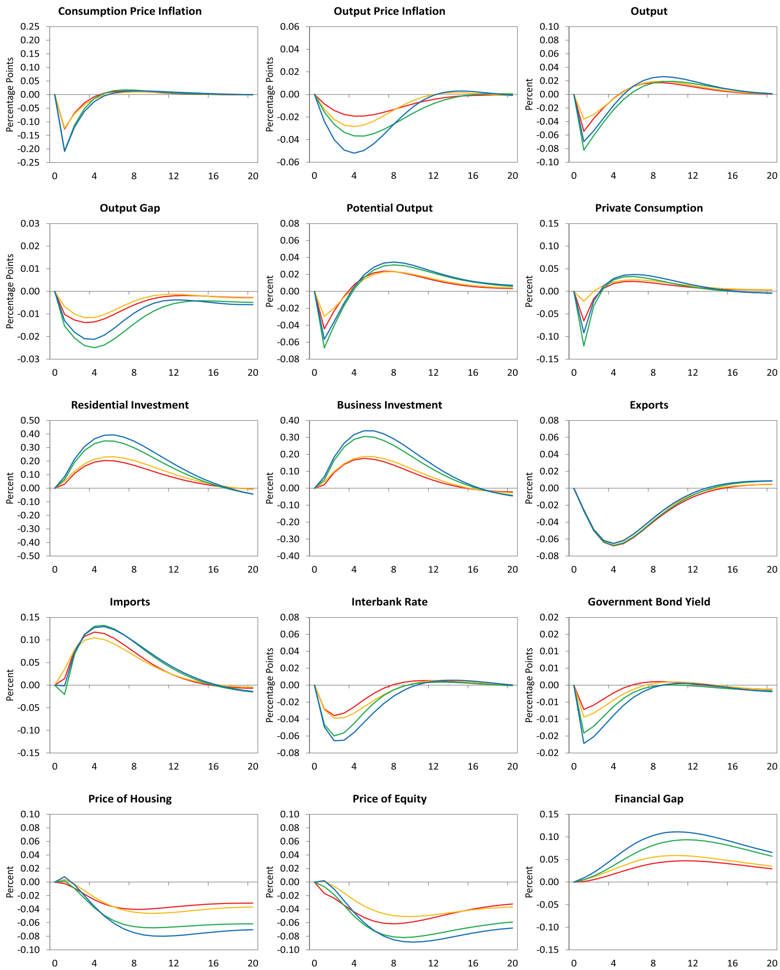
(*continued*)

## Figure A.1. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a monetary policy shock that reduces the interbank rate by 1 percentage point. All variables are annualized, where applicable.

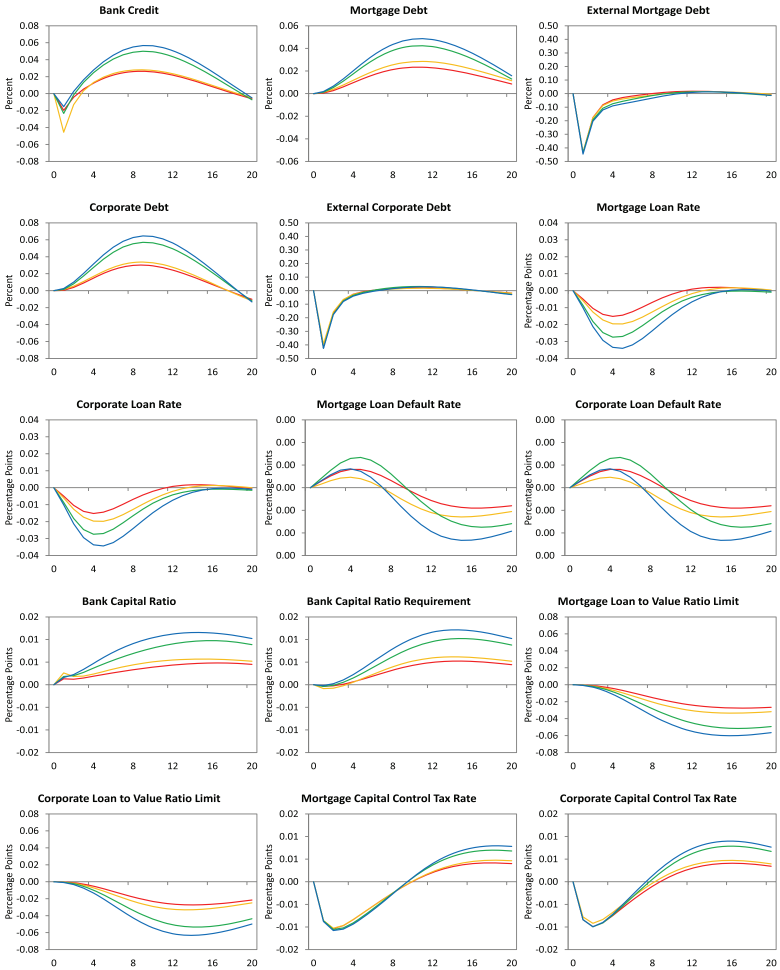
## Figure A.2. Foreign Exchange Intervention: Reserve Sales




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a foreign exchange intervention shock that reduces the foreign exchange reserve ratio by 1 percentage point. All variables are annualized, where applicable.

(*continued*)

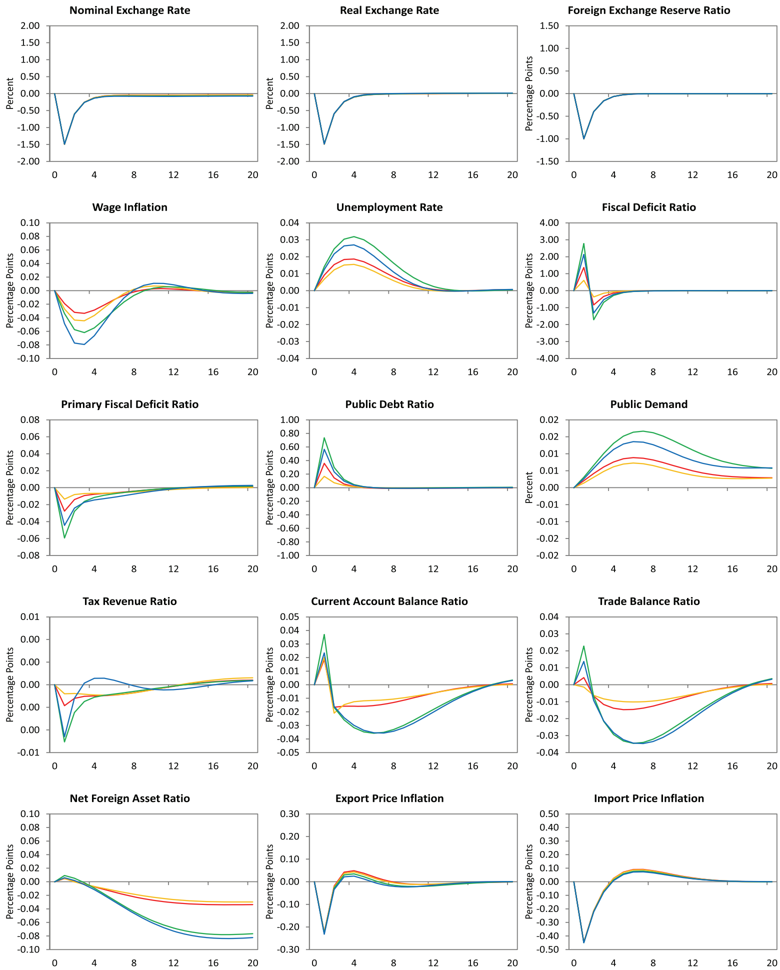
## Figure A.2. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a foreign exchange intervention shock that reduces the foreign exchange reserve ratio by 1 percentage point. All variables are annualized, where applicable.

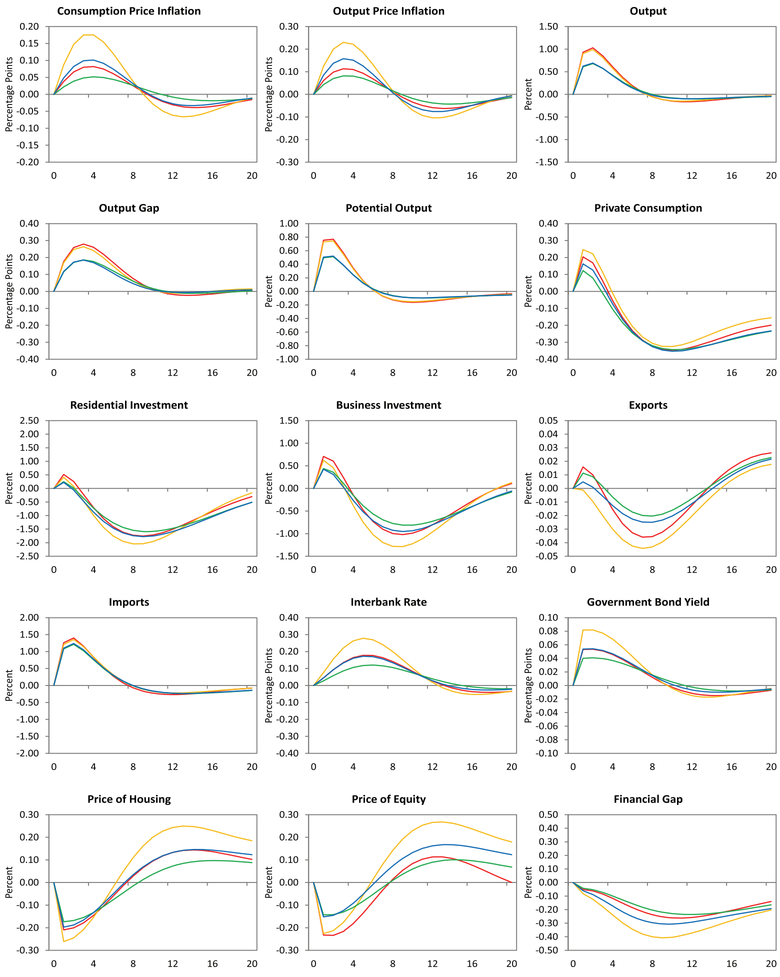
*(continued)*

## Figure A.2. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a foreign exchange intervention shock that reduces the foreign exchange reserve ratio by 1 percentage point. All variables are annualized, where applicable.

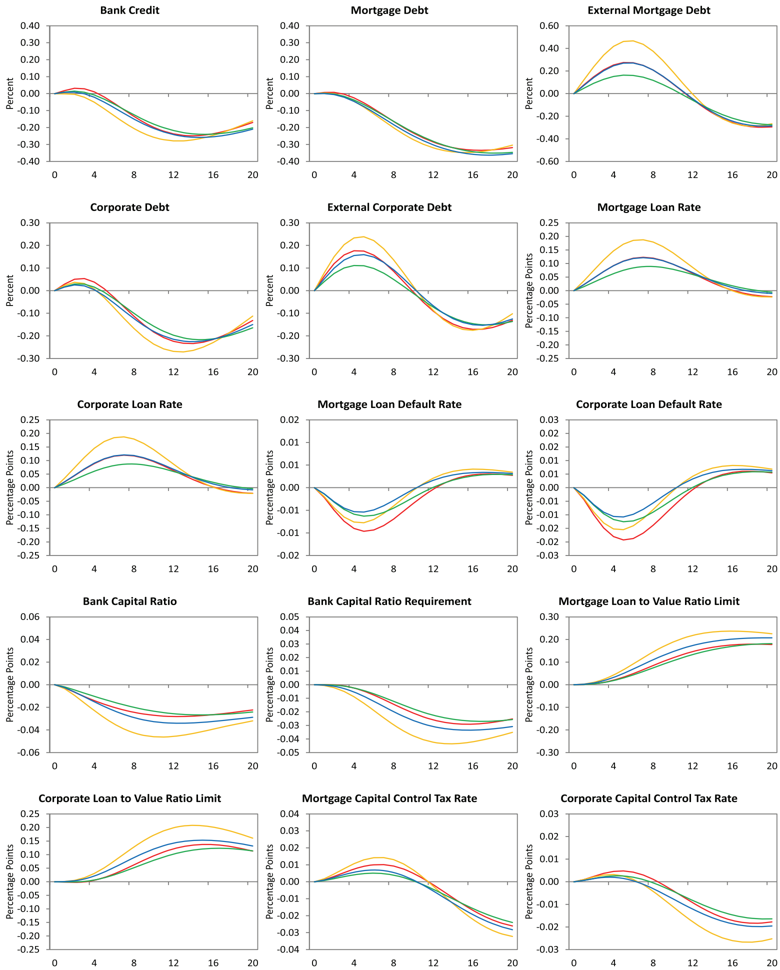
## Figure A.3. Fiscal Stimulus: Public Consumption Increase




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a public consumption demand shock that raises the primary fiscal deficit ratio by 1 percentage point. All variables are annualized, where applicable.

(*continued*)

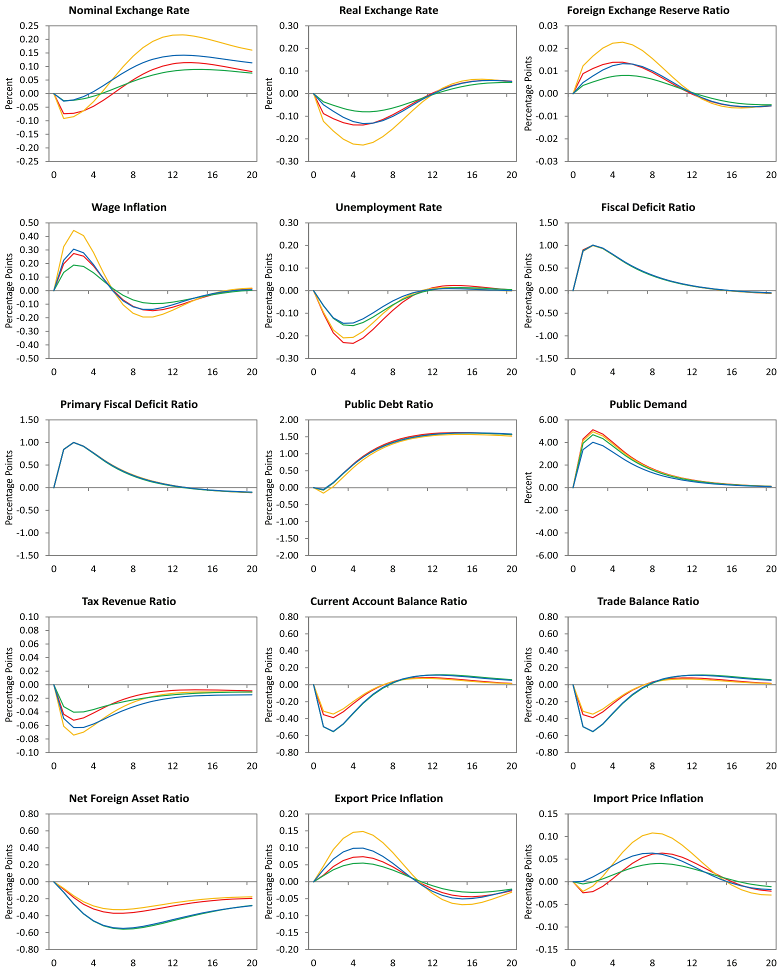
## Figure A.3. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a public consumption demand shock that raises the primary fiscal deficit ratio by 1 percentage point. All variables are annualized, where applicable.

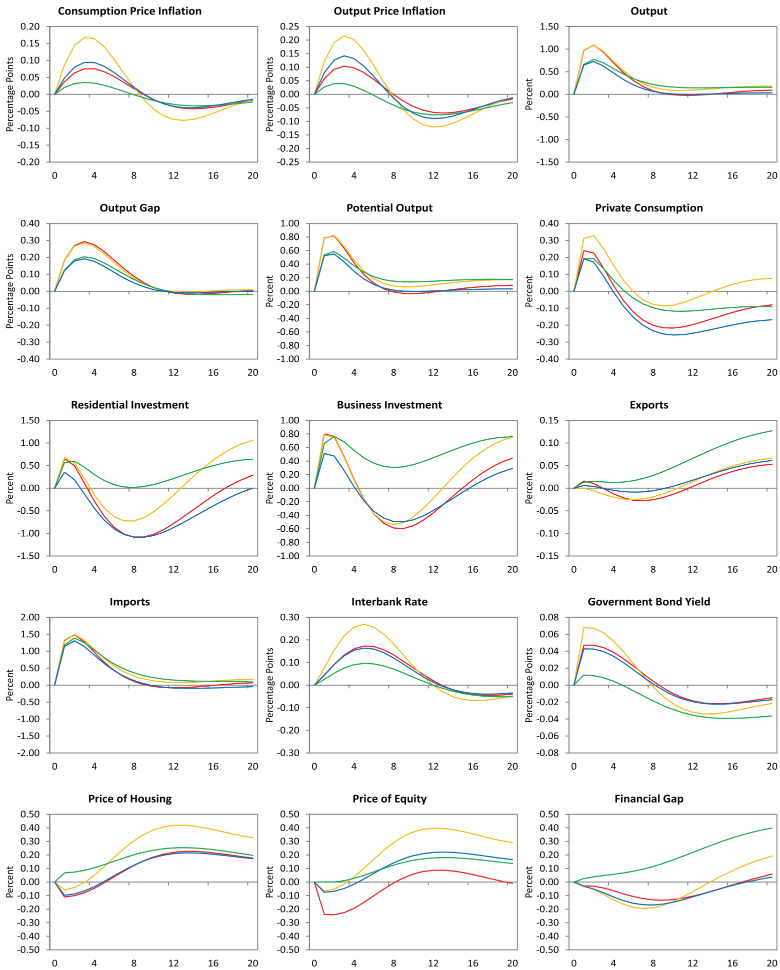
*(continued)*

## Figure A.3. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a public consumption demand shock that raises the primary fiscal deficit ratio by 1 percentage point. All variables are annualized, where applicable.

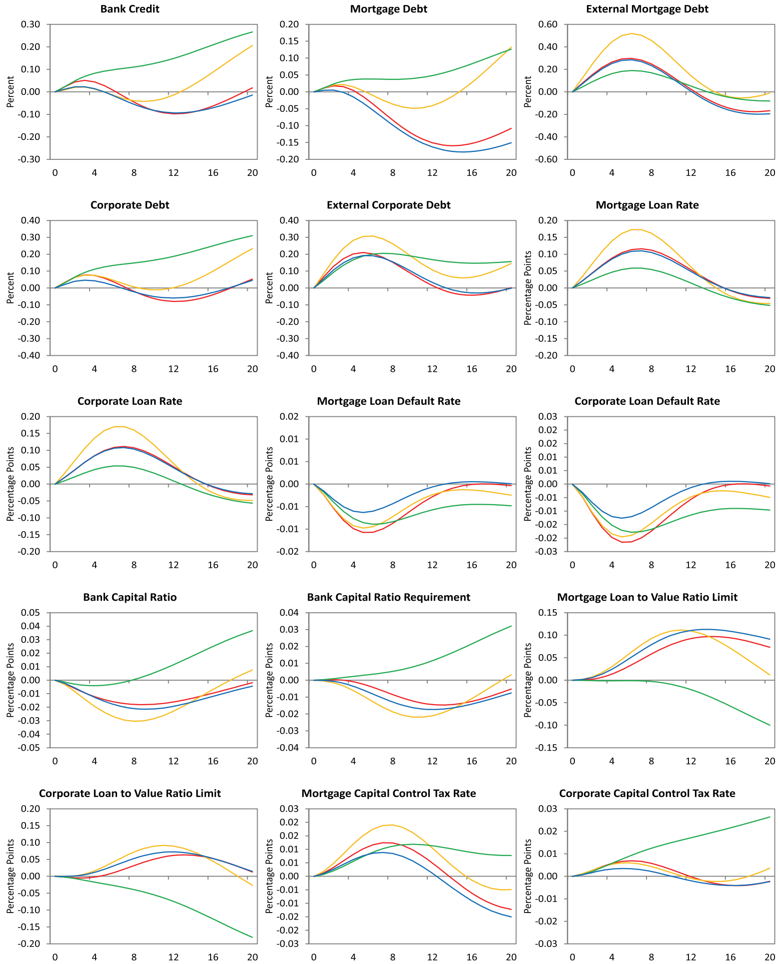
## Figure A.4. Fiscal Stimulus: Public Investment Increase




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a public investment demand shock that raises the primary fiscal deficit ratio by 1 percentage point. All variables are annualized, where applicable.

(*continued*)

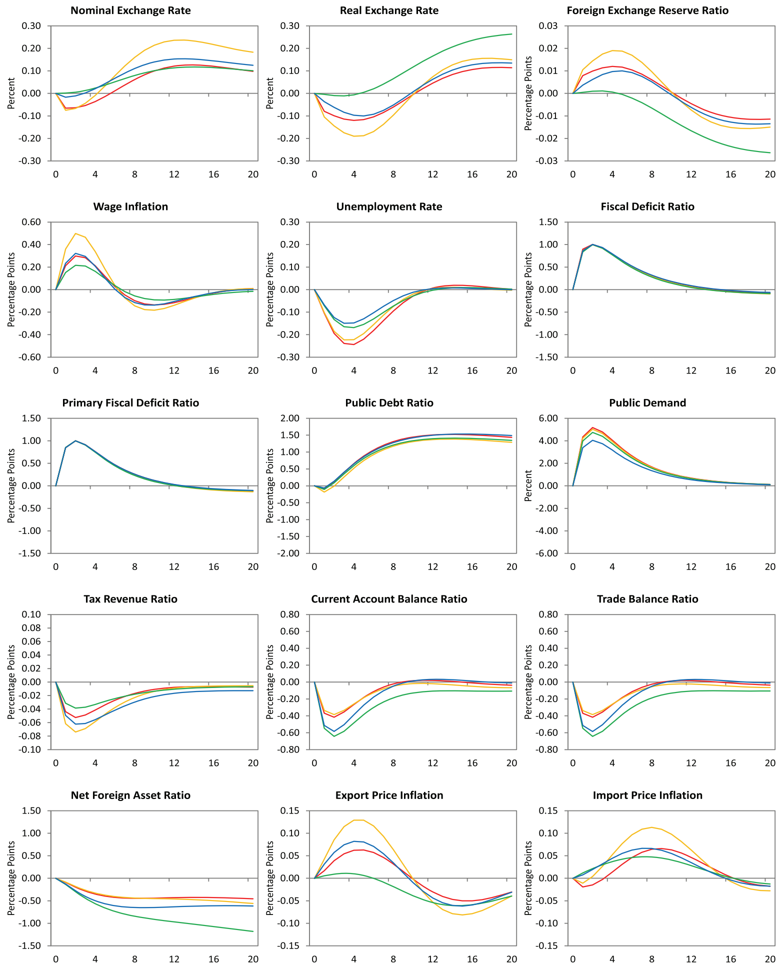
**Figure A.4. (Continued)**




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a public investment demand shock that raises the primary fiscal deficit ratio by 1 percentage point. All variables are annualized, where applicable.

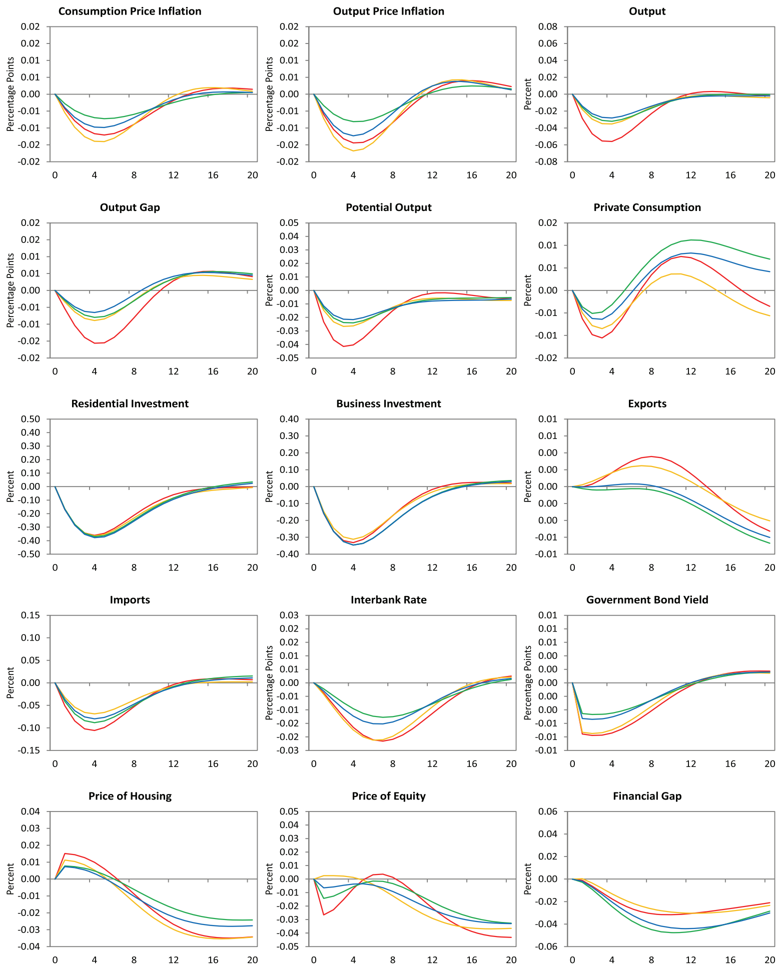
*(continued)*

# Figure A.4. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a public investment demand shock that raises the primary fiscal deficit ratio by 1 percentage point. All variables are annualized, where applicable.

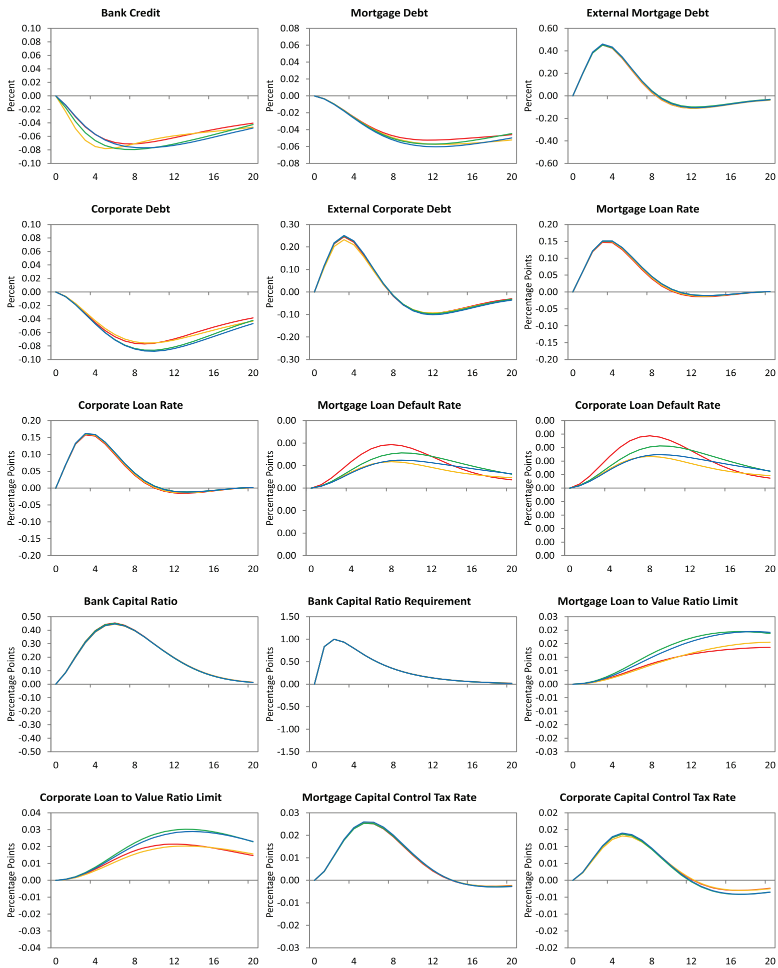
## Figure A.5. Macroprudential Tightening: Countercyclical Capital Buffer Increase




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a bank capital requirement shock that raises the bank capital ratio requirement by 1 percentage point. All variables are annualized, where applicable.

*(continued)*

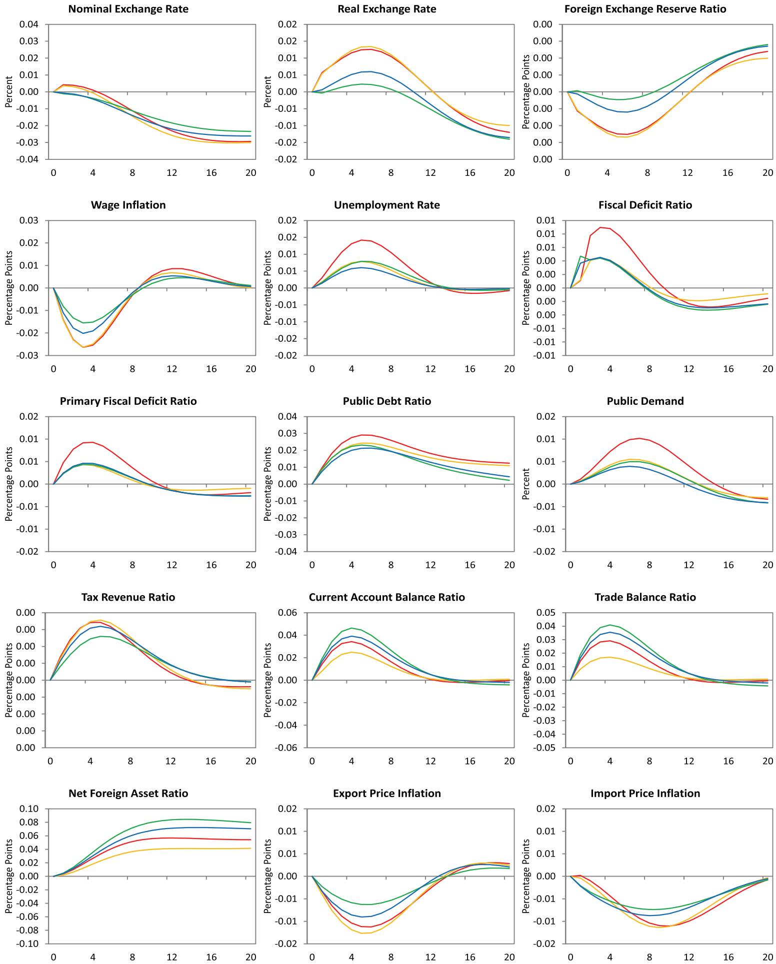
## Figure A.5. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a bank capital requirement shock that raises the bank capital ratio requirement by 1 percentage point. All variables are annualized, where applicable.

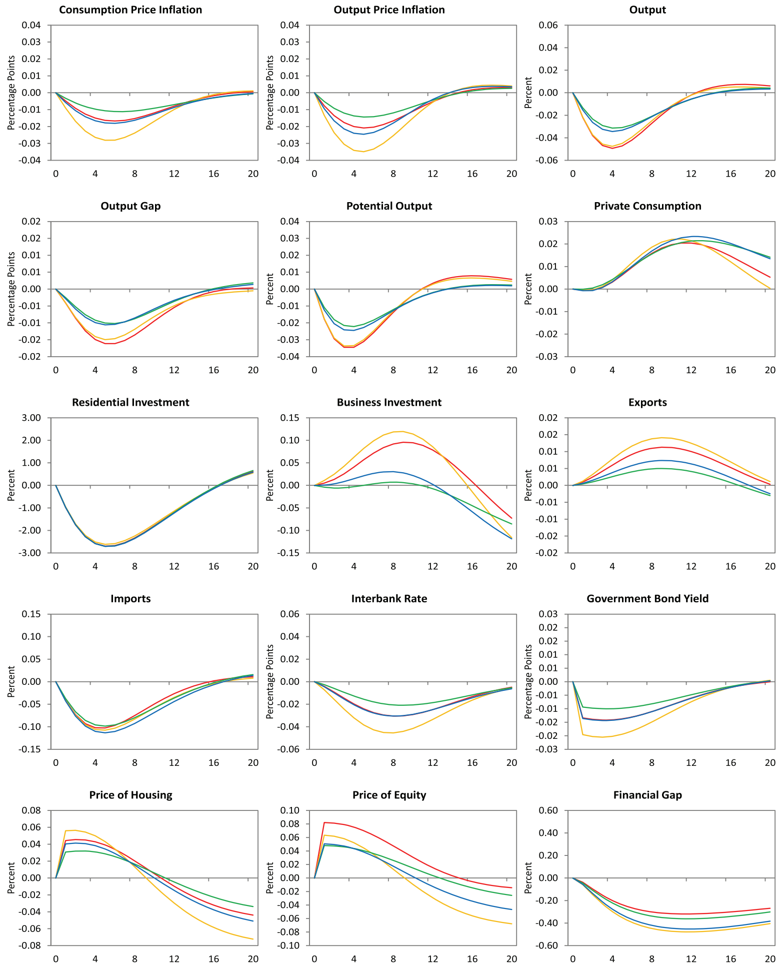
*(continued)*

# Figure A.5. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a bank capital requirement shock that raises the bank capital ratio requirement by 1 percentage point. All variables are annualized, where applicable.

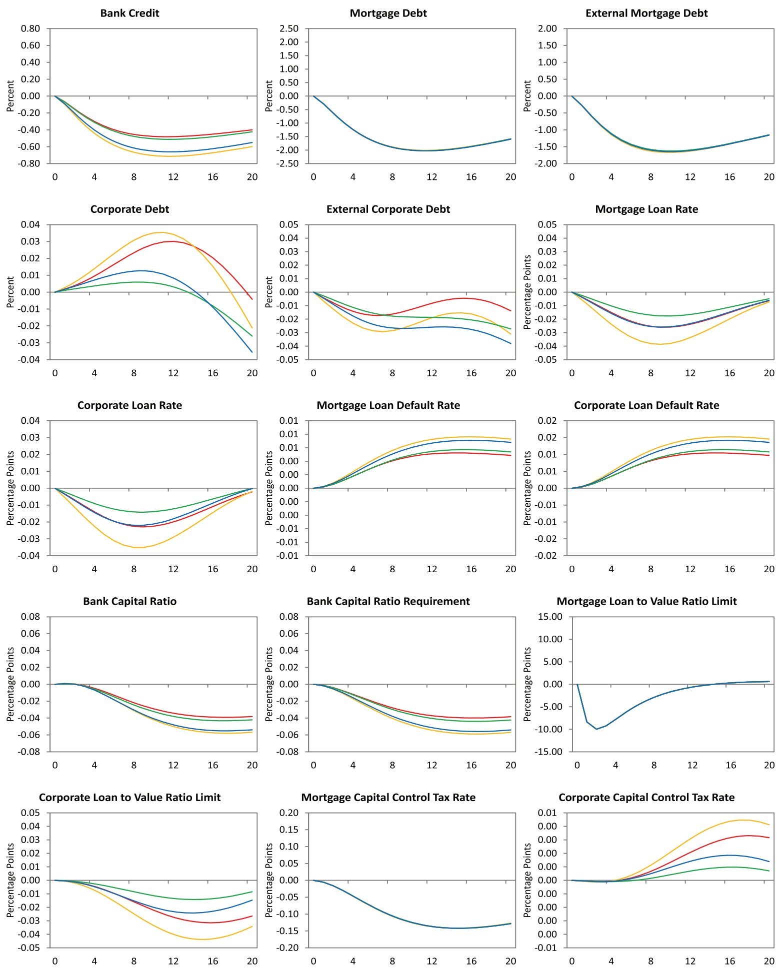
## Figure A.6. Macroprudential Tightening: Mortgage Loan to Value Limit Reduction




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a mortgage loan to value limit shock that reduces the mortgage loan to value ratio limit by 10 percentage points. All variables are annualized, where applicable.

(*continued*)

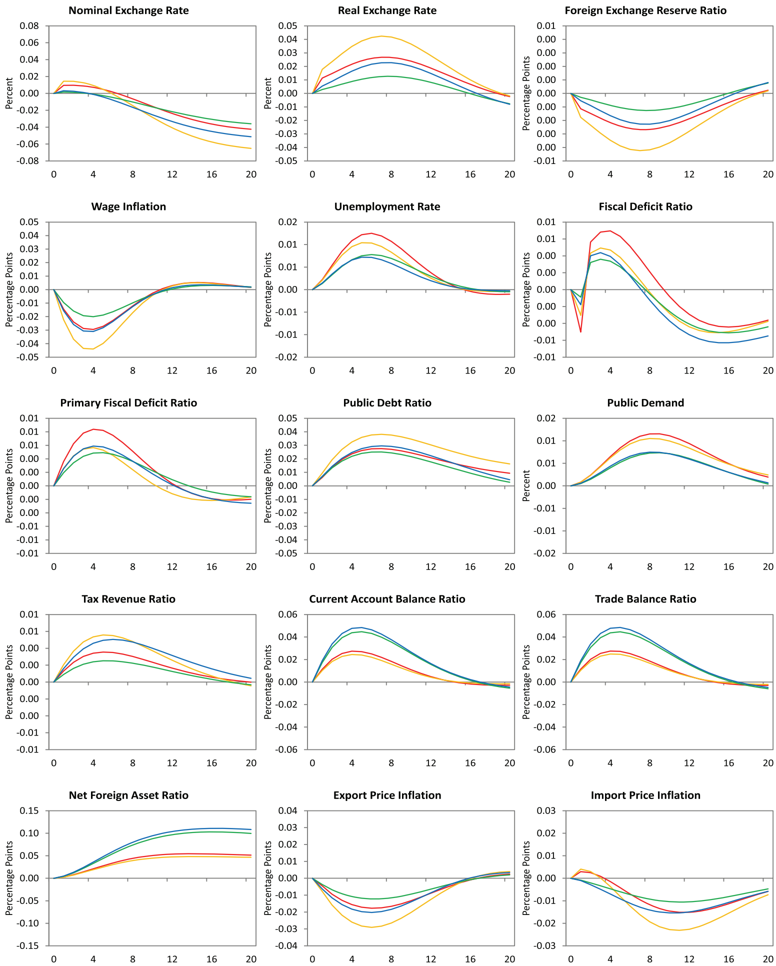
**Figure A.6. (Continued)**




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a mortgage loan to value limit shock that reduces the mortgage loan to value ratio limit by 10 percentage points. All variables are annualized, where applicable.

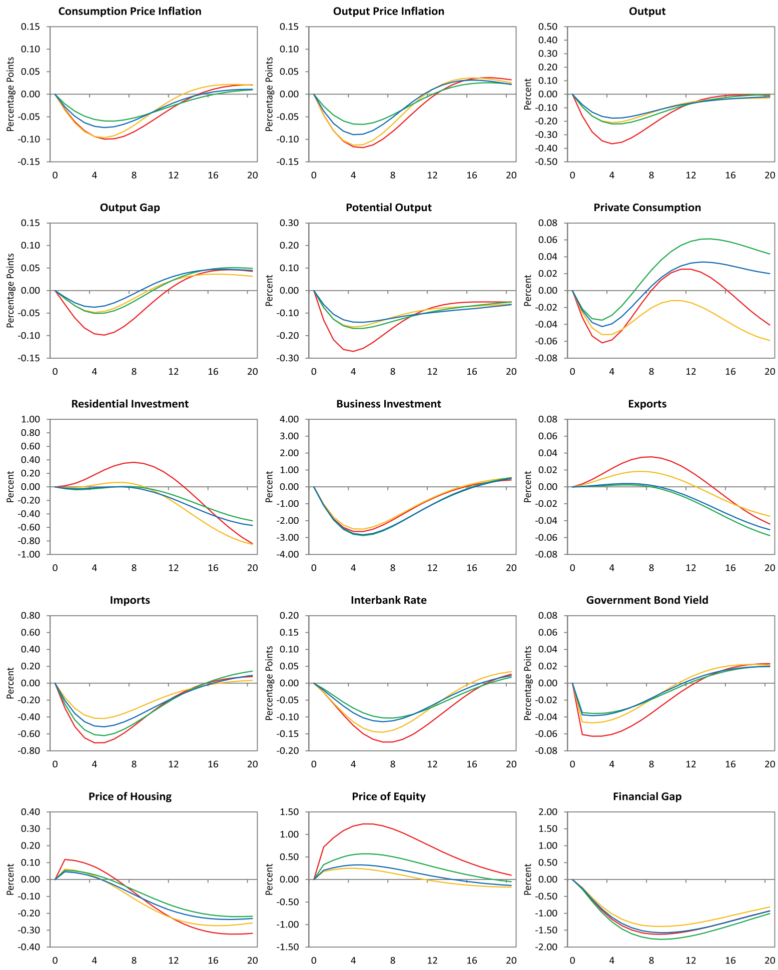
*(continued)*

## Figure A.6. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a mortgage loan to value limit shock that reduces the mortgage loan to value ratio limit by 10 percentage points. All variables are annualized, where applicable.

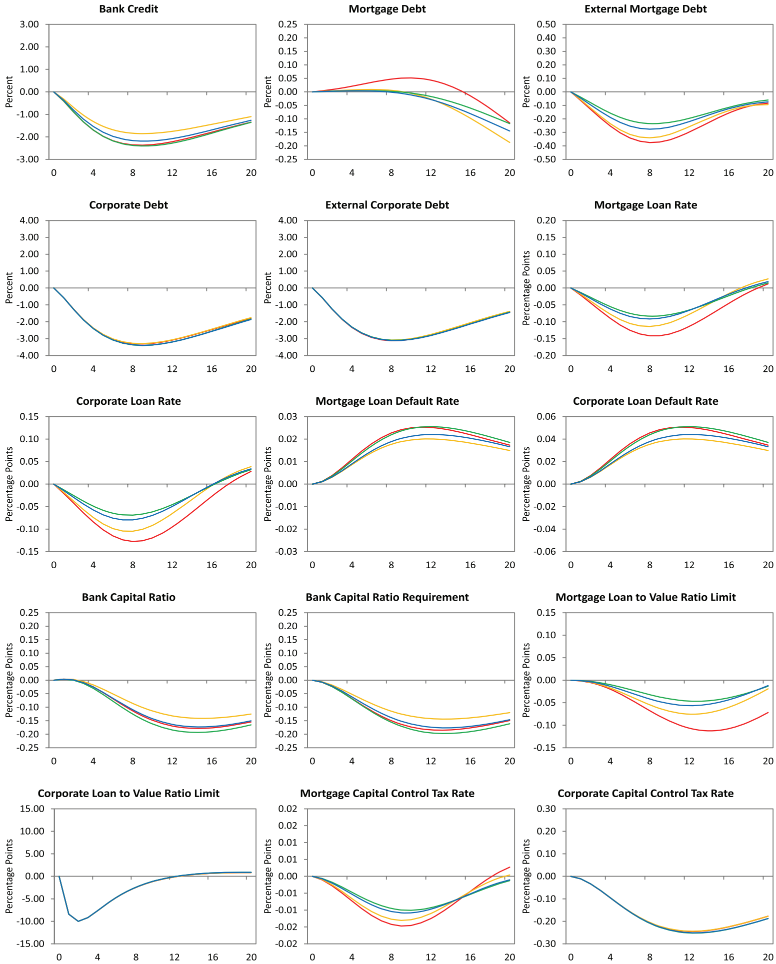
**Figure A.7. Macroprudential Tightening: Corporate Loan to Value Limit Reduction**




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a corporate loan to value limit shock that reduces the corporate loan to value ratio limit by 10 percentage points. All variables are annualized, where applicable.

*(continued)*

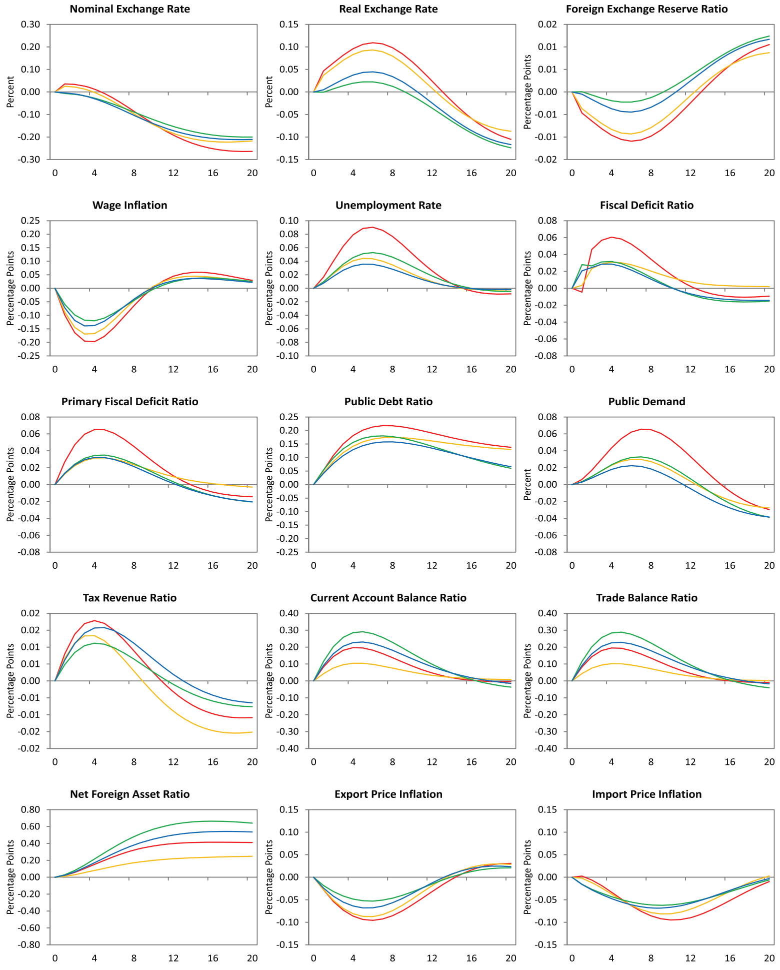
## Figure A.7. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a corporate loan to value limit shock that reduces the corporate loan to value ratio limit by 10 percentage points. All variables are annualized, where applicable.

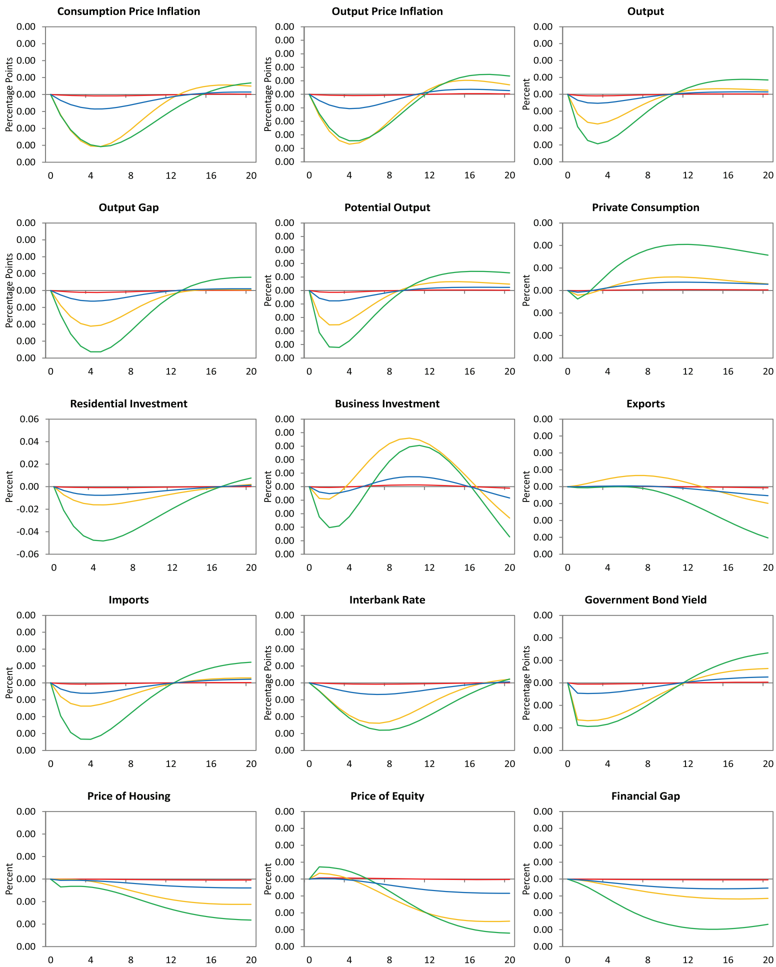
*(continued)*

**Figure A.7. (Continued)**




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a corporate loan to value limit shock that reduces the corporate loan to value ratio limit by 10 percentage points. All variables are annualized, where applicable.

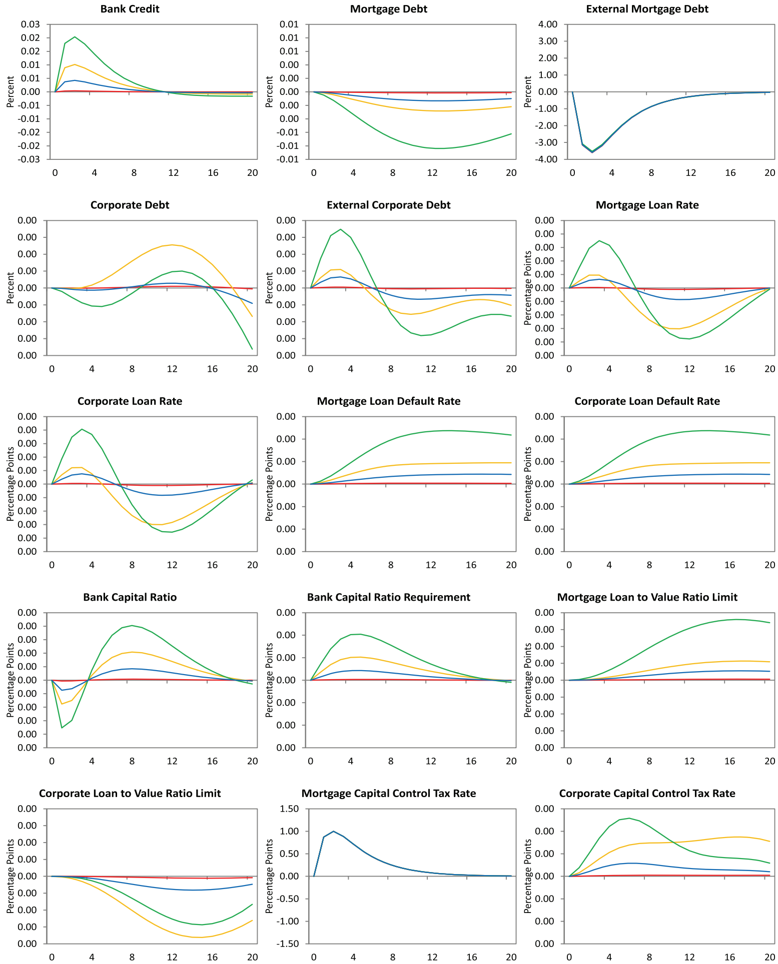
# Figure A.8. Capital Flow Management: Mortgage Capital Control Tightening




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a mortgage capital control shock that raises the mortgage capital control tax rate by 1 percentage point. All variables are annualized, where applicable.

*(continued)*

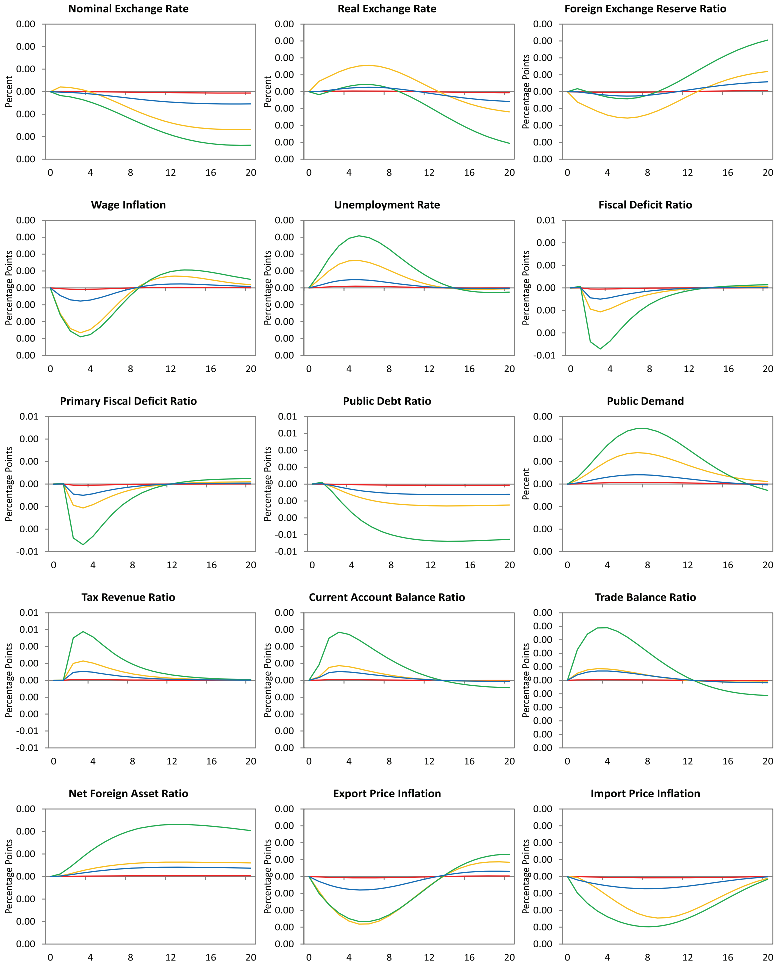
**Figure A.8. (Continued)**




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a mortgage capital control shock that raises the mortgage capital control tax rate by 1 percentage point. All variables are annualized, where applicable.

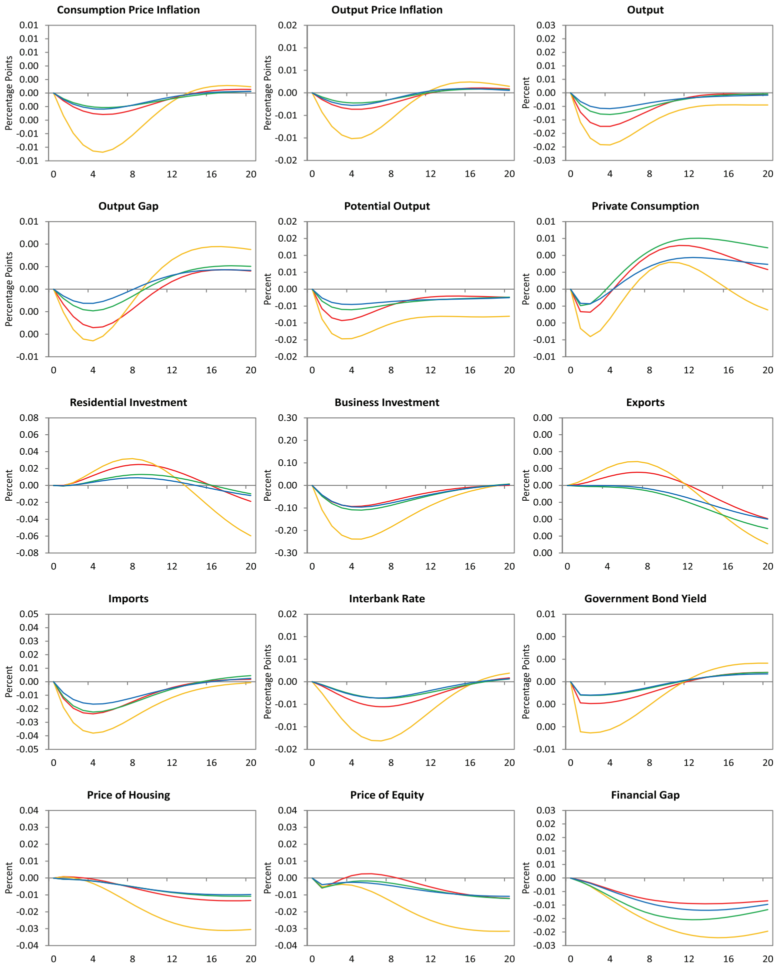
*(continued)*

**Figure A.8. (Continued)**




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a mortgage capital control shock that raises the mortgage capital control tax rate by 1 percentage point. All variables are annualized, where applicable.

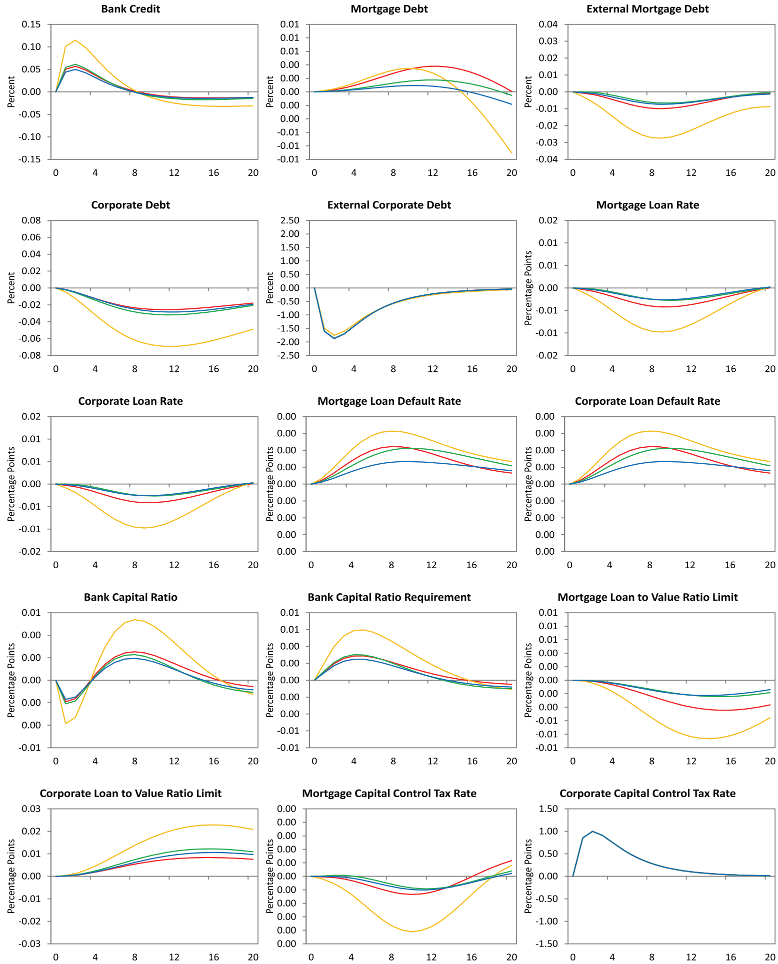
**Figure A.9. Capital Flow Management: Corporate Capital Control Tightening**




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a corporate capital control shock that raises the corporate capital control tax rate by 1 percentage point. All variables are annualized, where applicable.

*(continued)*

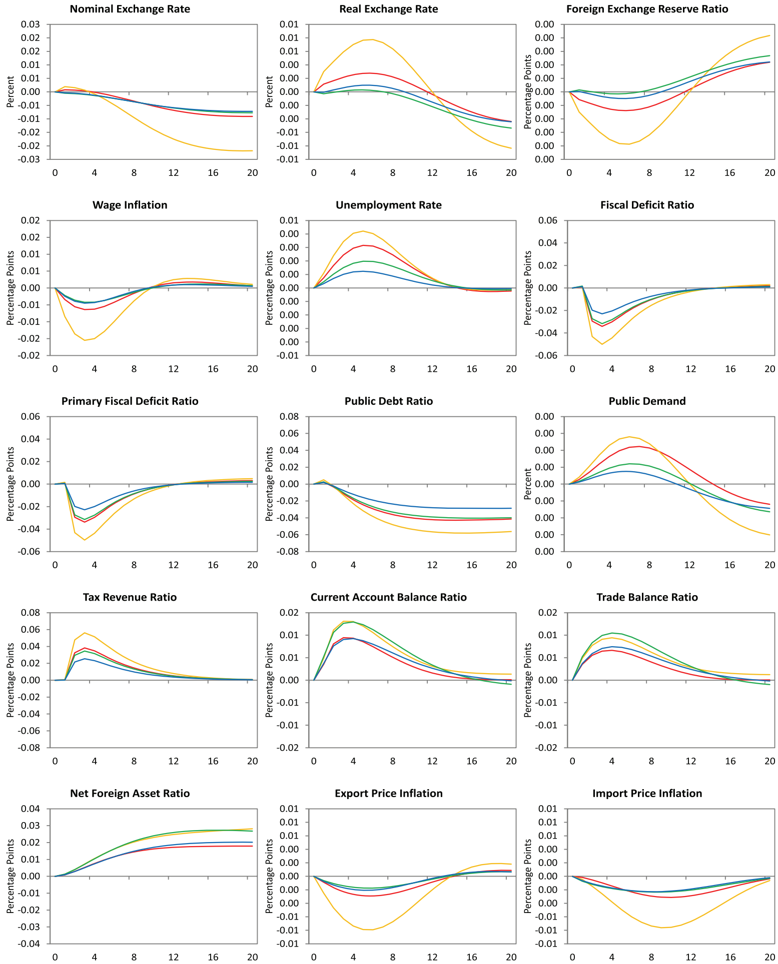
# Figure A.9. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a corporate capital control shock that raises the corporate capital control tax rate by 1 percentage point. All variables are annualized, where applicable.

*(continued)*

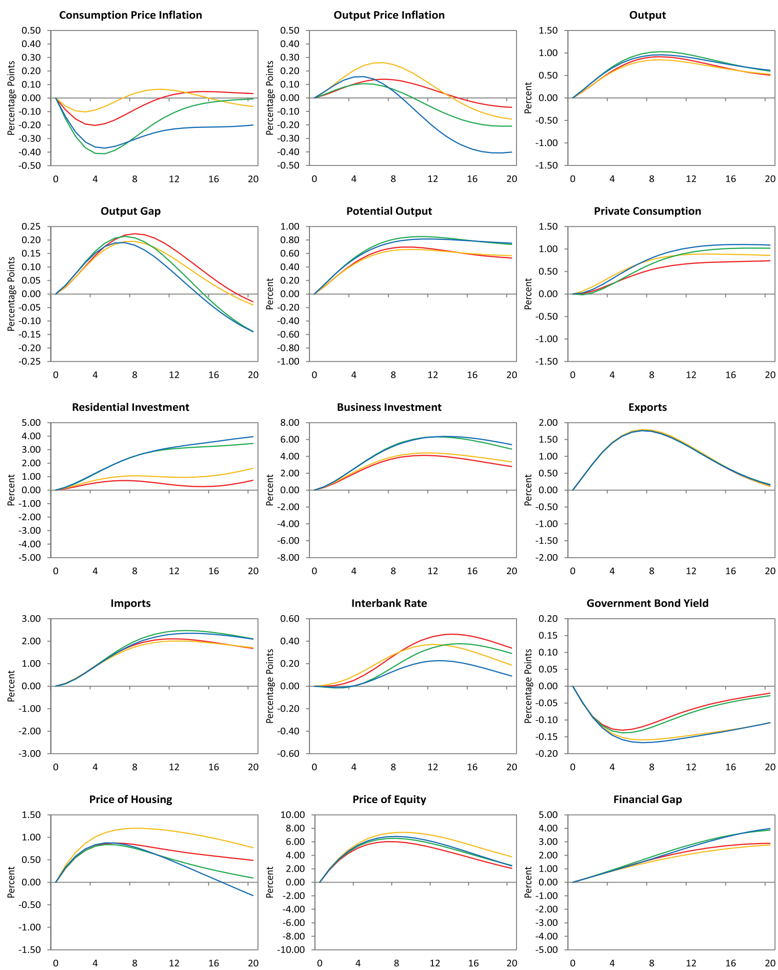
## Figure A.9. (Continued)




**Note:** Depicts impulse responses for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ to a corporate capital control shock that raises the corporate capital control tax rate by 1 percentage point. All variables are annualized, where applicable.

# Appendix B. Scenario Simulation Results

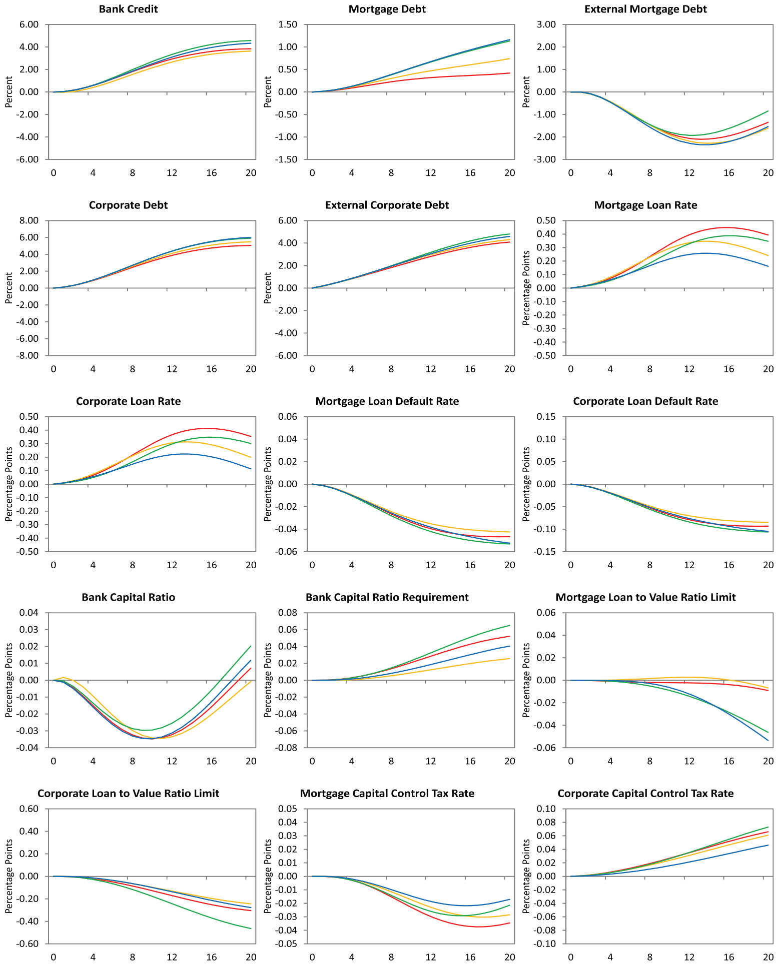
## Figure B.1. Global Financial Cycle Upturn Scenario




**Note:** Depicts simulation results for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ under our global financial cycle upturn scenario. All variables are annualized, where applicable.

(*continued*)

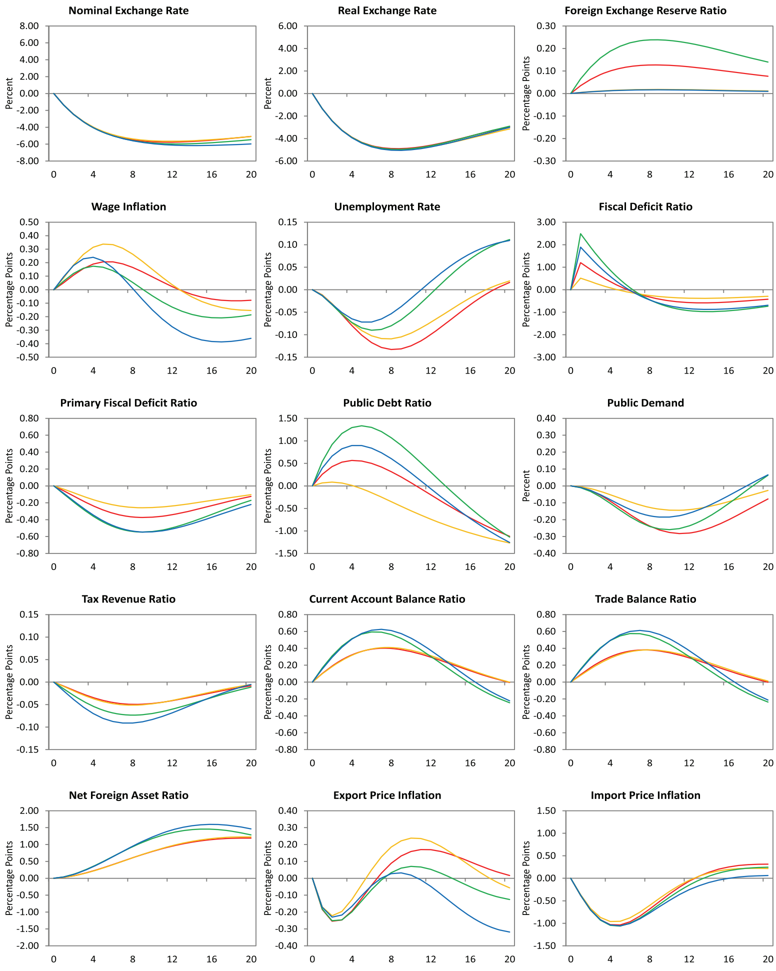
**Figure B.1. (Continued)**




**Note:** Depicts simulation results for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ under our global financial cycle upturn scenario. All variables are annualized, where applicable.

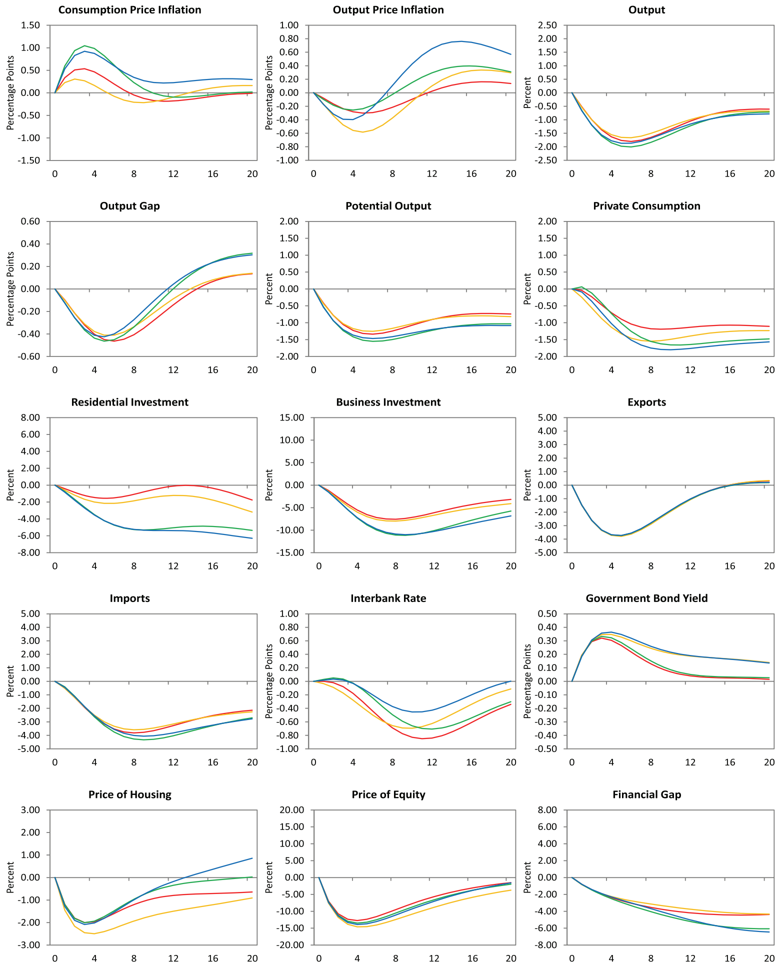
*(continued)*

# Figure B.1. (Continued)




**Note:** Depicts simulation results for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ under our global financial cycle upturn scenario. All variables are annualized, where applicable.

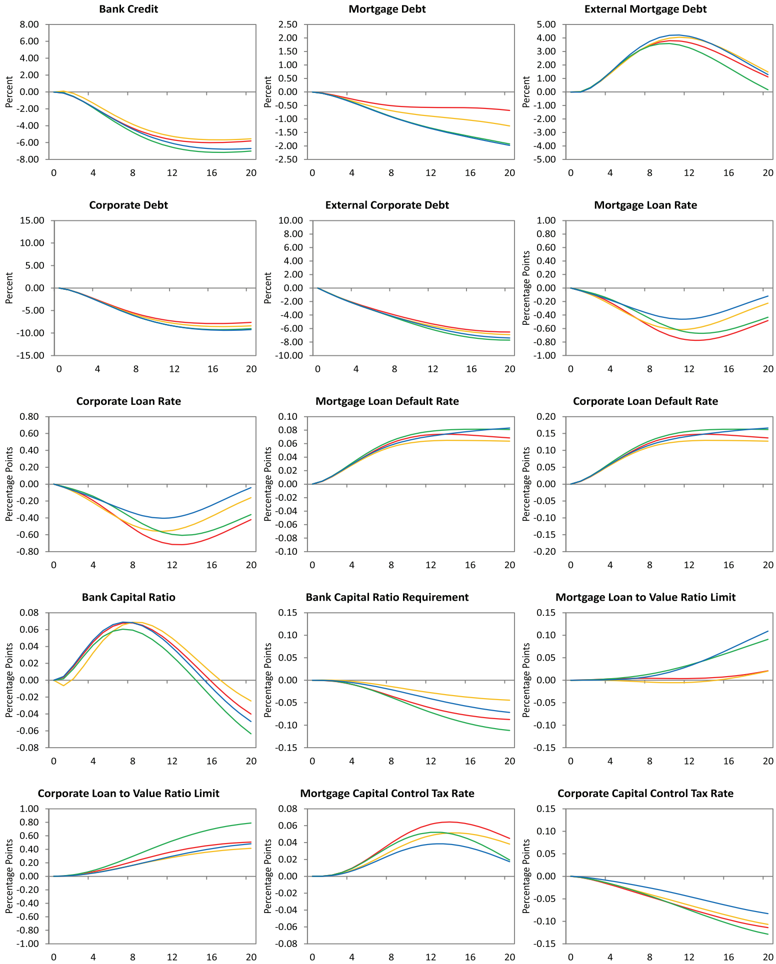
## Figure B.2. Global Financial Cycle Downturn Scenario




**Note:** Depicts simulation results for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ under our global financial cycle downturn scenario. All variables are annualized, where applicable.

*(continued)*

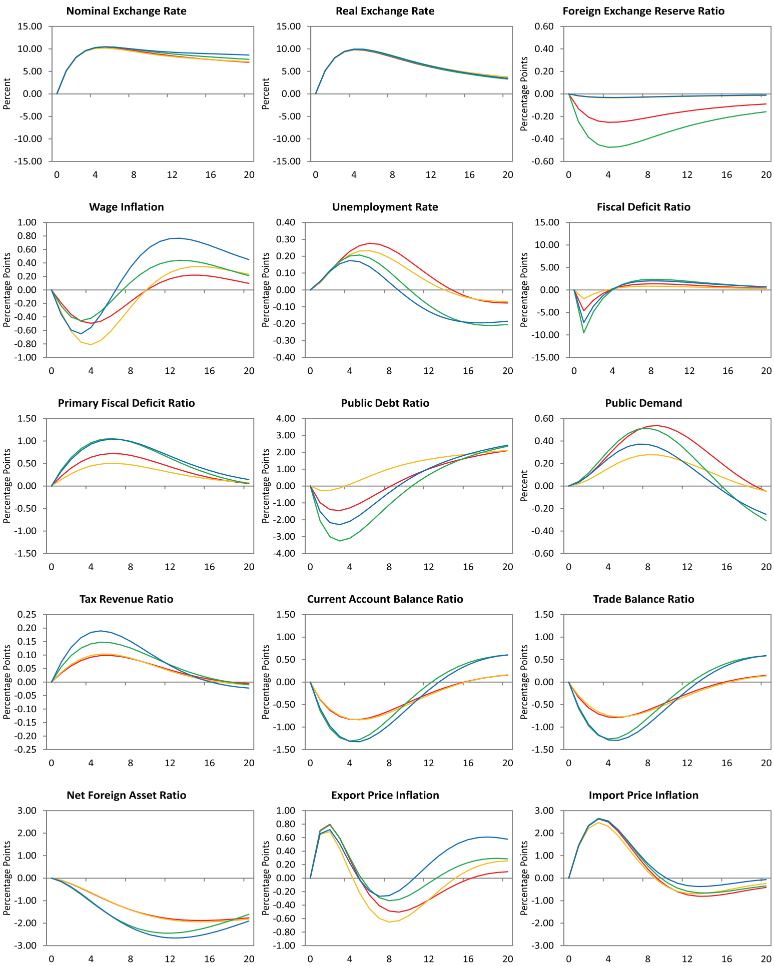
## Figure B.2. (Continued)




**Note:** Depicts simulation results for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ under our global financial cycle downturn scenario. All variables are annualized, where applicable.

(*continued*)

**Figure B.2. (Continued)**




**Note:** Depicts simulation results for Korea ■, South Africa ■, Switzerland ■, and Thailand ■ under our global financial cycle downturn scenario. All variables are annualized, where applicable.

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# Disinflations and Income Distribution*

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Bringing down inflation is once again a priority in many countries. While there is broad consensus regarding the fact that policies aimed at bringing down inflation have adverse consequences on aggregate output and unemployment, at least in the short run, we know little about the distributional impact of disinflations. We find that during disinflations, the Gini indices rise, and the income share of the richest decile and especially the top 1 percent of the income distribution significantly increase. We discuss the implications of these findings for monetary policy.

JEL Codes: E31, E32, E43, E52, E58, D31.

## 1. Introduction

Many countries around the world are facing inflation rates that exceed, often by a large percentage, the central bank's targets. Policymakers are again facing the challenge of bringing down inflation rates. In this paper, we contribute to our understanding of disinflations by studying how different income distribution variables have evolved during disinflations.

Large disinflations are usually triggered by central banks' tight policies and constitute the cleanest form of negative aggregate demand shocks (Blanchard, Cerutti, and Summers 2015). The literature has shown that big disinflations, as defined below, reduce aggregate output (Ball 1994, Mazumder 2014). This literature has quantified output losses relative to changes in inflation and has studied the determinants of these losses.

While there is consensus around the fact that tight monetary policies aimed at reducing inflation rates generate *aggregate* output

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losses, we know little as to how these output sacrifices are distributed and whether they affect some portions of the population more than others. In line with this literature, our paper studies disinflations, but we do it with a focus on their distributive effects rather than their aggregate consequences.

Why would income distribution change during disinflations? Tight monetary policies and disinflation in general can have distributive effects through several channels (see, for instance, Koedijk, Loungani, and Monnin 2018; Nakajima 2015):

- The proportion of labor and capital income is heterogeneous across households, with poorer households depending more on labor income. If monetary policies affect these sources of income in different ways, they will have an impact on income distribution.
- The risk of becoming unemployed during a downturn is also unevenly distributed: for instance, Elsby, Hobjin, and Sahin (2010) document that during recessions, the unemployment rate of young or less educated individuals increases more than for other groups in the population.
- On the capital income side, the impact of monetary policies also has heterogeneous effects across the returns of different assets. Thus, monetary policies will affect the income distribution through this channel, inasmuch as households do not hold homogenous portfolios.
- The change in inflation itself can also have distributive consequences. Debtors tend to lose and creditors tend to benefit from (unexpected) lower inflation. This increases the real value of debts, potentially increasing inequality.
- Additionally, lower inflation could reduce the inflation tax, which could favor low-income households that rely more on cash than richer households (Erosa and Ventura 2002).
- Not all prices change at the same time nor in the same magnitude. Thus, the relative prices of goods and services change, and this can have distributive consequences.

Our contribution is also related to a recent branch of the literature that has studied the distributional consequences of monetary shocks *directly*. Several papers have found that the inequality increases following contractionary monetary shocks: Coibion et al. (2017) report this finding for the United States, while Mumtaz and Theophilopoulou (2017) obtain similar conclusions for the United Kingdom. Furceri, Loungani, and Zdzienicka (2018) meanwhile corroborate the findings for a panel of 32 advanced and emerging countries, while Cantore, Ferroni, and León-Ledesma (2019), who study five developed economies, find that the share of output allocated to wages temporarily increases following an episode of monetary tightening. In our paper, we do not rely on the identification of monetary shocks (as those papers do) to study their impact on distributional outcomes. Our units of analysis, as in the sacrifice ratio literature, are disinflation episodes.

We use Mazumder's (2014) global sample of disinflations running from 1960 through 2009 to analyze how income distribution changes when inflation is brought down. Disinflations in Mazumder's sample are identified following Ball's (1994) methodology: episodes where trend inflation falls between a peak and trough by at least 1.5 percentage points. Moreover, it considers only episodes with inflation peaks below 20 percent, where the trade-offs between inflation and aggregate economic activity have been found to be relevant. In robustness estimations reported in the paper, we also run the baseline models using the Blanchard, Cerutti, and Summers (2015) sample of "intentional disinflations." The details of this identification of disinflations are explained later.

Using a sample of disinflations implies that our results do not hinge on estimated measures of monetary shocks (across countries and over time). This allows us to extend the study to a broader set of countries: papers relying on identifying monetary shocks require either long/high-frequency data on economic expectations or data that rely on narrative identification strategies (e.g., Romer and Romer 2004), which are harder to come by. Moreover, looking directly at disinflations provides an important complement to the already existing literature: as stated before, it is a well-established fact that disinflations scar aggregate economic performance, but we know less about the distributive consequences, if any, of these episodes. On the downside, an indirect way of identifying demand shocks might be less precise. For those more skeptical of this identification strategy, our results showing how measures of income inequality change in a typical disinflation episode are an important piece of information.

We find that during disinflations, Gini coefficients (both before and after taxes and transfers) increase, more so the longer the disinflations. The latter is consistent with the findings in the sacrifice ratio literature showing that long disinflations are associated with greater output losses (Mazumder 2014; Senda and Smith 2008). We also find that the shares of income going to the richest decile and especially to the top 1 percent increase during disinflations, while the income shares of the first seven deciles of the distribution, especially those in the middle—that is, the fourth, fifth, and sixth deciles—fall. Overall, the size of the effects on the income shares also rises with the length of disinflations.

## 2. Data

### *2.1 Disinflations*

We use Mazumder's (2014) sample of disinflations identified on 189 countries from 1960 to 2009. He follows Ball's (1994) widely used identification strategy: he identifies peaks (with a 20 percent limit) and troughs on trend inflation series—estimated as the three-year centered moving average of the headline inflation. Disinflations are episodes when inflation falls between peak and trough by at least 1.5 percentage points. Table A.1 in Appendix A lists the 248 disinflationary episodes in Mazmuders's sample for which we also have Gini indices (described below). The average length of an episode is 4.9 years—5.7 years for the OECD countries and 4.6 for non-OECD disinflations. The average change in inflation between peak and trough is 5.7. It is somewhat larger in non-OECD countries (6.0) relative to OECD members (5.1).

### *2.2 Income Distribution*

The first set of indicators we use are standardized Gini coefficients taken from the Standardized World Income Inequality Database (SWIID 6.1; Solt 2018). We use both market Gini indices (before taxes and transfers) and disposable indices (after taxes and transfers). In Table A.1 in Appendix A, we report the changes in Gini coefficients from peak to trough along the disinflation episodes. In Table A.2 we report further descriptive statistics of the Gini indices.

We have Gini indices for 54.4 percent of the disinflations in Mazumder's sample. As we explain in the next section, our empirical strategy requires data within disinflations but also outside them. The gaps in the Gini sample are not balanced over time or across countries. More developed countries have better data coverage and in general missing data are more frequent in the earlier parts of the sample. This unbalanced nature of our panel could bias the results. We address this concern using different subsamples and specifications. Our results are remarkably consistent.

The second set of income distribution variables that we study are the income shares over the different deciles of the distribution and for the top 1 percent, taken from the World Inequality Database (WID). The series are available for both market and disposable income.[1] We focus on OECD countries where we have data for 54 percent of our disinflationary episodes (data for non-OECD countries are only available for less than 10 percent of disinflations). Table A.3 in Appendix A provides the descriptive statistics for the shares of income for each decile and the top 1 percent.

### *2.3 Methodology*

We use an estimation strategy based on local projections (Jordà 2005), with clustered standard errors. Other papers in the related literature, such as Coibion et al. (2017) and Furceri, Loungani, and Zdzienicka (2018), also use variants of this methodology.

Our main regressions are as follows:

$$\begin{aligned}\Delta^k Y_{i,t} &= Y_{i,t+k} - Y_{i,t}\\ &= \alpha_i^k + \gamma_1^k trend_t + \sum_{j=1}^{2} \gamma_{1+j}^k \Delta Y_{i,t-j} + \beta^k D_{i,t}^k + \gamma_4^k Y_{i,t} + \varepsilon_{i,t}^k,\end{aligned} \tag{1}$$

which we estimate for horizons $k = 1, \ldots 6$.

[1]The shares are estimated as the national income that goes to the adults (20+ years), equally split among the adults in the household.

$Y_{i,t}$ is the income distribution measure (Gini or income share as described in the previous section) of country $i$ in year $t$; $\alpha_i^k$ is a country fixed effect; $trend_t$ is a linear trend; and $\Delta Y_{i,t-j}$ are lags (two in the baseline case) for changes in the income distribution measure.

Unlike a specification where the dummy is equal to 1 only at the start of the episode, our strategy recognizes that a disinflationary episode is not necessarily a one-year-long shock. For an episode in country $i$ with a peak in period 0 and a trough in period $T, D_{i,t}^k = 1$ for $t = 0$ up to $t = T - k$. In other words, $D_{i,t}^k$ is a dummy variable equal to 1 *during* a disinflationary episode, and zero otherwise. This specification aims at studying the changes in each income distribution variable *during* disinflations, relative to periods outside disinflations. The dummy variable changes with the horizon ($k$) so that as the horizon $k$ increases, $D_{i,t}^k$ is such that we still compare the outcomes *during* the disinflation relative to periods after the disinflation.

Hence, the coefficients $\beta^k$—our parameters of interest—represent the difference between two $Y$'s that are $k$ periods apart within a disinflationary episode, relative to two $Y$'s, also $k$ periods apart, during non-disinflationary times. $\beta^1$, for instance, represents the mean one-year change in $Y$ within the disinflationary episodes relative to one-year changes in $Y$ during non-disinflationary times.

Several clarifications are useful at this point. First, any failed attempts by central banks to bring inflation down are not identified as disinflationary episodes. If these attempts did influence inequality, then our $\beta^k$ would be underestimated, as these periods would be in the "control" group. (Under this terminology, "during disinflations" is the treatment group.) Second, while $k$ does not exactly represent the length of disinflationary episodes, the estimated effect for each $k$ requires that an episode be at least $k$ years long. In this sense, the evolution of the $\beta^k$ along $k$ is a proxy for the impact of the duration of a disinflationary episode on income distribution. Third, if disinflationary episodes affect the income distribution beyond the time of the trough (T), our coefficients will also underestimate the actual changes in income distribution along disinflations because the long-lasting outcomes would be in the control group.

## 3. Main Results

### *3.1 Gini*

In Figure 1, we plot $\beta^k$ along with 90 percent confidence intervals. As explained before, $\beta^k$ represent the change in Gini coefficients that are $k$ years apart within a disinflationary episode, relative to the same kinds of changes during non-disinflationary periods. The plot on the left reports the results for the whole sample; the other two plots report the effects for OECD countries and non-OECD countries. The latter two are estimated using Equation (1) with an extra interaction to estimate the differential effects over the two sets of countries. Results (not reported) are very similar if we run separate regressions—one for OECD and the other for non-OECD countries. In Table 1, we report the respective coefficients and their standard errors.

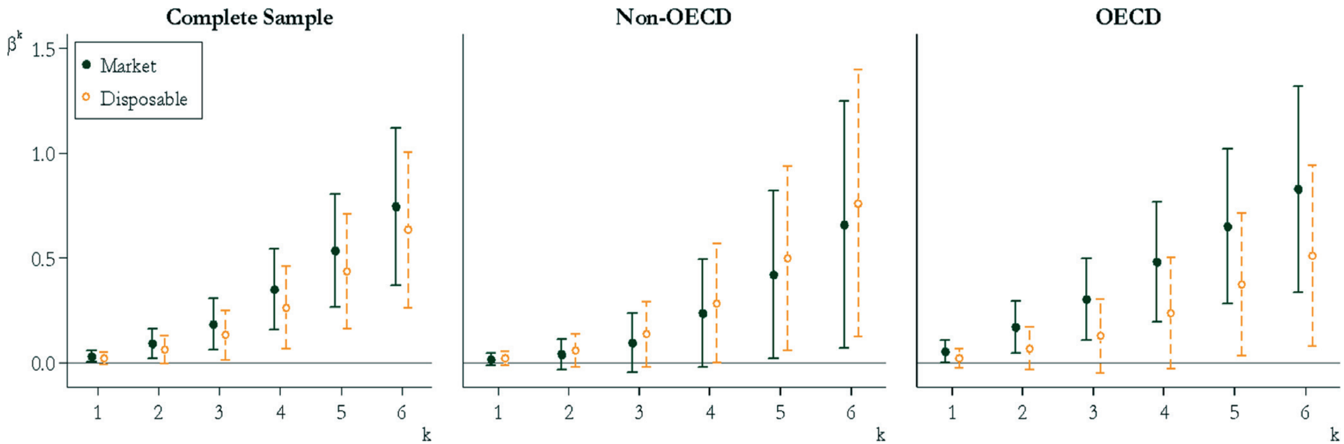
There are two general results, notwithstanding whether the coefficients are estimated with market or with disposable Ginis, for all countries or allowing for differential effects for OECD/non-OECD countries. First, all coefficients are positive, indicating that the Gini coefficients within disinflations increase relative to non-disinflationary times. The sacrifice ratio literature established that income decreases during disinflations; our result suggests that this aggregate income loss has also distributional consequences.

Second, the size and the statistical significance of all coefficients increase as $k$ rises. The fact that the $\beta^k$ are increasing over $k$ suggests that the adverse effects on income distribution are a positive function of the length of a disinflationary episode. The latter result is coherent with the sacrifice ratio literature—studying the output losses per point of inflation during disinflationary episodes—as it has established that long disinflationary episodes tend to be costlier (e.g., Hofstetter 2008; Mazumder 2014; and Senda and Smith 2008).

What do the coefficients reported in Table 1 mean quantitatively? Take, for instance, $\beta^5$ in the first column: the five-year change in the Gini indices during a disinflationary episode increases by 0.533 relative to the five-year change during non-disinflationary periods.

There are other important findings in the different estimates reported in Figure 1 and Table 1. On the one hand, for the estimates with the complete sample, the market Gini coefficients are

**Figure 1. $\beta^k$ for $Y$ = Gini**




**Note:** The results are based on estimations of Equation (1): the plots report $\beta^k$ (vertical axes) for different $k$'s (horizontal axes), along with 90 percent confidence intervals. The $\beta^k$ represent the change in Gini coefficients $k$ periods apart within a disinflationary episode relative to non-disinflationary periods.

**Table 1. $\beta^k$ for $Y$ = Gini**

| | Complete Sample | | Non-OECD | | OECD | |
|---|---|---|---|---|---|---|
| ***k*** | **Market** | **Disposable** | **Market** | **Disposable** | **Market** | **Disposable** |
| 1 | 0.030* | 0.020 | 0.016 | 0.019 | 0.054* | 0.021 |
| | (0.017) | (0.017) | (0.017) | (0.019) | (0.032) | (0.028) |
| 2 | 0.090** | 0.061 | 0.039 | 0.057 | 0.170** | 0.067 |
| | (0.043) | (0.039) | (0.044) | (0.048) | (0.076) | (0.061) |
| 3 | 0.182** | 0.130* | 0.094 | 0.135 | 0.303** | 0.126 |
| | (0.074) | (0.072) | (0.086) | (0.094) | (0.119) | (0.107) |
| 4 | 0.349*** | 0.261** | 0.234 | 0.282 | 0.481*** | 0.237 |
| | (0.118) | (0.119) | (0.157) | (0.173) | (0.173) | (0.162) |
| 5 | 0.533*** | 0.435*** | 0.419* | 0.497* | 0.648*** | 0.372* |
| | (0.164) | (0.166) | (0.244) | (0.267) | (0.224) | (0.206) |
| 6 | 0.744*** | 0.632*** | 0.657* | 0.759* | 0.828*** | 0.509* |
| | (0.228) | (0.226) | (0.358) | (0.387) | (0.299) | (0.262) |

**Note:** Results based on estimations of Equation (1). The $\beta^k$ represent the change in Gini coefficients $k$ periods apart within a disinflationary episode, relative to the same change during non-disinflationary periods. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are in parentheses.

statistically significant for all $k$'s. For the disposable Gini, the significance starts after $k = 3$, that is, the taxes and transfers mitigate the distributive consequences of short disinflations but are not enough to offset the consequences for the longer ones. On the other hand, continuing with the comparison between market and disposable Gini, we find that the two sets of coefficients are very similar among them in non-OECD countries (i.e., the role of the state through taxes and transfers makes almost no difference) while in OECD countries, the disposable Gini estimates are only marginally significant for the longer episodes (taxes and transfers mitigate the distributive impact of disinflations except for the longest episodes).

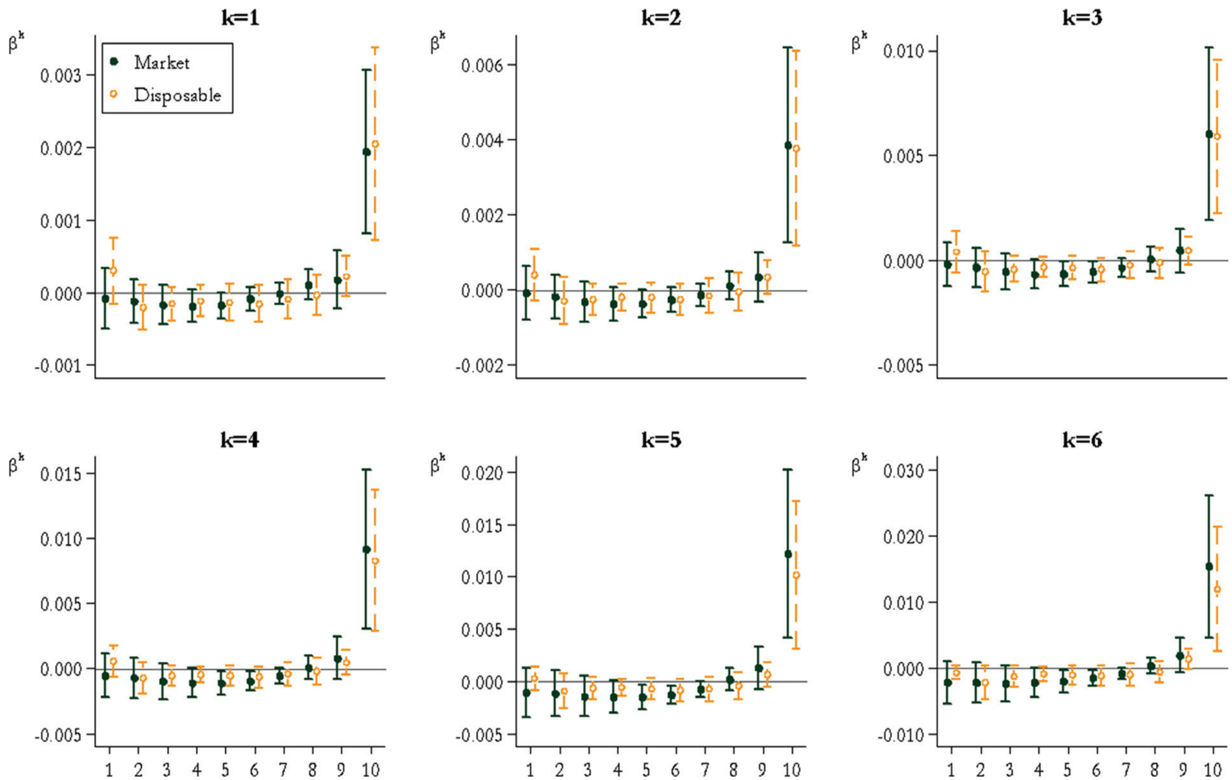
### *3.2 Income Shares: Deciles*

We use the same empirical strategy described in Equation (1), only now with $Y$ corresponding to the income share of each decile of the population instead of the Gini. We report the estimates for $k = 1$ through 6 in Figure 2 and Table 2.

The most salient result is the increase in the income share of the richest decile for all $k$'s and for both market and disposable income. This means that—relative to times outside disinflations—within disinflations the income shifts towards the richest decile even after accounting for the distributional role of fiscal policy. How big are these effects? The size of the coefficient increases with the proxy for the length of the episode (note that the scale of the vertical axes changes). The largest coefficient (0.01539) corresponds to the upper decile measured with market income, and for $k = 6$. Since the average income share for the 10th decile is 0.29 (see Table A.3), this increase in the income share of the upper decile reaches 5.3 percent relative to the mean.

The results in Figure 2 follow a J-curve kind of pattern, with the larger negative values for the deciles in the middle of the distribution and the large positive values for the upper decile. For the market income, negative coefficients on the shares for the fifth and sixth deciles are also statistically significant when $k \geq 3$. As for the size: take for instance the fifth decile, for the $k = 6$ case: the coefficient is $-0.002$ (the mean income share of the decile is 0.08). The fact that the negative coefficients are not significant when estimated with

**Figure 2. $\beta^k$, where $Y$ = Income Shares for Each Decile**




**Note:** The results are based on estimations of Equation (1) for OECD countries. The plots report $\beta^k$ (vertical axes) for different deciles (horizontal axes) along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of each decile $k$ periods apart within a disinflationary episode relative to the same change during non-disinflationary periods. The scale varies across the plots.

**Table 2. $\beta^k$ where $Y$ = Income Shares for Each Decile**

| | **Shares of Income: Coefficients** | | | | | |
|---|---|---|---|---|---|---|
| | $\boldsymbol{k=1}$ | | $\boldsymbol{k=2}$ | | $\boldsymbol{k=3}$ | |
| **Deciles** | $\beta^k$ **Market** | $\beta^k$ **Disp.** | $\beta^k$ **Market** | $\beta^k$ **Disp.** | $\beta^k$ **Market** | $\beta^k$ **Disp.** |
| 1 | −0.0001 | 0.0003 | −0.0001 | 0.0004 | −0.0002 | 0.0004 |
| | (0.0003) | (0.0003) | (0.0004) | (0.0004) | (0.0006) | (0.0006) |
| 2 | −0.0001 | −0.0002 | −0.0002 | −0.0003 | −0.0003 | −0.0005 |
| | (0.0002) | (0.0002) | (0.0004) | (0.0004) | (0.0006) | (0.0006) |
| 3 | −0.0002 | −0.0002 | −0.0003 | −0.0003 | −0.0006 | −0.0004 |
| | (0.0002) | (0.0001) | (0.0003) | (0.0003) | (0.0005) | (0.0004) |
| 4 | −0.0002 | −0.0001 | −0.0004 | −0.0002 | −0.0007 | −0.0003 |
| | (0.0001) | (0.0001) | (0.0003) | (0.0002) | (0.0004) | (0.0003) |
| 5 | −0.0002 | −0.0001 | −0.0004 | −0.0002 | −0.0007* | −0.0004 |
| | (0.0001) | (0.0002) | (0.0002) | (0.0002) | (0.0004) | (0.0003) |
| 6 | −0.0001 | −0.0002 | −0.0003 | −0.0003 | −0.0006* | −0.0004 |
| | (0.0001) | (0.0002) | (0.0002) | (0.0003) | (0.0003) | (0.0003) |
| 7 | 0.000 | −0.0001 | −0.0001 | −0.0002 | −0.0003 | −0.0002 |
| | (0.0001) | (0.0002) | (0.0002) | (0.0003) | (0.0003) | (0.0004) |
| 8 | 0.0001 | 0.000 | 0.0001 | 0.000 | 0.000 | −0.0001 |
| | (0.0001) | (0.0002) | (0.0002) | (0.0003) | (0.0004) | (0.0004) |
| 9 | 0.0002 | 0.0002 | 0.0003 | 0.0003 | 0.0005 | 0.0004 |
| | (0.0002) | (0.0002) | (0.0004) | (0.0003) | (0.0006) | (0.0004) |
| 10 | 0.0019*** | 0.00200** | 0.00380** | 0.00380** | 0.00600** | 0.00590** |
| | (0.0007) | (0.0008) | (0.0016) | (0.0016) | (0.0025) | (0.0022) |

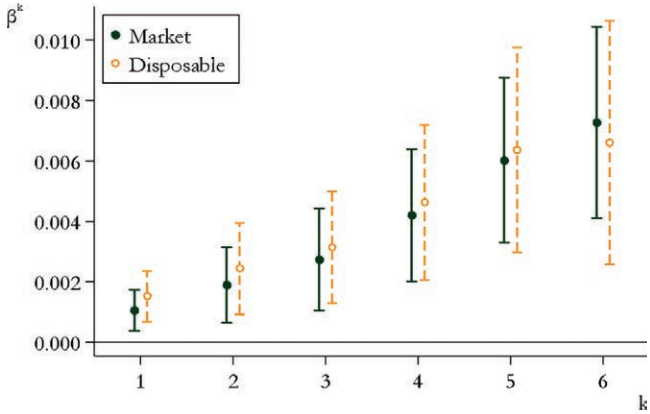
(*continued*)

**Table 2. (Continued)**

| | Shares of Income: Coefficients | | | | | |
|---|---|---|---|---|---|---|
| | $k = 4$ | | $k = 5$ | | $k = 6$ | |
| **Deciles** | $\beta^k$ **Market** | $\beta^k$ **Disp.** | $\beta^k$ **Market** | $\beta^k$ **Disp.** | $\beta^k$ **Market** | $\beta^k$ **Disp.** |
| 1 | –0.0005 | 0.0006 | –0.0011 | 0.0003 | –0.0022 | –0.0008 |
| | (0.001) | (0.0007) | (0.0014) | (0.0007) | (0.002) | (0.0006) |
| 2 | –0.0007 | –0.0007 | –0.0011 | –0.0009 | –0.0023 | –0.0022 |
| | (0.0009) | (0.0007) | (0.0014) | (0.001) | (0.0019) | (0.0015) |
| 3 | –0.001 | –0.0006 | –0.0014 | –0.0006 | –0.0024 | –0.0013 |
| | (0.0008) | (0.0005) | (0.0012) | (0.0007) | (0.0016) | (0.001) |
| 4 | –0.0011 | –0.0005 | –0.0015 | –0.0006 | –0.0023 | –0.001 |
| | (0.0007) | (0.0004) | (0.0009) | (0.0005) | (0.0013) | (0.0007) |
| 5 | –0.0011* | –0.0006 | –0.0015** | –0.0007 | –0.0020* | –0.0011 |
| | (0.0005) | (0.0005) | (0.0007) | (0.0006) | (0.001) | (0.0009) |
| 6 | –0.001** | –0.0007 | –0.0013** | –0.0009 | –0.0015** | –0.0012 |
| | (0.0004) | (0.0005) | (0.0005) | (0.0006) | (0.0007) | (0.0009) |
| 7 | –0.0006 | –0.0004 | –0.0007 | –0.0007 | –0.0009* | –0.0011 |
| | (0.0004) | (0.0006) | (0.0004) | (0.0007) | (0.0005) | (0.001) |
| 8 | 0.0001 | –0.0002 | 0.0002 | –0.0005 | 0.0003 | –0.0007 |
| | (0.0005) | (0.0006) | (0.0006) | (0.0008) | (0.0007) | (0.001) |
| 9 | 0.0008 | 0.0004 | 0.0013 | 0.0006 | 0.0018 | 0.0013 |
| | (0.001) | (0.0006) | (0.0012) | (0.0007) | (0.0016) | (0.0009) |
| 10 | 0.00920** | 0.00829** | 0.01219** | 0.01020** | 0.01539** | 0.01190** |
| | (0.0037) | (0.0033) | (0.0049) | (0.0043) | (0.0066) | (0.0057) |

**Note:** The results are based on estimations of Equation (1) for OECD countries. The $\beta^k$ represent changes in the income share for each decile, $k$ periods apart during a disinflationary episode, relative to the same change during non-disinflationary periods. Standard errors are in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

**Figure 3. $\beta^k$, where $Y$ = Income Share of the Top 1 Percent**




**Note:** Based on estimations of Equation (1) for OECD countries. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary periods.

disposable income suggests that the effects are attenuated through taxes and transfers.

Summing up: inequality increases over the course of a disinflationary episode, and this can be explained by a gain in the income share of the richest decile at the expense of the deciles in the middle of the distribution. The size of the coefficients (in absolute terms) rises with $k$, that is, the distributive consequences are a positive function of how long a disinflationary episode lasts.

### *3.3 Income Shares: The Top 1 Percent*

The top centile of the income distribution has received a lot of attention by scholars and media over the last few years (e.g., Alvaredo et al. 2013). We estimate Equation (1) to analyze how the share of income of the top 1 percent changes over the course of disinflationary episodes. In Figure 3 and Table 3 we report the $\beta^k$ for the top centile of the income distribution (for OECD countries only).

**Table 3. $\beta^k$ where $Y$ = Share of the Top 1 Percent**

| $k$ | Pre-tax | After Tax |
|---|---|---|
| 1 | 0.001** | 0.002*** |
| | (0.0004) | (0.0005) |
| 2 | 0.002** | 0.002** |
| | (0.0008) | (0.0009) |
| 3 | 0.003** | 0.003** |
| | (0.001) | (0.0011) |
| 4 | 0.004*** | 0.004*** |
| | (0.0013) | (0.0016) |
| 5 | 0.006*** | 0.006*** |
| | (0.0017) | (0.0021) |
| 6 | 0.007*** | 0.007** |
| | (0.0019) | (0.0025) |

**Note:** The results are based on estimations of Equation (1) for OECD countries. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode, relative to the same change during non-disinflationary periods. Standard errors are in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

The income shares of the top 1 percent increase for all $k$'s during disinflationary episodes relative to non-disinflationary times. The coefficients are also statistically relevant for all $k$, before and after taxes. The figures are economically important: one way to emphasize the size of the effect is to note that 45 percent (0.007/0.01539) of the increase before taxes and transfers of the richest *decile* is explained by the gains of the top 1 percent. After taxes and transfers, the figure is even larger, 59 percent.

## 4. Further Results

### *4.1 Exploring the Determinants of the Increase in Inequality during Disinflations*

One important question that cannot be answered within the methodological framework in Equation (1) is whether the size of the disinflation plays a role in shaping the episode's distributional consequences.

To address the question, we explore how the changes in Gini coefficients *within* disinflations are correlated with the characteristics of the episodes—namely, the length and the change in inflation from peak to trough. These types of regressions are standard in the sacrifice ratio literature, except there the dependent variable is the output loss per point of inflation. In that literature, one robust result is that slow disinflations are costlier. The literature explains this finding, arguing that sharp regime shifts enhance the credibility and allow faster adjustments of inflation expectations and thus less painful price slowdowns (e.g., Ball 1994; De Roux and Hofstetter 2014).

We run regressions where each observation corresponds to one disinflation episode ($e$):

$$Gini_e^{trough} - Gini_e^{peak} = \alpha_0 + \alpha_1 length_e + \alpha_2(\pi_e^{peak} - \pi_e^{trough}) + \nu_e. \quad (2)$$

The descriptive statistics for the data used in these regressions are reported in Table A.4 in Appendix A and the results are reported in Table 4.

The change of Gini coefficients during disinflations does depend on its length: the longer the episodes, the larger the increase in the market Gini. Each extra year increases the difference between the Gini at the peak and the trough by 0.288 points. The same way the sacrifice ratio literature establishes that longer disinflations are more harmful to output, we establish that the consequences on Gini go in the same direction. The disinflations' size (change in inflation between peak and trough) does not seem relevant.

### *4.2 Unemployment: Exploring Channels*

Amberg et al. (2021), using administrative data from Sweden, show that the labor income reaction to monetary policy shapes its distributional effects, especially at the lower deciles of the distribution; capital incomes matter more to understand the reaction in the upper tail of the distribution. While in our setting, following many countries over a long period of time, it's not possible to find data to analyze unemployment by income deciles, looking at the behavior of aggregate unemployment is in any case informative as to the channels that might explain our results.

**Table 4. Determinants of the Change in Market Gini**

| | | **Length** | $\Delta\pi$ |
|---|---|---|---|
| Complete Sample | | 0.2880***<br>(0.0548) | –0.0246<br>(0.0289) |
| N<br>$R^2$<br>$R^2$ Adjusted | 212<br>0.122<br>0.113 | | |
| Non-OECD | | 0.0828<br>(0.0562) | 0.0338<br>(0.0274) |
| N<br>$R^2$<br>$R^2$ Adjusted | 142<br>0.0427<br>0.0289 | | |
| OECD | | 0.4219***<br>(0.1244) | –0.0517<br>(0.0704) |
| N<br>$R^2$<br>$R^2$ Adjusted | 70<br>0.1571<br>0.1319 | | |
| **Note:** Standard errors are in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. | | | |

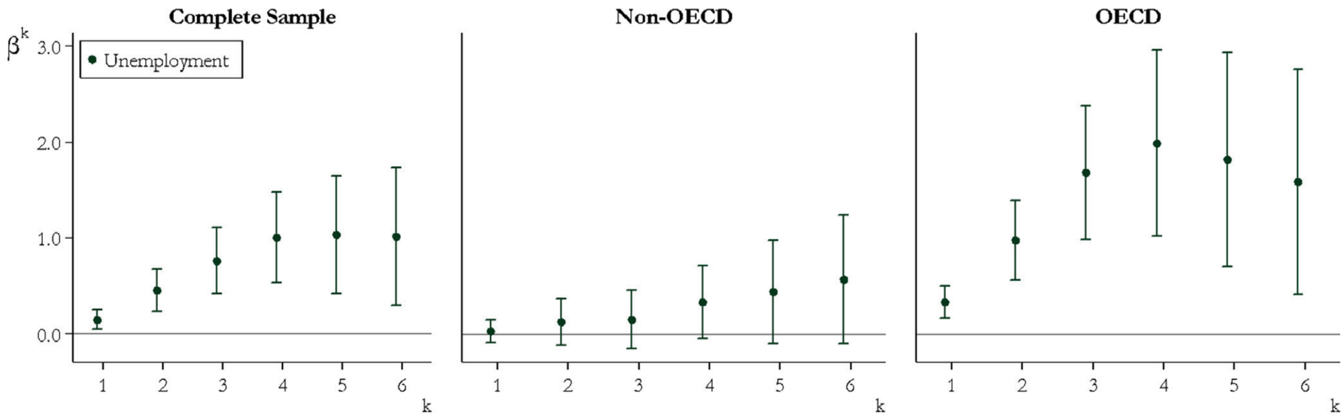
In Figure 4, we report the results when we estimate Equation (1) for the unemployment rate. Note that, as expected, during disinflations the unemployment rate goes up. Given that our results hint at losses in the income shares for all deciles except the upper ones (with strong statistical significance for the shares in the middle of the distribution), this increase during disinflations could reflect a rise in the unemployment rate especially for individuals in these deciles. Exploring further this conjecture remains an important task for future research.

## 5. Robustness

### *5.1 Intentional Disinflations*

We have so far used Ball's (1994) method to identify disinflations. As discussed, his strategy is to detect large changes on trend inflation as a way of focusing on episodes where arguably the central bank is

**Figure 4.** $\beta^k$ **for** $Y$ **= Unemployment Rate**




**Note:** The results are based on estimations of Equation (1): the plots report $\beta^k$ (vertical axes) for different $k$'s (horizontal axes), along with 90 percent confidence intervals. The $\beta^k$ represent the change in unemployment $k$ periods apart within a disinflationary episode relative to non-disinflationary periods. Data for OECD countries come from OECD-Stats. For non-OECD countries the data are taken from WDI.

playing a role in pushing down the price increases. As Ball (1994) and Hofstetter (2008) show, the strategy works very well to flag the *successful* attempts of monetary policy to control the inflation rate.

There are other ways to identify the episodes. Blanchard, Cerutti, and Summers (2015) construct a sample of "intentional disinflations." They identify recessions in a sample of 23 advanced countries starting in 1960 and, if they find evidence of a monetary policy tightening coinciding with the recession, they flag the episodes as intentional disinflations, which according to them "represent the purest case of demand shocks."

Twenty of the intentional disinflations in Blanchard, Cerutti, and Summers (2015) overlap with disinflations in our sample. For the country and years in their sample, we estimate again the regressions based on Equation (1).[2] Notice that all the disinflations in our sample (within this group of 23 countries) that are not identified as intentional disinflations will now be part of the control group. If they did cause some effects on the income distribution, the coefficients will underestimate the effect. In Figures 5–7, we report the results.

All the results follow a similar pattern relative to that in the baseline. For the market-based income distribution measures, the statistical significance is also comparable to the baseline cases. As for the disposable income distribution, most of the results are now not statistically significant. One way to interpret the outcome is that, in this sample of industrialized countries, the *intentional* disinflations affected the market-based income distribution but did not affect the (disposable) income distribution, thanks to the role of taxes and transfers. We believe though that the setting in these estimates is strongly against finding statistically relevant effects, as many of our identified disinflations are now in the control group.

### *5.2 Changes in the Specification of Equation (1)*

**No Trend.** Equation (1) has a time trend and country fixed effects. The fixed effects pick up any time-invariant country-specific characteristics that might explain the evolution of the income distribution.

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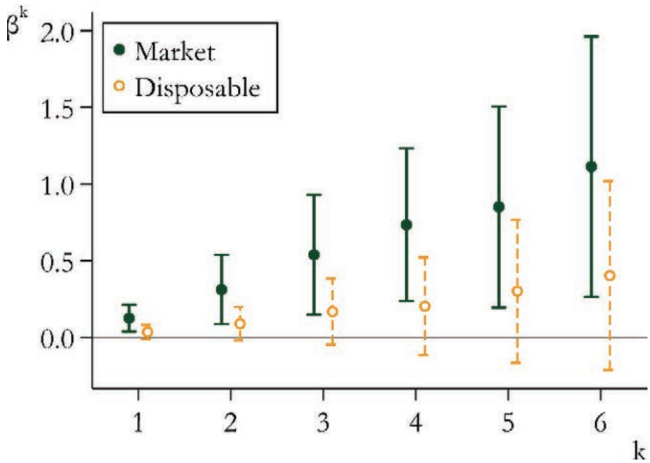
[2]To make sure results are comparable, we use the starting and ending dates of the episodes corresponding to the inflation peaks and troughs.

**Figure 5. $\beta^k$ for $Y$ = Gini Coefficients**



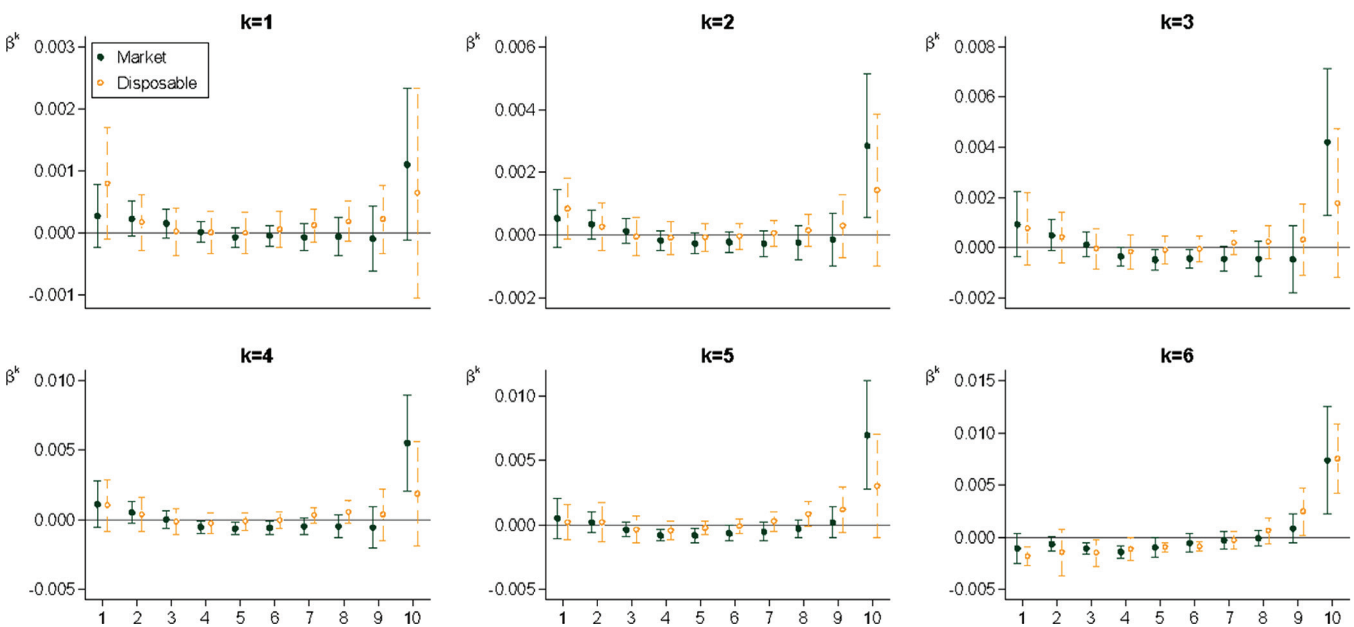

**Note:** The results are based on estimations of Equation (1) for the 23 countries used in Blanchard, Cerutti, and Summers (2015). The plots report $\beta^k$ (vertical axes) for different $k$'s (horizontal axes), along with 90 percent confidence intervals. The $\beta^k$ represent the change in Gini coefficients $k$ periods apart within an *intentional* disinflationary episode relative to non-intentional disinflationary periods.

The time trend takes care of the general trend of the changes in the income distribution across countries. We check the results if we re-estimate the models excluding the trend. Figures B.1, B.2, and B.3 in Appendix B report the results: the main conclusions hold.

**Country-Specific Trends.** The baseline specification does not control for country-specific time trends. While very demanding in terms of parameters to be estimated, it's still worth checking the outcomes in a setting with country-specific time trends. We report them in Figures B.4–B.6. The conclusions do not change.

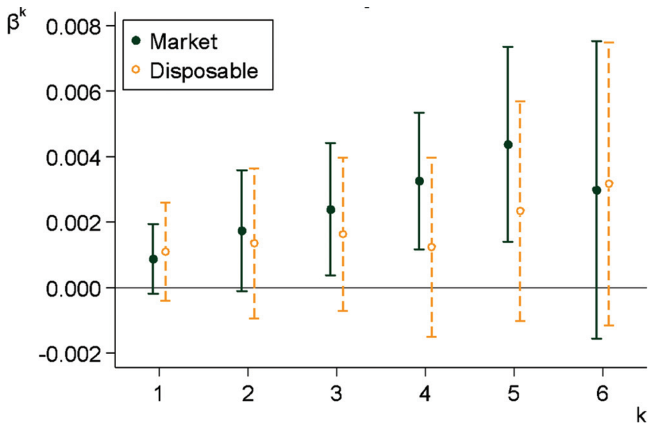
**Number of Lags.** In the baseline results we estimated Equation (1) using two lags, following the practice of most papers in the related literature. We checked the number of lags suggested by Bayesian and Akaike information criteria. The number changes across regressions, but in 85 percent of the cases both criteria suggested between one and three lags. We report the main outcomes for

**Figure 6. $\beta^k$, where $Y$ = Income Shares for Each Decile**




**Note:** The results are based on estimations of Equation (1) for 23 countries used in Blanchard, Cerutti, and Summers (2015). The plots report $\beta^k$ (vertical axes) for different deciles (horizontal axes) along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of each decile, $k$ periods apart within an *intentional* disinflationary episode relative to the same change during non-intentional disinflationary periods. The scale varies across the plots.

**Figure 7. $\beta^k$, where $Y$ = Income Share of the Top 1 Percent**




**Note:** Based on estimations of Equation (1) for 23 countries used in Blanchard, Cerutti, and Summers (2015). The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during an *intentional* disinflationary episode relative to the same change during non-intentional disinflationary periods.

market and disposable income measures if we use one and three lags in Appendix B, Figures B.7–B.12. The conclusions do not change.

## 6. Conclusions

We study the link between disinflations and income distribution. Disinflationary episodes are generally triggered by monetary policy actions that cool off aggregate economic activity. While there seems to be a consensus that tight monetary policies reduce economic activity, at least in the short run, the distributional consequences of these episodes have not received as much attention in the literature. Only recently have some papers identified the evolution of income distribution variables following monetary policy shocks (e.g., Coibion et al. 2017; Furceri, Loungani, and Zdzienicka 2018; and Mumtaz and Theophilopoulou 2017).

We analyze a global sample of disinflationary episodes, running from 1969 to 2009, for 189 countries (Mazumder 2014). We find that within disinflationary episodes, Gini indices increase. Moreover, in OECD countries the income shares of the top decile of the income distribution and especially that of the top 1 percent increase during disinflationary episodes. The income shares of the rest of the deciles, especially the fourth to sixth deciles, decrease.

Bringing down inflation has often been advertised as a policy aimed at protecting the poor, the reasoning being that they are the ones least able to protect themselves from price increases. Our results suggest that the *process* of bringing inflation down also affects the income distribution by increasing the Gini and the share of income that goes to the richest portions of the population. It is in the hands of central banks and the mandates societies give them to balance the goals with the side effects of the policies needed to achieve them. Voinea and Monnin (2017) point out that securing a fair distribution of the benefits and costs of price stability is a public good. The same could be argued with respect to disinflationary episodes.

Throughout the paper, we have interpreted the results as evidence that disinflations, often triggered by central banks' policies, cause economic activity to deteriorate, in a manner that is unevenly distributed across a population's income. Reverse causality is possible: rising inequality could reduce aggregate demand, because those at the top of the wealth distribution tend to consume a smaller share of their income than those at the bottom. This could *cause* the disinflation. Nevertheless, Ball (1994) and Hofstetter (2008) show that large disinflationary episodes, such as the ones examined in this paper, are mostly the consequence of monetary policies aimed at producing lower inflation rates. We also checked the results within a sample of "intentional disinflations" (Blanchard, Cerutti, and Summers 2015). Moreover, it looks unlikely that we will observe changes in income distributions rapid and strong enough to produce such sizable disinflationary processes. Nonetheless, the issue remains an interesting one for future study.

# Appendix A. Descriptive Statistics

**Table A.1. List of Episodes**

| Country | Year | Duration | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ $Mkt.Gini$ |
|---|---|---|---|---|---|---|
| Algeria | 1985 | 4 | 2.7 | | 39.4 | |
| Argentina | 2003 | 3 | 6.3 | 48.2 | 46.8 | –1.4 |
| Armenia | 2003 | 4 | 1.6 | 44.6 | 43.2 | –1.4 |
| Australia | 1975 | 5 | 5.5 | 38.6 | 39.9 | 1.3 |
| Australia | 1981 | 5 | 3.7 | 40.5 | 43.1 | 2.6 |
| Australia | 1987 | 7 | 6.7 | 43.4 | 45.9 | 2.5 |
| Australia | 1995 | 4 | 2.2 | 47.4 | 48 | 0.6 |
| Austria | 1981 | 7 | 4.5 | | 34.3 | |
| Austria | 1992 | 7 | 2.7 | 39.7 | 43 | 3.3 |
| Bangladesh | 1994 | 4 | 2.6 | 38.1 | 39.4 | 1.3 |
| Bangladesh | 1998 | 4 | 4.1 | 39.7 | 40.4 | 0.7 |
| Barbados | 1980 | 7 | 11.2 | 46.7 | 47 | 0.3 |
| Barbados | 1990 | 5 | 4.1 | 47.2 | 47.3 | 0.1 |
| Barbados | 1996 | 4 | 3.1 | 47.4 | 47.7 | 0.3 |
| Belgium | 1975 | 5 | 6.3 | | 41.3 | |
| Belgium | 1982 | 6 | 6.7 | 41.8 | 42.7 | 0.9 |
| Belgium | 1990 | 9 | 2.0 | 44.3 | 48.3 | 4.0 |
| Belize | 1995 | 5 | 4.5 | 54.7 | 53 | –1.7 |
| Benin | 2001 | 3 | 1.9 | | 43.5 | |
| Bolivia | 1991 | 4 | 7.4 | 45.7 | 48.3 | 2.6 |
| Bolivia | 1995 | 8 | 8.3 | 49.2 | 53.4 | 4.2 |
| Bosnia Herzegovina | 1998 | 6 | 8.1 | | 48.1 | |
| Botswana | 1980 | 6 | 5.0 | | 62.1 | |
| Botswana | 1992 | 9 | 6.4 | 63.6 | 64.5 | 0.9 |
| Botswana | 2001 | 3 | 7.2 | 64.6 | 64.6 | 0.0 |
| Brazil | 2002 | 6 | 5.5 | 60.3 | 56.7 | –3.6 |
| Bulgaria | 2001 | 4 | 3.3 | 34.9 | 35.1 | 0.2 |
| Burkina Faso | 1995 | 2 | 4.3 | 48.6 | 48.6 | 0.0 |
| Burkina Faso | 1997 | 4 | 3.3 | 48.7 | 47.7 | –1.0 |
| Burundi | 2004 | 2 | 2.6 | 39.1 | 38.8 | –0.3 |

*(continued)*

**Table A.1. (Continued)**

| Country | Year | Duration | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ $Mkt.Gini$ |
|---|---|---|---|---|---|---|
| Cambodia | 1997 | 5 | 8.7 | 44 | 42.9 | –1.1 |
| Cameroon | 1995 | 5 | 13.9 | | 44.5 | |
| Cameroon | 2001 | 4 | 1.9 | 44.6 | 44.7 | 0.1 |
| Canada | 1974 | 4 | 1.6 | 39.8 | 40.6 | 0.8 |
| Canada | 1981 | 5 | 7.0 | 39.3 | 41.8 | 2.5 |
| Canada | 1990 | 4 | 4.0 | 42.2 | 44 | 1.8 |
| Cape Verde Islands | 1996 | 6 | 6.7 | | 52.2 | |
| Cape Verde Islands | 2002 | 3 | 2.2 | 52.2 | 51.5 | –0.7 |
| Central African Republic | 1990 | 3 | 1.6 | | 54.1 | |
| Central African Republic | 1995 | 4 | 16.4 | 53.6 | 53 | –0.6 |
| Central African Republic | 2002 | 2 | 2.0 | 52.2 | 52 | –0.2 |
| Chad | 2001 | 3 | 7.8 | | 42 | |
| China | 1979 | 5 | 3.2 | 34.6 | 34.7 | 0.1 |
| China | 1989 | 3 | 8.8 | 37.6 | 39.1 | 1.5 |
| China | 1995 | 6 | 18.2 | 42.5 | 47.7 | 5.2 |
| Costa Rica | 1995 | 8 | 8.1 | 40.4 | 43.5 | 3.1 |
| Cote D'Ivoire | 1987 | 4 | 7.2 | 42.1 | 41.9 | –0.2 |
| Cote D'Ivoire | 1995 | 6 | 11.8 | 42.1 | 42.9 | 0.8 |
| Croatia | 1999 | 5 | 3.7 | 42.8 | 43 | 0.2 |
| Cyprus | 1980 | 8 | 8.8 | | 44.9 | |
| Cyprus | 1992 | 7 | 3.0 | 45.6 | 46.3 | 0.7 |
| Czech Republic | 1997 | 7 | 7.7 | 43.5 | 46.1 | 2.6 |
| Denmark | 1981 | 6 | 7.3 | 41.8 | 42 | 0.2 |
| Denmark | 1988 | 7 | 2.7 | 42.5 | 44.4 | 1.9 |
| Djibouti | 1995 | 8 | 3.8 | | 42 | |
| Dominican Republic | 1996 | 2 | 2.6 | 48.5 | 48.7 | 0.2 |

*(continued)*

**Table A.1. (Continued)**

| **Country** | **Year** | **Duration** | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ $Mkt.Gini$ |
|---|---|---|---|---|---|---|
| Egypt | 1981 | 2 | 1.6 | 46.7 | 47.1 | 0.4 |
| Egypt | 1990 | 4 | 8.0 | 50.3 | 51.3 | 1.0 |
| Egypt | 1994 | 8 | 9.4 | 51.6 | 52.8 | 1.2 |
| Equatorial Guinea | 2002 | 5 | 3.4 | | 50.8 | |
| Estonia | 2001 | 3 | 1.8 | 50 | 49.6 | –0.4 |
| Ethiopia | 1994 | 4 | 13.3 | | 36.8 | |
| Ethiopia | 1998 | 4 | 6.3 | 35.8 | 33.9 | –1.9 |
| Fiji | 1975 | 4 | 6.0 | | 44.8 | |
| Fiji | 1980 | 6 | 7.3 | 45 | 45.4 | 0.4 |
| Fiji | 1989 | 7 | 6.7 | 45.7 | 45.4 | –0.3 |
| Fiji | 1997 | 5 | 2.0 | 45.1 | 44.5 | –0.6 |
| Finland | 1975 | 5 | 7.3 | 41.2 | 40 | –1.2 |
| Finland | 1981 | 7 | 7.0 | 39.4 | 39 | –0.4 |
| Finland | 1989 | 7 | 5.0 | 39.9 | 46.2 | 6.3 |
| Finland | 2001 | 4 | 1.9 | 46.9 | 47.2 | 0.3 |
| France | 1975 | 3 | 2.2 | 47.5 | 46.3 | –1.2 |
| France | 1981 | 7 | 10.1 | 48.1 | 49.3 | 1.2 |
| France | 1990 | 9 | 2.6 | 48.5 | 47.9 | –0.6 |
| Gambia | 2002 | 5 | 15.8 | 47.9 | 47.3 | –0.6 |
| Georgia | 2000 | 2 | 4.5 | 47.7 | 48 | 0.3 |
| Germany | 1974 | 5 | 3.1 | 39 | 41.3 | 2.3 |
| Germany | 1981 | 7 | 5.3 | 41.1 | 43.2 | 2.1 |
| Germany | 1993 | 7 | 3.1 | 45.4 | 46.8 | 1.4 |
| Ghana | 2004 | 2 | 5.3 | 42.9 | 43.2 | 0.3 |
| Greece | 1974 | 4 | 5.7 | 51.4 | 50.6 | –0.8 |
| Greece | 1991 | 10 | 15.5 | 47.6 | 47.2 | –0.4 |
| Guatemala | 1980 | 4 | 8.5 | | 48.9 | |
| Guinea | 1992 | 7 | 15.2 | 45.7 | 44.6 | –1.1 |
| Guinea Bissau | 2001 | 3 | 4.9 | 41.2 | 41.7 | 0.5 |
| Hong Kong | 1978 | 2 | 3.0 | 41.2 | 41.3 | 0.1 |
| Hong Kong | 1982 | 4 | 6.5 | 41.7 | 42.3 | 0.6 |
| Hong Kong | 1989 | 11 | 13.4 | 43.3 | 45.6 | 2.3 |
| Hungary | 1979 | 4 | 1.6 | 45.3 | 45.5 | 0.2 |

*(continued)*

## Table A.1. (Continued)

| Country | Year | Duration | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ *Mkt.Gini* |
|---|---|---|---|---|---|---|
| Iceland | 2001 | 4 | 1.8 | 33.2 | 36.1 | 2.9 |
| India | 1973 | 5 | 16.2 | | 42.5 | |
| India | 1982 | 4 | 3.4 | 43.3 | 43.8 | 0.5 |
| India | 1991 | 4 | 2.6 | 44.5 | 45 | 0.5 |
| India | 1997 | 6 | 5.8 | 45.6 | 47 | 1.4 |
| Indonesia | 1980 | 7 | 8.9 | 40.3 | 38.9 | –1.4 |
| Indonesia | 2002 | 3 | 2.2 | 39.2 | 40.5 | 1.3 |
| Iran | 1976 | 4 | 3.4 | 54.2 | 55.7 | 1.5 |
| Iran | 2003 | 3 | 1.8 | 47.4 | 46.9 | –0.5 |
| Ireland | 1975 | 4 | 6.4 | 47.6 | 48.5 | 0.9 |
| Ireland | 1980 | 8 | 10.3 | 49 | 50.9 | 1.9 |
| Ireland | 1990 | 5 | 5.2 | 50.4 | 49.8 | –0.6 |
| Ireland | 2001 | 4 | 2.3 | 48.6 | 50.1 | 1.5 |
| Israel | 1990 | 5 | 7.7 | 47 | 48.2 | 1.2 |
| Israel | 1995 | 6 | 8.7 | 48.7 | 51.6 | 2.9 |
| Israel | 2001 | 4 | 2.1 | 52.4 | 51.9 | –0.5 |
| Italy | 1975 | 4 | 2.5 | 48.9 | 47.1 | –1.8 |
| Italy | 1981 | 7 | 13.8 | 45.2 | 44.6 | –0.6 |
| Italy | 1990 | 4 | 1.8 | 43.7 | 46.5 | 2.8 |
| Italy | 1994 | 5 | 2.7 | 46.9 | 47.7 | 0.8 |
| Jamaica | 2004 | 3 | 2.0 | 56.2 | | |
| Japan | 1974 | 6 | 10.3 | 35.9 | 36.3 | 0.4 |
| Japan | 1980 | 8 | 5.0 | 36.6 | 39.4 | 2.8 |
| Japan | 1990 | 6 | 2.6 | 40.6 | 42.4 | 1.8 |
| Japan | 1997 | 5 | 1.6 | 43.2 | 44.5 | 1.3 |
| Jordan | 1980 | 7 | 11.6 | | 43.1 | |
| Jordan | 1990 | 5 | 15.0 | 45 | 45.2 | 0.2 |
| Jordan | 1997 | 4 | 3.2 | 43.8 | 43.5 | –0.3 |

*(continued)*

**Table A.1. (Continued)**

| **Country** | **Year** | **Duration** | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ $Mkt.Gini$ |
|---|---|---|---|---|---|---|
| Kazakhstan | 2000 | 4 | 3.6 | 37.6 | 36.8 | –0.8 |
| Kenya | 1975 | 6 | 5.0 | | 55.2 | |
| Kenya | 1981 | 7 | 7.5 | 54.9 | 52.9 | –2.0 |
| Kenya | 1997 | 6 | 3.1 | 49 | 48.6 | –0.4 |
| Kiribati and Tuvalu | 1992 | 6 | 4.0 | | 47.4 | |
| Kiribati and Tuvalu | 2002 | 4 | 4.5 | 46 | 45.5 | –0.5 |
| Kuwait | 1995 | 4 | 1.7 | | 37.2 | |
| Laos | 2003 | 4 | 6.0 | 39.2 | 40.3 | 1.1 |
| Lebanon | 2003 | 2 | 2.0 | 43.3 | 42.9 | –0.4 |
| Lesotho | 1987 | 4 | 3.2 | 56.5 | 57 | 0.5 |
| Lesotho | 1992 | 4 | 3.7 | 57.4 | 57.7 | 0.3 |
| Lesotho | 1996 | 5 | 9.4 | 57.5 | 56.8 | –0.7 |
| Lesotho | 2003 | 3 | 10.3 | 56.5 | 56.5 | 0.0 |
| Luxembourg | 1982 | 6 | 6.7 | | 38.3 | |
| Luxembourg | 1990 | 9 | 2.0 | 38.5 | 42.5 | 4.0 |
| Macedonia | 2001 | 4 | 4.3 | 54.7 | 55.7 | 1.0 |
| Madagascar | 1974 | 4 | 7.0 | 47.8 | 48.3 | 0.5 |
| Madagascar | 1987 | 4 | 9.0 | 47.4 | 46.8 | –0.6 |
| Madagascar | 2001 | 2 | 4.4 | 45.4 | 45 | –0.4 |
| Malawi | 1975 | 5 | 9.5 | 54.3 | 55.6 | 1.3 |
| Malaysia | 1974 | 3 | 6.8 | 47.5 | 48.6 | 1.1 |
| Malaysia | 1981 | 6 | 6.7 | 49.3 | 47.6 | –1.7 |
| Malaysia | 1997 | 6 | 2.4 | 46.4 | 45.7 | –0.7 |
| Mali | 1995 | 5 | 13.8 | 43.8 | 42.3 | –1.5 |
| Mali | 2001 | 3 | 3.0 | 41.6 | 41.4 | –0.2 |
| Mauritania | 1985 | 3 | 3.6 | | 43.4 | |
| Mauritania | 1992 | 4 | 3.3 | 43.2 | 42.2 | –1.0 |
| Mauritania | 1997 | 5 | 1.8 | 42.2 | 42.1 | –0.1 |

(*continued*)

**Table A.1. (Continued)**

| Country | Year | Duration | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ $Mkt.Gini$ |
|---|---|---|---|---|---|---|
| Mauritius | 1989 | 4 | 4.4 | 41.3 | 41.2 | –0.1 |
| Mauritius | 1998 | 5 | 3.4 | 40.9 | 40.4 | –0.5 |
| Morocco | 1981 | 4 | 2.0 | | 41.2 | |
| Morocco | 1985 | 4 | 6.9 | 41.2 | 41.2 | 0.0 |
| Morocco | 1994 | 5 | 4.0 | 41.3 | 41.3 | 0.0 |
| Mozambique | 2003 | 4 | 4.8 | 46.7 | 46.4 | –0.3 |
| Namibia | 1994 | 4 | 4.7 | 67.3 | 67 | –0.3 |
| Namibia | 2004 | 4 | 4.8 | 66.2 | 65.6 | –0.6 |
| Nepal | 1973 | 5 | 8.5 | | 48.5 | |
| Nepal | 1981 | 4 | 4.8 | 47.3 | 46.5 | –0.8 |
| Nepal | 1987 | 3 | 4.2 | 45.7 | 45.1 | –0.6 |
| Nepal | 1991 | 4 | 5.8 | 44.6 | 43.7 | –0.9 |
| Nepal | 1997 | 5 | 5.4 | 43.8 | 45.1 | 1.3 |
| Netherlands | 1975 | 4 | 4.7 | | 45.1 | |
| Netherlands | 1981 | 7 | 6.3 | 46.3 | 47.2 | 0.9 |
| Netherlands | 2001 | 5 | 1.9 | 44.7 | 46 | 1.3 |
| New Zealand | 1981 | 3 | 7.5 | | 40.6 | |
| New Zealand | 1986 | 8 | 13.4 | 41.4 | 45 | 3.6 |
| New Zealand | 1995 | 4 | 1.8 | 45.8 | 46.3 | 0.5 |
| Nicaragua | 1997 | 6 | 6.2 | 52.6 | 50.3 | –2.3 |
| Niger | 1989 | 4 | 2.8 | | 40.2 | |
| Niger | 1995 | 6 | 15.8 | 40.7 | 40.9 | 0.2 |
| Niger | 2001 | 3 | 2.8 | 41 | 41.1 | 0.1 |
| Nigeria | 2004 | 4 | 7.2 | 44.6 | 44.9 | 0.3 |
| Norway | 1975 | 4 | 2.8 | 37.3 | 37.4 | 0.1 |
| Norway | 1981 | 5 | 5.6 | 37.2 | 36.6 | –0.6 |
| Norway | 1987 | 7 | 5.5 | 36.8 | 40.3 | 3.5 |

*(continued)*

**Table A.1. (Continued)**

| **Country** | **Year** | **Duration** | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ $Mkt.Gini$ |
|---|---|---|---|---|---|---|
| Pakistan | 1980 | 7 | 6.1 | 36.4 | 36.7 | 0.3 |
| Pakistan | 1995 | 8 | 8.6 | 36.6 | 37 | 0.4 |
| Panama | 1972 | 5 | 2.9 | 52.1 | 52.3 | 0.2 |
| Panama | 1980 | 8 | 9.3 | 52.6 | 53.3 | 0.7 |
| Papua New Guinea | 1999 | 8 | 13.1 | 57.6 | 55.5 | –2.1 |
| Paraguay | 2002 | 4 | 3.8 | 49.2 | 47.9 | –1.3 |
| Philippines | 1973 | 4 | 11.0 | 47.5 | 47.4 | –0.1 |
| Philippines | 1980 | 3 | 5.2 | 47.3 | 47.2 | –0.1 |
| Philippines | 1990 | 5 | 6.2 | 48.6 | 49.7 | 1.1 |
| Philippines | 1997 | 5 | 5.0 | 50.3 | 48.6 | –1.7 |
| Portugal | 1990 | 9 | 9.9 | 51.9 | 52.6 | 0.7 |
| Republic of South Africa | 1981 | 3 | 1.7 | 62.5 | 62.8 | 0.3 |
| Republic of South Africa | 1986 | 4 | 3.1 | 63.4 | 64 | 0.6 |
| Republic of South Africa | 1990 | 11 | 9.4 | 64.1 | 66.3 | 2.2 |
| Republic of South Africa | 2002 | 4 | 5.3 | 66.8 | 67.8 | 1.0 |
| Rwanda | 1983 | 5 | 9.4 | | 38.4 | |
| Rwanda | 2005 | 2 | 1.7 | 52.7 | 52.7 | 0.0 |
| Samoa | 2003 | 2 | 2.1 | 50 | 50 | 0.0 |
| Samoa | 2005 | 2 | 3.6 | 49.9 | 49.9 | 0.0 |
| Senegal | 1995 | 5 | 13.4 | 43.6 | 42.9 | –0.7 |
| Singapore | 1974 | 3 | 13.6 | 39.7 | 39.7 | 0.0 |
| Singapore | 1980 | 7 | 7.1 | 39.9 | 40.6 | 0.7 |
| Singapore | 1990 | 10 | 2.7 | 41.5 | 43.4 | 1.9 |
| Slovakia | 1994 | 4 | 4.4 | 41.1 | 43 | 1.9 |
| Slovakia | 2000 | 3 | 3.6 | 43.9 | 44.4 | 0.5 |
| Slovakia | 2003 | 4 | 3.5 | 44.6 | 43.1 | –1.5 |
| Slovenia | 2001 | 5 | 5.4 | 37.7 | 39.7 | 2.0 |
| Solomon Islands | 2002 | 4 | 1.9 | | 50.4 | |
| South Korea | 1991 | 4 | 2.9 | 29.9 | 29.9 | 0.0 |
| South Korea | 1997 | 4 | 3.3 | 30.7 | 31.6 | 0.9 |

(*continued*)

**Table A.1. (Continued)**

| **Country** | **Year** | **Duration** | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ *Mkt.Gini* |
|---|---|---|---|---|---|---|
| Spain | 1990 | 9 | 4.4 | 42.5 | 47.2 | 4.7 |
| Sri Lanka | 1974 | 3 | 6.4 | 38.5 | 39.7 | 1.2 |
| Sri Lanka | 1981 | 6 | 12.6 | 42 | 41.6 | –0.4 |
| Sri Lanka | 1989 | 6 | 6.4 | 41.4 | 42.2 | 0.8 |
| Sri Lanka | 1997 | 3 | 4.9 | 43.8 | 44.8 | 1.0 |
| Sri Lanka | 2002 | 2 | 2.2 | 46.4 | 46.6 | 0.2 |
| St. Kitts and Nevis | 1998 | 4 | 3.3 | | 42 | |
| St. Lucia | 1995 | 3 | 2.6 | 47 | 46.9 | –0.1 |
| St. Lucia | 1999 | 4 | 2.6 | 46.9 | 46.7 | –0.2 |
| St. Vincent and the Grenadines | 1997 | 5 | 1.7 | 51.1 | 50.3 | –0.8 |
| Swaziland | 1986 | 5 | 6.0 | 50 | 51.7 | 1.7 |
| Swaziland | 1994 | 5 | 5.6 | 53.5 | 53.3 | –0.2 |
| Swaziland | 2001 | 5 | 5.4 | 53.1 | 52.5 | –0.6 |
| Sweden | 1981 | 7 | 6.7 | 41.2 | 42.8 | 1.6 |
| Sweden | 1990 | 4 | 5.7 | 44.2 | 46.7 | 2.5 |
| Sweden | 1994 | 5 | 2.8 | 47.6 | 47.4 | –0.2 |
| Switzerland | 1981 | 7 | 4.0 | 39.8 | 39.8 | 0.0 |
| Switzerland | 1991 | 7 | 4.7 | 40.1 | 39.3 | –0.8 |
| Syria | 1994 | 6 | 17.0 | | 39.8 | |
| Taiwan | 1980 | 6 | 14.9 | 27.2 | 27.7 | 0.5 |
| Taiwan | 1995 | 4 | 2.7 | 31.2 | 30.3 | –0.9 |
| Thailand | 1974 | 3 | 9.4 | 43.8 | 44.4 | 0.6 |
| Thailand | 1980 | 6 | 12.4 | 46.4 | 48 | 1.6 |
| Thailand | 1997 | 4 | 5.3 | 47.3 | 47.4 | 0.1 |
| Tonga | 1986 | 3 | 8.1 | 40 | 40.6 | 0.6 |
| Tonga | 1991 | 4 | 8.3 | 41.6 | 42.3 | 0.7 |
| Tonga | 2003 | 4 | 4.1 | 45 | 45.7 | 0.7 |

(*continued*)

**Table A.1. (Continued)**

| Country | Year | Duration | $\Delta\pi$ | $Mkt.Gini^{peak}$ | $Mkt.Gini^{trough}$ | $\Delta$ $Mkt.Gini$ |
|---|---|---|---|---|---|---|
| Trinidad and Tobago | 1974 | 4 | 7.0 | 44.3 | 44.3 | 0.0 |
| Trinidad and Tobago | 1980 | 7 | 6.8 | 44.2 | 44 | –0.2 |
| Trinidad and Tobago | 1989 | 4 | 3.0 | 43.9 | 44 | 0.1 |
| Trinidad and Tobago | 1993 | 4 | 4.6 | 43.9 | 43.9 | 0.0 |
| Tunisia | 1985 | 5 | 2.9 | 43.4 | 42.9 | –0.5 |
| Tunisia | 1990 | 4 | 2.7 | 42.8 | 42.7 | –0.1 |
| Tunisia | 1994 | 7 | 2.4 | 42.6 | 42 | –0.6 |
| Uganda | 1995 | 5 | 5.4 | 42.6 | 43.5 | 0.9 |
| Uganda | 2000 | 2 | 2.3 | 43.8 | 44.3 | 0.5 |
| United Kingdom | 1975 | 4 | 6.4 | 39 | 40.7 | 1.7 |
| United Kingdom | 1980 | 8 | 10.3 | 42.3 | 50 | 7.7 |
| United Kingdom | 1990 | 5 | 5.2 | 51.1 | 53.4 | 2.3 |
| United States | 1974 | 4 | 2.2 | 41.7 | 42.4 | 0.7 |
| United States | 1980 | 7 | 8.7 | 42.9 | 45.9 | 3.0 |
| United States | 1990 | 9 | 2.8 | 46.7 | 48 | 1.3 |
| Uruguay | 2003 | 4 | 7.8 | 53.2 | 53 | –0.2 |
| Venezuela | 1980 | 4 | 4.4 | 40.3 | 40.1 | –0.2 |
| Vietnam | 1997 | 5 | 4.8 | 40.7 | 41.3 | 0.6 |
| Yemen | 2005 | 2 | 1.5 | 41.8 | 42.1 | 0.3 |
| **Mean** | | 4.9 | 5.7 | 45.5 | 45.7 | 0.5 |
| **Mean OECD** | | 5.7 | 5.1 | 43.2 | 44.2 | 1.3 |
| **Mean Non-OECD** | | 4.6 | 6.0 | 46.6 | 46.4 | 0.1 |
| **Median** | | 4.0 | 4.9 | 44.6 | 45.0 | 0.3 |
| **Min.** | | 2.0 | 1.5 | 27.2 | 27.7 | –3.6 |
| **Max.** | | 11.0 | 18.2 | 67.3 | 67.8 | 7.7 |
| **Standard Deviation** | | 1.8 | 3.6 | 6.6 | 6.3 | 1.5 |

**Table A.2. Mean ($\mu$) and Standard Deviations ($\sigma$) of Market and Disposable Income Gini Indices**

| | Complete Sample | | | | Non-OECD | | | | OECD | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Market | | Disposable | | Market | | Disposable | | Market | | Disposable | |
| | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ |
| 1969–1979 | 43.9 | 6.9 | 36.8 | 9.5 | 42.2 | 5.5 | 29.5 | 7.6 | 45.2 | 7.5 | 42.0 | 7.1 |
| 1980–1989 | 44.4 | 7.1 | 36.8 | 9.6 | 42.8 | 5.2 | 28.9 | 6.9 | 45.4 | 7.9 | 41.5 | 7.7 |
| 1990–1999 | 45.6 | 6.7 | 38.4 | 9.1 | 45.0 | 5.3 | 30.1 | 7.1 | 45.8 | 7.1 | 41.4 | 7.7 |
| 2000–2009 | 46.2 | 6.4 | 39.3 | 8.3 | 46.8 | 4.7 | 30.9 | 6.1 | 46.0 | 6.8 | 41.5 | 7.4 |
| **1969–2009** | **45.4** | **6.8** | **38.2** | **9.0** | **44.4** | **5.5** | **29.9** | **6.9** | **45.7** | **7.2** | **41.5** | **7.5** |

**Table A.3. Mean ($\mu$) and Standard Deviations ($\sigma$) for the Shares of Income of Each Decile and for the Top 1 Percent, OECD Countries**

| | Decile 1 (Poorest) | | | | Decile 2 | | | | Decile 3 | | | | Decile 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-tax | | After Tax | | Pre-tax | | After Tax | | Pre-tax | | After Tax | | Pre-tax | | After Tax | |
| | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ |
| 1969–1979 | 0.01 | 0.00 | 0.02 | 0.00 | 0.03 | 0.00 | 0.04 | 0.00 | 0.04 | 0.00 | 0.05 | 0.00 | 0.06 | 0.00 | 0.06 | 0.00 |
| 1980–1989 | 0.03 | 0.02 | 0.03 | 0.01 | 0.05 | 0.01 | 0.05 | 0.01 | 0.06 | 0.01 | 0.06 | 0.01 | 0.07 | 0.01 | 0.07 | 0.01 |
| 1990–1999 | 0.03 | 0.01 | 0.02 | 0.01 | 0.04 | 0.01 | 0.05 | 0.01 | 0.05 | 0.01 | 0.06 | 0.01 | 0.06 | 0.01 | 0.07 | 0.01 |
| 2000–2009 | 0.02 | 0.01 | 0.02 | 0.01 | 0.04 | 0.01 | 0.05 | 0.01 | 0.05 | 0.01 | 0.06 | 0.01 | 0.06 | 0.01 | 0.07 | 0.01 |
| **1969–2009** | **0.03** | **0.01** | **0.02** | **0.01** | **0.04** | **0.01** | **0.05** | **0.01** | **0.05** | **0.01** | **0.06** | **0.01** | **0.06** | **0.01** | **0.07** | **0.01** |

| | Decile 5 | | | | Decile 6 | | | | Decile 7 | | | | Decile 8 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-tax | | After Tax | | Pre-tax | | After Tax | | Pre-tax | | After Tax | | Pre-tax | | After Tax | |
| | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ |
| 1969–1979 | 0.07 | 0.00 | 0.08 | 0.00 | 0.08 | 0.00 | 0.09 | 0.00 | 0.10 | 0.00 | 0.10 | 0.00 | 0.12 | 0.00 | 0.10 | 0.00 |
| 1980–1989 | 0.08 | 0.01 | 0.08 | 0.01 | 0.09 | 0.01 | 0.09 | 0.01 | 0.10 | 0.00 | 0.11 | 0.00 | 0.12 | 0.00 | 0.11 | 0.00 |
| 1990–1999 | 0.07 | 0.01 | 0.08 | 0.01 | 0.09 | 0.01 | 0.09 | 0.01 | 0.10 | 0.01 | 0.10 | 0.00 | 0.12 | 0.01 | 0.10 | 0.00 |
| 2000–2009 | 0.07 | 0.01 | 0.08 | 0.01 | 0.08 | 0.01 | 0.09 | 0.01 | 0.10 | 0.01 | 0.10 | 0.00 | 0.11 | 0.01 | 0.10 | 0.00 |
| **1969–2009** | **0.08** | **0.01** | **0.08** | **0.01** | **0.09** | **0.01** | **0.09** | **0.01** | **0.10** | **0.01** | **0.10** | **0.00** | **0.12** | **0.01** | **0.10** | **0.00** |

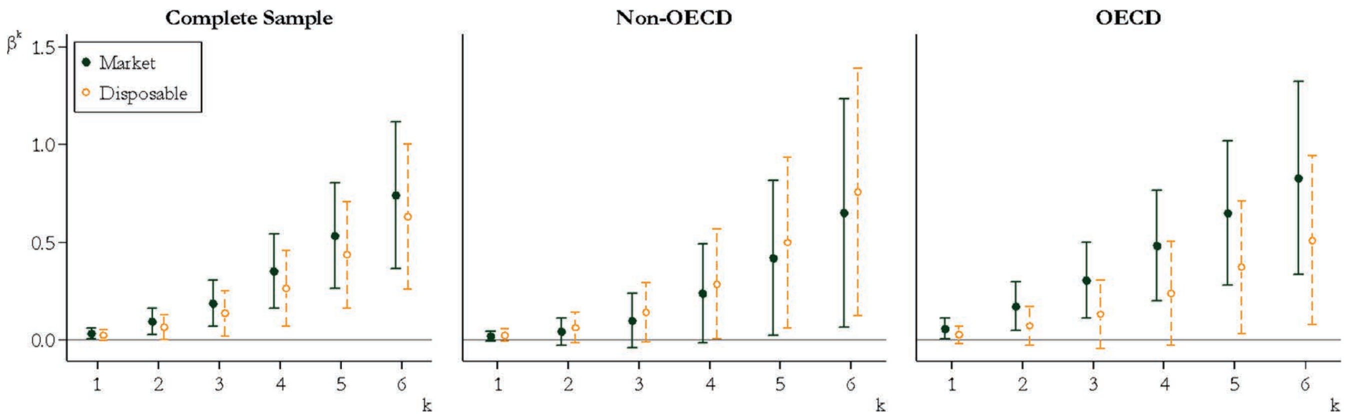
| | Decile 9 | | | | Decile 10 (Richest) | | | | Top 1 Percent | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-tax | | After Tax | | Pre-tax | | After Tax | | Pre-tax | | After Tax | |
| | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ |
| 1969–1979 | 0.15 | 0.00 | 0.14 | 0.00 | 0.34 | 0.01 | 0.30 | 0.00 | 0.10 | 0.01 | 0.09 | 0.00 |
| 1980–1989 | 0.14 | 0.01 | 0.14 | 0.01 | 0.25 | 0.05 | 0.24 | 0.05 | 0.06 | 0.02 | 0.06 | 0.02 |
| 1990–1999 | 0.14 | 0.01 | 0.14 | 0.01 | 0.29 | 0.08 | 0.26 | 0.04 | 0.08 | 0.05 | 0.07 | 0.02 |
| 2000–2009 | 0.14 | 0.01 | 0.14 | 0.01 | 0.31 | 0.06 | 0.28 | 0.04 | 0.09 | 0.04 | 0.08 | 0.02 |
| **1969–2009** | **0.14** | **0.01** | **0.14** | **0.01** | **0.29** | **0.07** | **0.26** | **0.05** | **0.08** | **0.04** | **0.07** | **0.02** |

**Table A.4. Descriptive Statistics of the Episodes Used in the Estimation of Regression 2**

| | **Complete Sample** | **Non-OECD** | **OECD** |
|---|---|---|---|
| Number of Episodes | 212 | 142 | 70 |
| Average $Gini^{trough} - Gini^{peak}$ Market | 0.52 | 0.11 | 1.34 |
| Average $Gini^{trough} - Gini^{peak}$ Disposable | 0.24 | 0.09 | 0.55 |
| Average Length | 4.96 | 4.58 | 5.73 |
| Average $\pi_e^{peak} - \pi_e^{trough}$ | 5.70 | 6.02 | 5.04 |

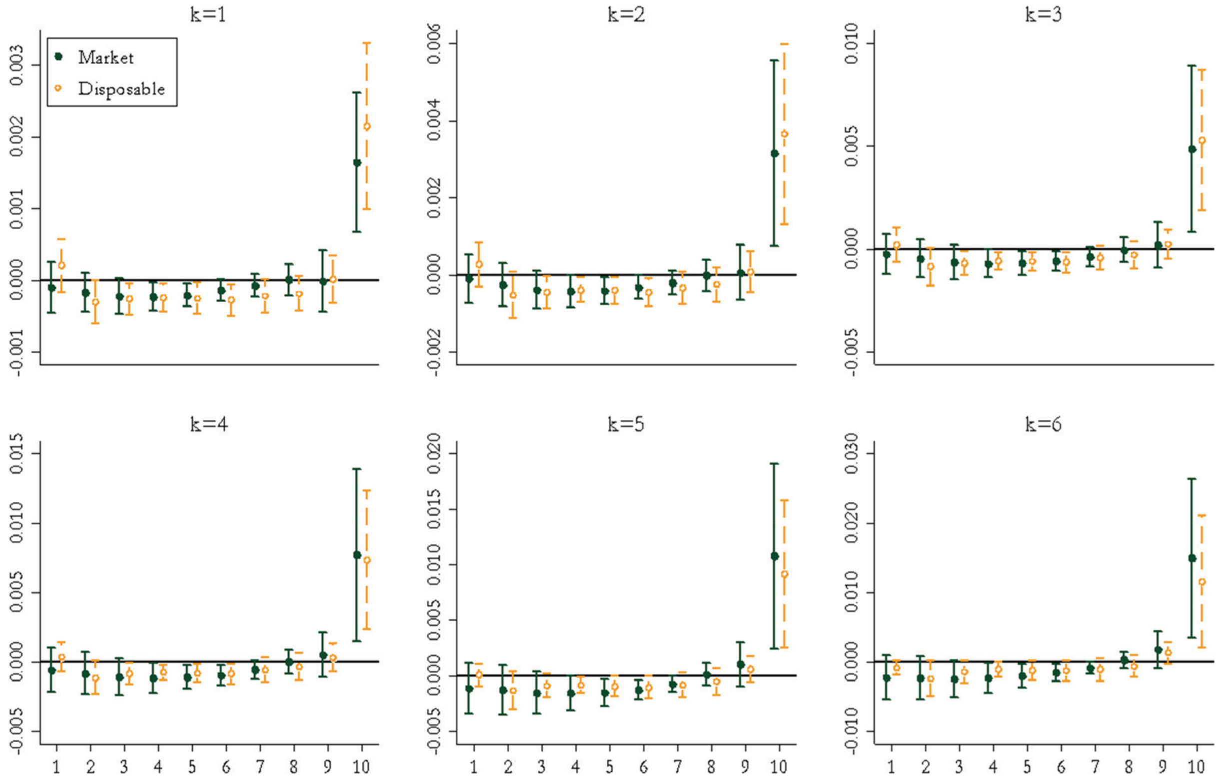
## Appendix B. Robustness

### Figure B.1. $\beta^k$ for $Y$ = Gini Coefficients



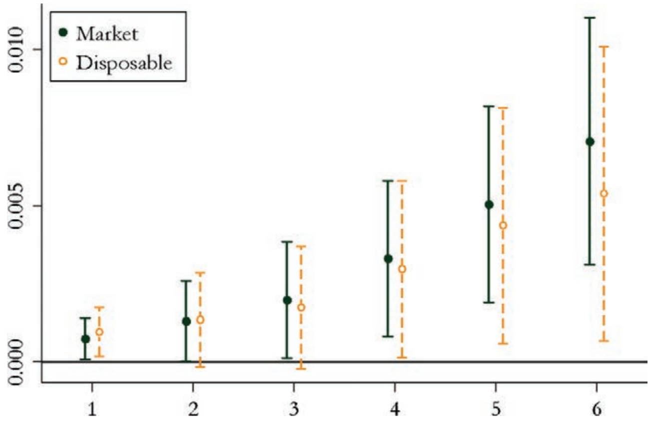

**Note:** The results are based on estimations of Equation (1) without a trend: the plots report $\beta^k$ (vertical axes) for different $k$'s (horizontal axes), along with 90 percent confidence intervals. The $\beta^k$ represent the change in Gini coefficients $k$ periods apart within a disinflationary episode relative to non-disinflationary periods.

**Figure B.2. $\beta^k$, where $Y$ = Income Shares for Each Decile**



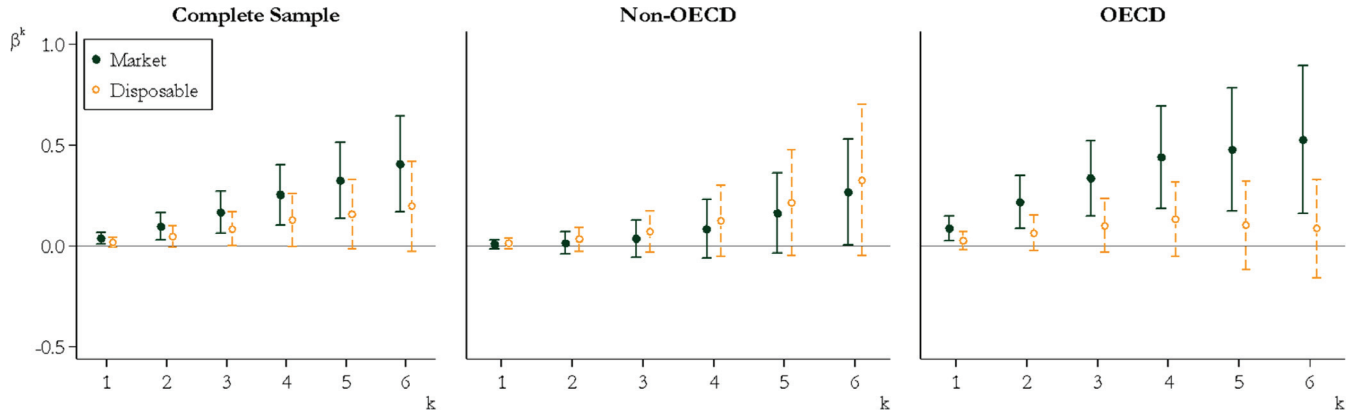

**Note:** The results are based on estimations of Equation (1) without a trend for OECD countries. The plots report $\beta^k$ (vertical axes) for different deciles (horizontal axes) along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of each decile, $k$ periods apart within a disinflationary episode relative to the same change during non-disinflationary periods. The scale varies across the plots.

**Figure B.3. $\beta^k$, where $Y$ = Income Share of the Top 1 Percent**



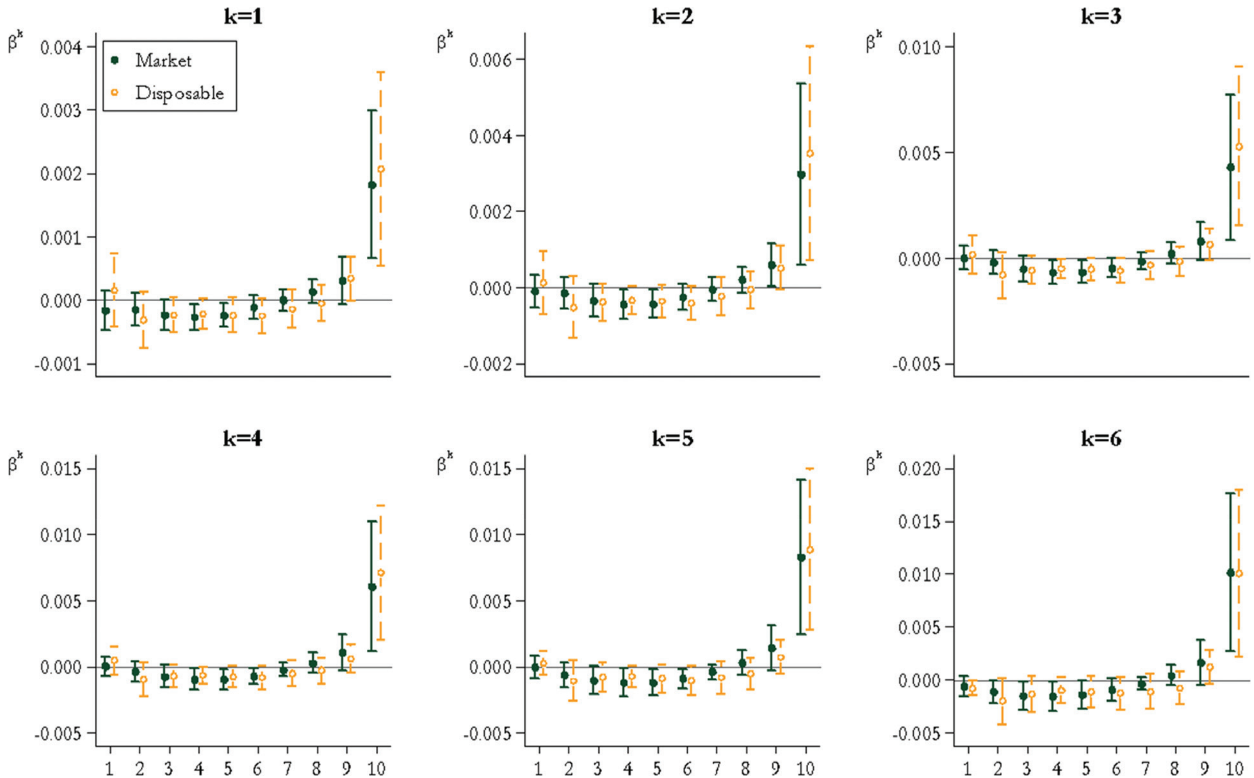

**Note:** Based on estimations of Equation (1) for OECD countries, without a trend. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary periods.

## Figure B.4. $\beta^k$ for $Y$ = Gini Coefficients



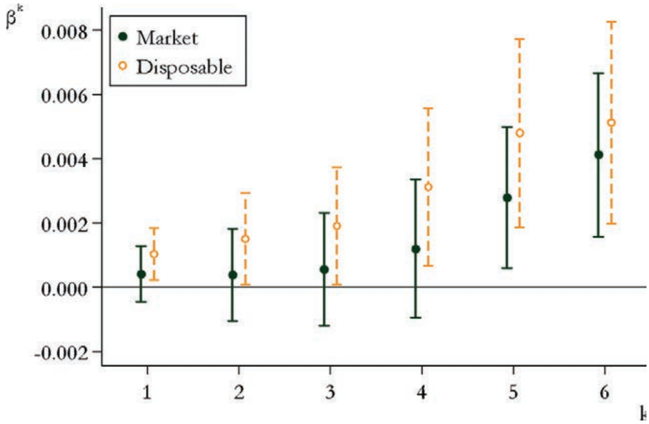

**Note:** The results are based on estimations of Equation (1) <u>with country-specific trends</u>: the plots report $\beta^k$ (vertical axes) for different $k$'s (horizontal axes), along with 90 percent confidence intervals. The $\beta^k$ represent the change in Gini coefficients $k$ periods apart within a disinflationary episode relative to non-disinflationary periods.

**Figure B.5. $\beta^k$, where $Y$ = Income Shares for Each Decile**



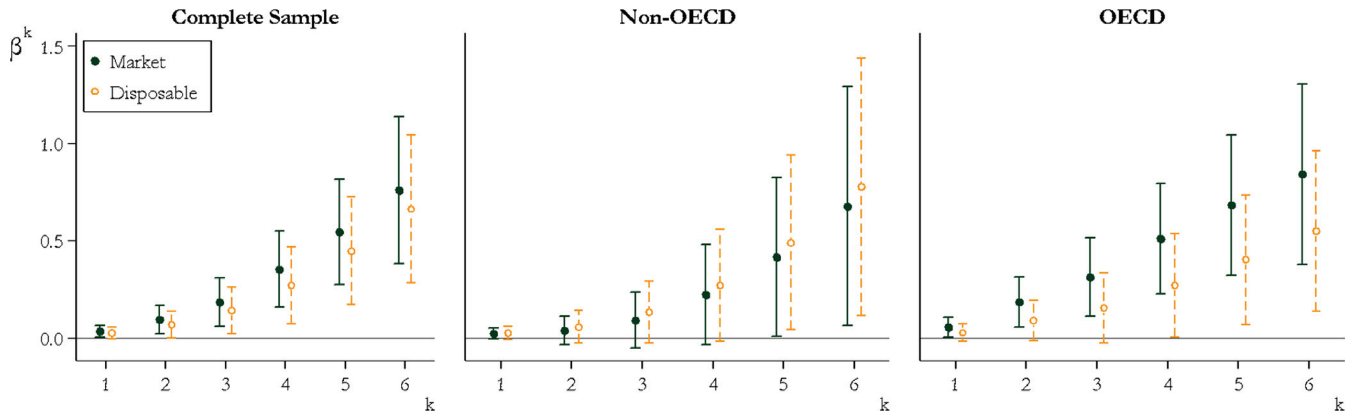

**Note:** The results are based on estimations of Equation (1) with country-specific trends for OECD countries. The plots report $\beta^k$ (vertical axes) for different deciles (horizontal axes) along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of each decile, $k$ periods apart within a disinflationary episode relative to the same change during non-disinflationary periods. The scale varies across the plots.

**Figure B.6. $\beta^k$, where $Y$ = Income Share of the Top 1 Percent**



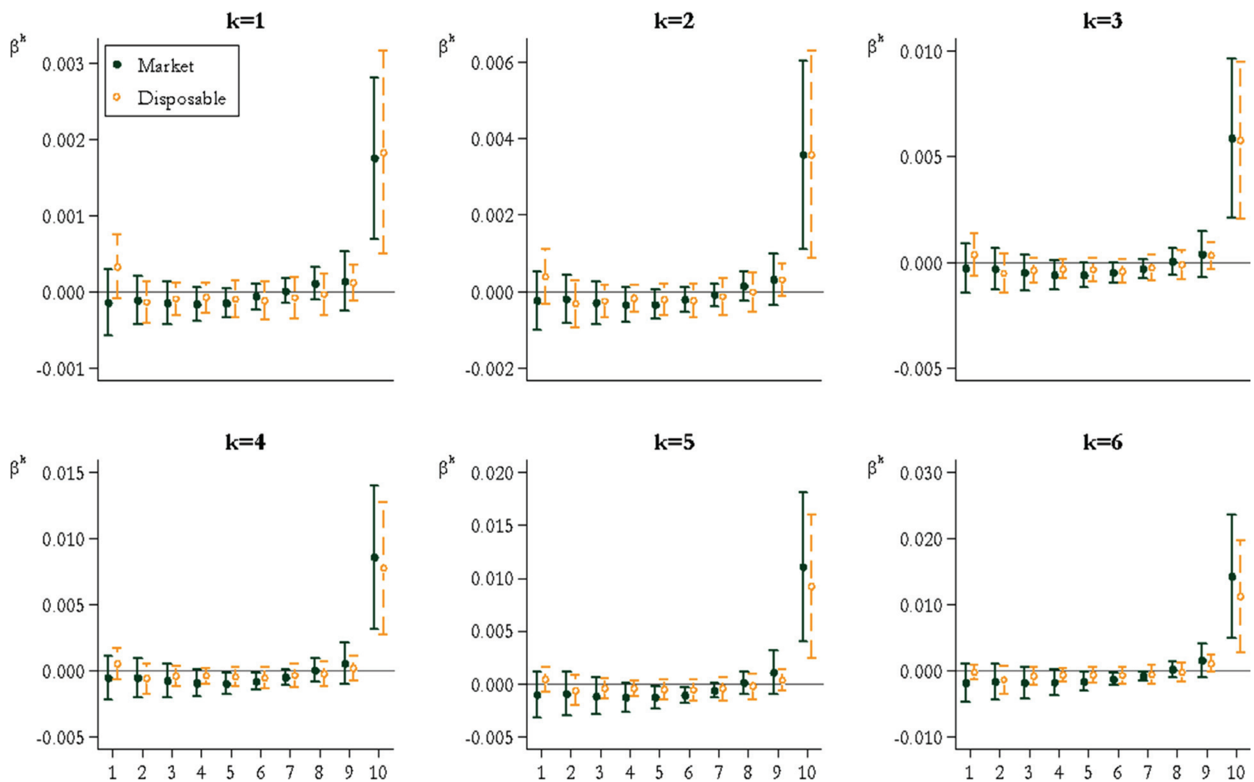

**Note:** Based on estimations of Equation (1) for OECD countries, with country-specific trends. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary periods.

**Figure B.7. $\beta^k$, where $Y$ = Gini**



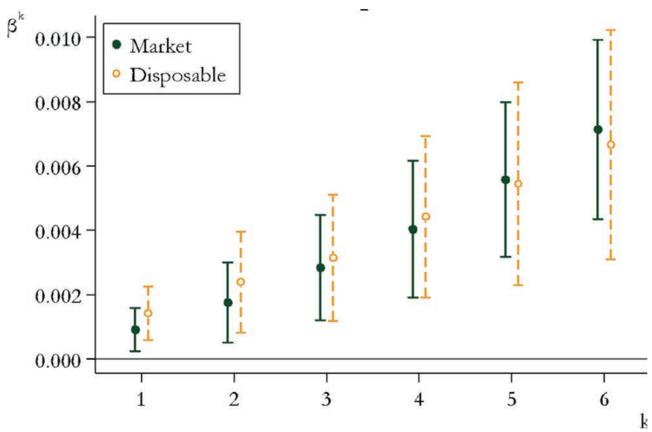

**Note:** The results are based on estimations of Equation (1) for OECD countries, with one lag. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary periods.

**Figure B.8. $\beta^k$, where $Y$ = Income Share by Deciles**



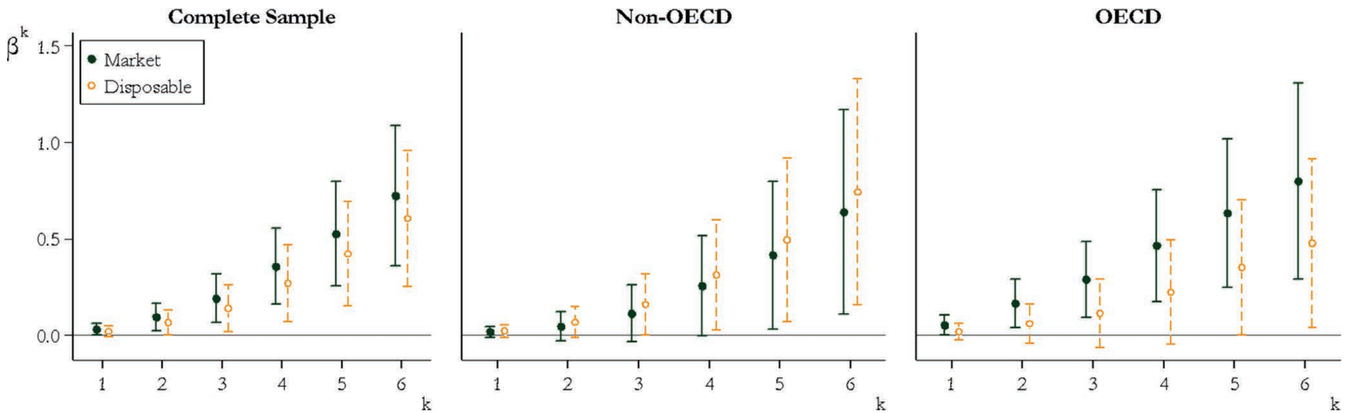

**Note:** The results are based on estimations of Equation (1) for OECD countries, <u>with one lag</u>. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary periods.

**Figure B.9. $\beta^k$, where $Y$ = Income Share of the Top 1 Percent**



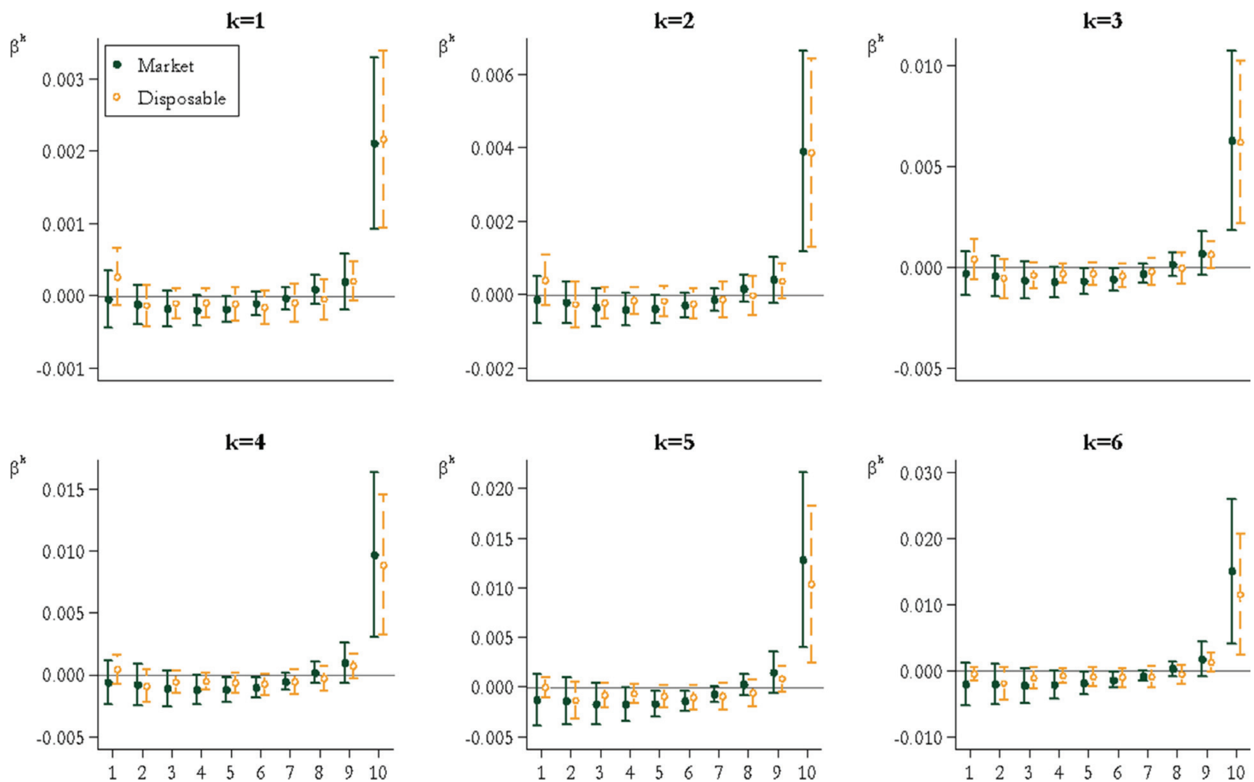

**Note:** The results are based on estimations of Equation (1) for OECD countries, with one lag. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary periods.

**Figure B.10.** $\beta^k$**, where** $Y$ **= Gini**



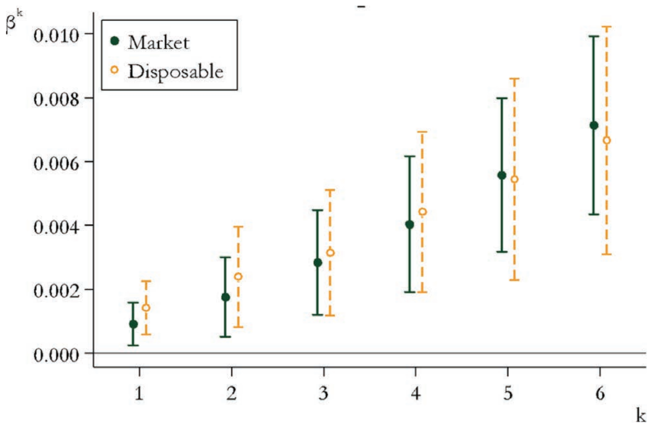

**Note:** The results are based on estimations of Equation (1) for OECD countries, with three lags. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary periods.

**Figure B.11. $\beta^k$, where $Y$ = Income Shares by Deciles**




**Note:** The results are based on estimations of Equation (1) for OECD countries, <u>with three lags</u>. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary periods.

**Figure B.12. $\beta^k$, where $Y$ = Income Share of the Top 1 Percent**




**Note:** The results are based on estimations of Equation (1) for OECD countries, with three lags. The plots report $\beta^k$ (vertical axes) for different $k$'s along with 90 percent confidence intervals. The $\beta^k$ represent the change in the income share of the top 1 percent, $k$ periods apart during a disinflationary episode relative to the same change during non-disinflationary times.

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# Financial Stability Governance and Central Bank Communications*

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We investigate how central banks' financial stability governance frameworks influence their financial stability communication strategies and their effectiveness in preventing financial stress. Using data for 24 central banks, we test how communication strategies and their effectiveness depend on the powers assigned to these institutions. We find robust evidence that communications by central banks represented in interagency financial stability committees with more powers are more effective in mitigating a deterioration in financial conditions. These central banks also use macroprudential tools more consistently with their communications and, after conditions deteriorate, transmit a calmer message, suggesting that the ability to use macroprudential tools strengthens incentives not to just "cry wolf."

JEL Codes: G15, G28.

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## 1. Introduction

After the global financial crisis of 2008 to 2009, many countries took steps to prevent the buildup of vulnerabilities and enhance the resilience of their financial systems. Among these steps, countries strengthened their macroprudential regulatory frameworks. Many central banks also obtained a more explicit financial stability mandate and incorporated financial stability objectives in their decisionmaking process (see also Jeanneau 2014). With these changes, financial stability monitoring has become an even more important task for central banks.

Communications about financial stability have also become a tool to influence financial agents' behavior (see, for instance, Born, Ehrmann, and Fratzscher 2014). Although the literature on monetary policy communications is large (see, for instance, Blinder et al. 2008; Ericsson 2016; and Stekler and Symington 2016), central banks' financial stability communications have garnered less research attention.[1] Specifically, the drivers and the effects of financial stability communications, including how such communications interact with financial stability governance frameworks, have largely remained unexplored in the literature.

In this paper, we study how differences in financial stability governance frameworks across countries relate to central banks' financial stability communication strategies and the relative effectiveness of these communications in preventing a deterioration in financial vulnerabilities. To understand how governance frameworks might interact with central banks' communication strategies, we start with proposing a set of testable hypotheses. Our first hypothesis refers to how the relation between financial stability communications and the evolution of the financial cycle might depend on each country's financial stability governance framework, based on the notion that this framework may influence both the willingness to be transparent about the assessment of the state of vulnerabilities and how the central bank communicates about vulnerabilities. The second hypothesis explores how different communication strategies might

[1] Arseneau (2020) explores how central bank communications related to financial stability may be associated with the financial cycle from a theoretical perspective.

explain differences in the effectiveness of financial stability communications across central banks conditional on their financial stability governance frameworks. Variations in communication strategies should show up in how the sentiment in central bank communications differs from that conveyed in news articles, which should not contain any strategic goals, and should relate to the central bank's ability to use other policy tools, including macroprudential tools and monetary policy rates.

To empirically test these hypotheses, we merge three databases. The first one details the macroprudential governance frameworks of 24 countries (see Correa, Edge, and Liang 2019 and Edge and Liang 2017). We focus our attention on whether the central bank participates or not in an interagency financial stability committee. The second database uses text analysis techniques to determine the sentiment conveyed by communications used by central banks to transmit their assessment of financial vulnerabilities. In particular, we extend the database of financial stability sentiment (FSS) indices constructed from financial stability reports (FSRs) by Correa et al. (2021) (CGLM hereafter). We also calculate a sentiment index using news articles related to financial stability, which we name NS. The third database includes a set of country-specific measures of financial vulnerabilities, where we center our attention on the credit-to-GDP gap.

We use panel-data and probit models to assess how cross-country differences in macroprudential governance frameworks affect central banks' communication strategies. We exploit the cross-country heterogeneity to investigate how the FSS conveyed by central banks' communications affects the evolution of financial cycle characteristics, depending on three governance characteristics: (i) whether the central bank participates in an interagency financial stability committee, either de facto or de jure; (ii) whether the committee exists de jure—that is, implemented through a formal legal arrangement; and (iii) whether the committee has the power to implement policy tools, including macroprudential instruments.

In our first set of empirical tests, we explore whether a country's governance framework matters for the effectiveness of central banks' financial stability communications. We find that the communication of those central banks participating in interagency financial stability committees is relatively more effective in limiting a deterioration of financial cycle characteristics than communications of other central banks. We also explore whether the effect of central banks' communications varies by governance characteristics around turning points in the financial cycle, where turning points are defined as local credit-to-GDP maximums followed by a decrease in the credit-to-GDP gap over at least the next four quarters. Our evidence suggests that central banks participating in interagency committees are more effective in limiting a buildup of financial vulnerabilities through communications irrespective of whether we consider episodes around turning points in the financial cycle or not.

We next use a probit model to assess whether the predictive power of the FSS index for financial cycle turning points depends on the macroprudential governance framework. We find that for central banks *not* participating in financial stability committees, a deterioration in the communicated sentiment helps predict financial cycle turning points—a 1 percent increase in the FSS index (that is, a deterioration in sentiment) of these central banks is associated with a 0.21 to 0.26 percent higher probability of a turning point. In other words, those central banks often "cry wolf" and the "wolf actually comes." However, communication by central banks participating in a committee with the ability to implement macroprudential tools is effective in reducing the probability of a turning point in the financial cycle. Thus, these central banks signal financial stability risks and act in accordance, which then reduces the likelihood of financial stresses.

In the second set of empirical tests, we investigate the drivers of the relative effectiveness of communications by exploring whether governance frameworks matter for how central banks incorporate information in their financial stability communications. Our second hypothesis suggests that some central banks could strategically deviate from the publicly available information (that should have no strategic bias) when communicating through FSRs. We test for this by exploring the dynamic relation between the sentiment in financial stability reports and that in news articles (FSS and NS, respectively).

We find that after a deterioration in the sentiment conveyed by news articles, central banks participating in financial stability committees transmit a calmer message in their FSRs than central banks not participating in such committees—that is, even as public information signals a deterioration in financial conditions, a central bank participating in a financial stability committee transmits a calmer message than central banks without this characteristic.

These findings suggest that a central bank having at its disposal policy instruments to influence the financial cycle, or being able to make other agencies use such policy instruments, acts differently. To explore this possibility further, we assess whether the FSS index is associated with either changes in macroprudential instruments (Cerutti et al. 2016) or the monetary policy rate. We expect the communication of a central bank that can influence, directly or indirectly, macroprudential actions to be positively correlated with such actions. Consistent with this intuition, we find that a deterioration in sentiment conveyed by central banks participating in interagency financial stability committees with authority for macroprudential or related policy instruments is followed by a tightening of these instruments. In contrast, we find that the sentiment in FSRs is not related to monetary policy rates, which is a blunter tool to address financial stability concerns.

In terms of the literature, our paper combines two strands: that focusing on financial stability governance frameworks and that focusing on central bank communications. The literature on central banks' financial stability governance frameworks and the implementation of macroprudential policies has gained much interest after the global financial crisis (see Edge and Liang 2017, Masciandaro and Volpicella 2016, and papers cited therein). The literature on central banks' communication strategies and their interactions with central banks' characteristics has focused mostly on communicating monetary policy and the role of transparency (see, for instance, Blinder et al. 2008; Cukierman 2009; Ehrmann and Fratzscher; and Morris and Shin 2002). Some recent studies have explored aspects of the sentiment conveyed in monetary policy communications, including how communications can spill over across countries (Armelius et al. 2018). We contribute to this literature by showing that governance frameworks shape financial stability communication strategies and their effectiveness to alleviate a deterioration in financial cycle conditions.

The literature on financial stability communications is still developing. To date, it has been mostly descriptive (see, for instance, Allen, Francke, and Swinburne 2004; Cihak 2006; and Cihak et al. 2012), and only a few papers have explored the effect of financial stability communications on financial cycle characteristics. Osterloo, de Haan, and Jong-A-Pin (2011) explore the effect of the publication of FSRs on a number of business and financial cycle characteristics, while Harris et al. (2019) analyze the effects of the Bank of England's FSR publication on stock returns and credit default swaps (CDS) spreads. Born, Ehrmann, and Fratzscher (2014) and CGLM use text analysis techniques to proxy the sentiment conveyed by central banks' financial stability communications and to investigate the effect of sentiment on financial cycle characteristics.[2] CGLM show that their FSS index is a useful predictor of banking crises, as sentiment deteriorates just prior to the start of a crisis.[3] At the same time, this evidence suggests that financial stability communication alone is insufficient to avoid a deterioration in financial vulnerabilities. Our evidence, however, suggests that financial stability communication can be more powerful in preventing financial crises for those countries with robust central bank governance frameworks.

Our work can also help explain why central banks without a direct macroprudential role rely more on communication to transmit concerns about financial stability, as they may signal to other agencies the need to act when financial vulnerabilities increase. Our empirical evidence also suggests that those central banks with direct or indirect control over macroprudential instruments might transmit a calmer message that conveys the system's resilience following an adverse shock.

The rest of the paper is organized as follows. Section 2 provides the intuition for the interaction between governance frameworks and central banks' communication strategies and outlines our hypotheses. Section 3 provides our data sources and presents the empirical evidence regarding the role of governance frameworks in explaining the effectiveness of central banks' financial stability communications. Section 4 explores differences in communication strategies, including

[2]Born, Ehrmann, and Fratzscher (2014) use Diction, a general-purpose text analysis dictionary, to extract the sentiment conveyed by these communications. CGLM construct a dictionary tailored to the financial stability context, as they find that a large portion of words in FSRs convey a different sentiment when used in a financial stability context.

[3]Other studies also use textual information to complement other indicators in models designed as early warning systems. For example, Huang et al. (2019) use the text from the *Financial Times* in a model to predict financial crises.

the deviation from the sentiment in news articles and the implementation of macroprudential and monetary policy tools. Section 5 concludes.

## 2. Understanding Central Banks' Communication Strategies

Central bank financial stability communications have evolved in recent years, in part driven by a desire to make central banks' views in this area more transparent, with the aim of increasing the resilience of the financial system (Arseneau 2020). However, as noted by Cihak (2006), financial stability communication has several limitations, particularly when compared to monetary policy communication. For example, communications about financial stability may actually trigger stresses in the financial system if market participants already have concerns about the fragility of the sector. Also, and in contrast to monetary policy communications, to achieve financial stability goals, central banks need to interact with other agencies that have microprudential and supervisory powers or are in charge of deploying macroprudential tools. These interactions may also shape their communications. These and other dimensions of financial stability communications make it important to assess empirically whether the sentiment conveyed in these communications relates to the general financial stability governance framework of countries and, specifically, to the governance of prudential instruments. This section discusses these issues to motivate the hypotheses tested empirically in Sections 3 and 4.[4]

As modeled in Arseneau (2020), central banks are typically assumed to have more information than the public about the state of vulnerabilities in the financial sector, as they might have some private information. For example, central banks that have supervisory powers can obtain private information about the financial institutions they supervise. Having more information generates a strategic decision for central banks: They can be completely transparent about vulnerabilities as they see them; or they can withhold

[4]Section A.1 of the appendix provides a stylized conceptual framework that further motivates the discussion in this section.

(or alter) information depending on the potential effects of revealing that information. We therefore pose that each country's financial stability governance framework, including the degree to which central banks can use other tools to manage financial vulnerabilities, may determine their communication strategies and the effectiveness of communications in the evolution of those vulnerabilities.

Our first hypothesis centers around the effectiveness of financial stability communications. As noted in Correa et al. (2021), the sentiment conveyed in financial stability communications is associated with various financial cycle indicators, suggesting that financial stability communications may influence the path of the financial cycle. The effect of those communications may also depend on the financial governance structure in a given country. Governance frameworks may influence both the willingness to be transparent about the central bank's assessment of the state of vulnerabilities and the way that the central bank communicates about them. These conjectures lead us to the first hypothesis that we will test empirically:

HYPOTHESIS 1. *Financial stability governance frameworks influence the effect of central bank financial stability communications on the evolution of the financial cycle.*

The differential effects of financial stability communications may also arise because communication strategies differ depending on each country's financial stability governance framework. Therefore, we conjecture the following second general hypothesis:

HYPOTHESIS 2. *Financial stability governance frameworks and the availability and use of policy instruments influence central bank communication strategies.*

We next propose three specific testable hypotheses as to how differences in communication strategies relate to financial stability governance frameworks and the use of policy instruments. First, financial stability governance may influence how a central bank communicates, because some governance frameworks lead a central bank to withhold some information strategically in its communications. In this case, we should observe a divergence between the financial stability sentiment conveyed in communications that are publicly available and have no strategic bias, such as news articles, and the sentiment conveyed by the central bank in its FSRs. The first hypothesis related to communication strategies is therefore the following:

HYPOTHESIS 2a. *Financial stability governance frameworks affect the sentiment conveyed in central bank communications relative to the sentiment conveyed in news articles.*

A divergence between the sentiment in FSRs and that in news articles could, of course, be explained by the central bank's strategic decision to withhold private information (conditional on the central bank having access to this information) or by the central bank's ability to use (or support the use of) other policy instruments, such as macroprudential tools and the monetary policy rate. Macroprudential instruments have been found to mitigate vulnerabilities associated with financial crises and reduce the risks of related economic recessions (see Claessens 2015 for a review). The deployment of macroprudential tools is, in many cases, left to relevant agencies' discretion, with some ex ante consulting and ex post reporting requirements.[5] As such, both the deployment of macroprudential tools and communication on financial stability would depend on governance arrangements (Committee on the Global Financial System 2016; Masciandaro and Volpicella 2016). We expect central banks that have control over macroprudential tools (or can influence other agencies that control such instruments) to be more likely to use them as their financial stability communications become more negative. This would amount to coherent communication. At the same time, substitution is possible too. For example, sentiment communicated through FSRs could become more negative in situations where macroprudential policies reach their limits (for practical, statuary, or political economy reasons). This intuition leads to our second testable hypothesis related to communication strategies.

HYPOTHESIS 2b. *Central banks that have direct or indirect (e.g., through a financial stability committee) control over macroprudential*

[5]There are only international guidelines for the activation of the countercyclical capital buffer and the use of surcharge for systemic banks, and even these guidelines still give ample room for discretion.

*tools are more coherent and use such tools more when the sentiment in their communications deteriorates.*

Central banks are (foremost) monetary policy decisionmakers. There is a large debate on the role of monetary policy in financial stability, with some arguing in favor of a policy of systemically "leaning against the wind" (Borio, Disyatat, and Rungcharoenkitkul 2019), while others argue this is too costly (Svensson 2017). Related to this debate is the interaction between monetary and macroprudential policy in mitigating financial stability risks. On the one hand, if the central bank has macroprudential policies at its disposal (directly or indirectly) and these are largely effective, then it may reserve monetary policy for addressing inflation or economic activity and employment goals. On the other hand, in the presence of constraints on either (or both) macroprudential or monetary policy, both policies may need to be employed in the pursuit of financial stability (International Monetary Fund 2013). In turn, this means that the relation between financial stability communications and monetary policy is ambiguously shaped by macroprudential governance arrangements. If the central bank also has macroprudential tools at its disposal, it could use those tools when it communicates a change in its financial stability sentiment and, at the same time, choose not to change its monetary policy. Alternatively, it could use its monetary policy tools to internalize any constraints it faces on the use of macroprudential instruments. Given this ambiguity, whether central banks' use of monetary policy to curtail financial vulnerabilities varies by governance framework becomes an empirical question, which we test in a third hypothesis related to communication strategies.

HYPOTHESIS 2c. *Central banks use monetary policy to curtail a deterioration in financial vulnerabilities if they have limited direct or indirect access to macroprudential instruments.*

## 3. The Effectiveness of Financial Stability Communications

In this section, we test the first hypothesis introduced in Section 2 and explore whether the effectiveness of central banks' communications depends on countries' financial stability governance frameworks. We first introduce the data and then assess which features make communication strategies relatively more (or less) effective in alleviating the deterioration of financial cycle characteristics and the risks of turning points in the cycle.

### *3.1 Data*

We use a panel data set consisting of quarterly data for 24 countries for the sample period between 2005 and 2019.[6] Our data set consists of three types of data: (i) an index of sentiment from FSRs (FSS index), (ii) a set of characteristics related to countries' financial stability governance frameworks, and (iii) a set of financial cycle indicators.

**Financial Stability Sentiment.** For each country, we characterize central banks' financial stability communications using the FSS index as developed in CGLM. For each FSR, the FSS index is calculated as follows:

$$FSS\ index_{country,period} = \frac{\#Negative\ words - \#Positive\ words}{\#Total\ words}, \tag{1}$$

where the negative (or positive) connotation of words is obtained from the financial stability dictionary proposed by CGLM.[7] Although many central banks currently publish FSRs, we restrict our sample to those central banks that have published at least one FSR annually since 2005. As pointed out by CGLM, working with this reduced sample has two main advantages. First, it allows us to compare the indices for a homogeneous period. Second, it increases the reliability of the empirical tests because most countries excluded from our sample began publishing FSRs only around the global financial crisis. Because FSRs are published at a biannual or annual frequency, we assume a step function to interpolate between any two dates when reports are available.

Panel A of Figure 1 shows the time series for the cross-country average of the FSS indices demeaned at the country level. We use

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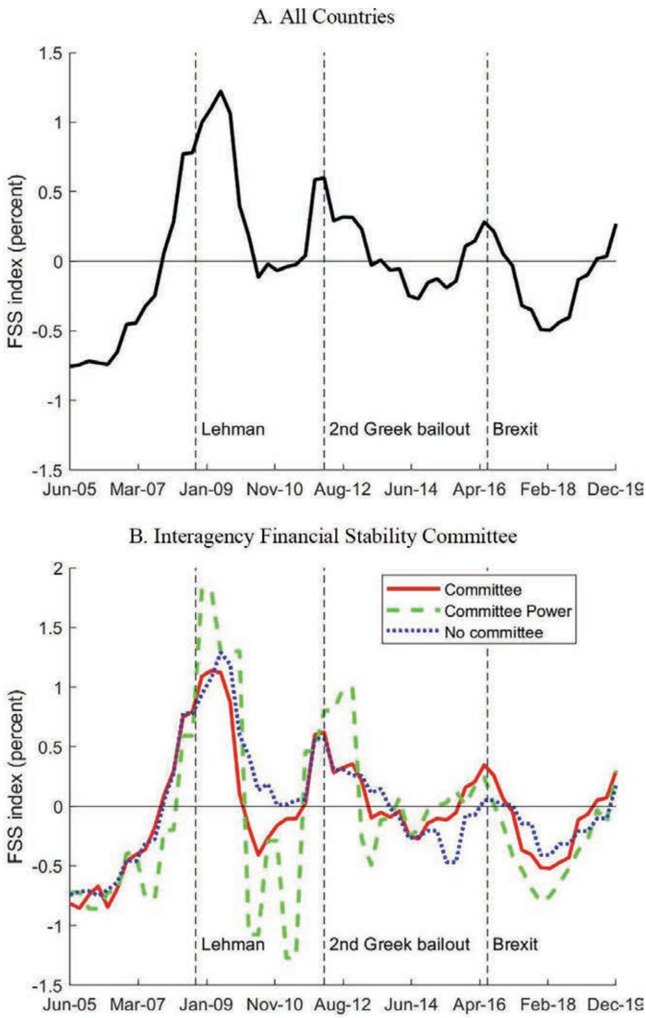
[6]We use information for individual countries within the euro area (instead of using communications from the European Central Bank), as the authority to use macroprudential instruments is mostly available at the national level.

[7]The dictionary created by Correa et al. (2017) can be found at Juan M. Londono's website: https://juanmlondono.wordpress.com/.

**Figure 1. Financial Stability Sentiment Indices: Averages across Countries**




**Note:** Panel A shows the equally weighted average of all countries' demeaned financial stability sentiment (FSS) indices. Panel B shows the average across all countries for which the central bank participates (red solid line), in a committee with powers (dashed green line), or does not participate (dotted blue line) in an interagency financial stability committee. For reference, we add vertical lines for the following key dates (quarterly equivalent): the collapse of Lehman Brothers (marked as October 2008), the second Greek bailout (marked as March 2012), and the Brexit referendum (marked as July 2016).

demeaned FSS indices to control for systematic differences across countries. Table 1 shows a set of summary statistics for the FSS indices. As shown in Figure 1, the average FSS increases (that is, sentiment deteriorates) during several key episodes, such as the failure of Lehman Brothers in September of 2008, the approval of the second EU-IMF bailout for Greece in the first quarter of 2012, and the Brexit referendum in the summer of 2016. Around these episodes, FSS reached historical maximums for most countries in our sample, as shown in Table 1.

**Governance Frameworks.** Table 2 summarizes the governance framework characteristics for the central banks in our sample as of December 2019. We center our attention on those characteristics related to participating in a financial stability interagency committee, as reported in the financial stability governance framework database of Correa, Edge, and Liang (2019). For each entry, we add a time dimension to capture changes in the status of a country's governance framework. These not mutually exclusive characteristics are whether (i) the central bank participates in an interagency financial stability committee; (ii) the committee is official ("de jure"), and (iii) the committee has the power to implement policy tools, including macroprudential tools. The table also includes the date(s) for whenever changes in each characteristic occurred within the sample period (in most cases, from not having a particular characteristic, "N", to having it, "Y").

Panel B of Figure 1 shows the time series of three cross-country average FSS indices: for those central banks that participate in a financial stability committee; for those where that committee has powers; and for those countries where the central bank does not participate in a committee. This panel provides some intuition for the way communication strategies and the effectiveness of communication could vary across central banks depending on governance frameworks. Although the three FSS indices—for central banks participating in committees, in committees with powers, and not participating in committees—are highly correlated, there are differences in the levels and dynamics of the indices, especially in episodes of high uncertainty. Notably, the FSS index for central banks participating in committees with powers increases much more around the collapse of Lehman Brothers in 2008 and during the euro area crises in 2012. This index is also more volatile, in part due to the fact that

**Table 1. Financial Stability Sentiment Index: Summary Statistics**

| Country | Mean | St. Dev. | Minimum | Date Minimum | Maximum | Date Maximum |
|---|---|---|---|---|---|---|
| Argentina | −0.24 | 0.70 | −1.55 | 2005:Q2 | 1.16 | 2009:Q2 |
| Australia | 1.34 | 0.64 | 0.13 | 2006:Q1 | 2.70 | 2019:Q4 |
| Austria | 0.59 | 0.74 | −1.00 | 2018:Q4 | 2.18 | 2009:Q2 |
| Belgium | 0.93 | 0.53 | 0.10 | 2005:Q2 | 2.13 | 2009:Q2 |
| Canada | 2.18 | 0.97 | 0.35 | 2017:Q4 | 3.81 | 2008:Q4 |
| Chile | 0.75 | 0.66 | −1.29 | 2005:Q1 | 2.19 | 2007:Q4 |
| Czech Republic | 1.19 | 0.61 | 0.42 | 2006:Q2 | 2.49 | 2009:Q2 |
| Demark | 1.19 | 1.11 | 0.02 | 2017:Q2 | 4.43 | 2008:Q4 |
| Germany | 1.57 | 0.61 | 0.43 | 2005:Q1 | 2.73 | 2018:Q4 |
| Hong Kong | 0.63 | 0.89 | −0.87 | 2017:Q3 | 2.45 | 2008:Q4 |
| Hungary | 1.31 | 0.78 | 0.22 | 2005:Q2 | 2.92 | 2011:Q4 |
| Indonesia | 0.28 | 0.73 | −1.45 | 2010:Q3 | 1.83 | 2009:Q1 |
| Netherlands | 1.97 | 0.84 | 0.37 | 2017:Q4 | 3.93 | 2009:Q2 |
| New Zealand | 1.18 | 0.74 | −0.06 | 2010:Q2 | 3.04 | 2008:Q4 |
| Norway | 1.48 | 0.92 | −0.28 | 2005:Q1 | 2.53 | 2014:Q4 |
| Poland | 0.83 | 0.50 | −0.05 | 2006:Q2 | 1.85 | 2009:Q2 |
| Portugal | 0.80 | 0.69 | −0.03 | 2018:Q2 | 2.47 | 2009:Q2 |
| Singapore | 1.14 | 1.05 | −0.48 | 2006:Q2 | 3.56 | 2008:Q4 |
| South Africa | 2.07 | 0.71 | 0.94 | 2018:Q2 | 4.07 | 2009:Q1 |
| Spain | 0.79 | 0.96 | −1.08 | 2006:Q2 | 2.55 | 2011:Q4 |
| Sweden | 1.46 | 0.64 | 0.59 | 2005:Q1 | 3.08 | 2008:Q4 |
| Switzerland | 1.54 | 0.98 | −0.09 | 2006:Q2 | 3.53 | 2009:Q2 |
| Turkey | 0.34 | 0.66 | −0.96 | 2017:Q2 | 1.63 | 2011:Q4 |
| United Kingdom | 1.87 | 0.70 | 0.89 | 2014:Q2 | 3.45 | 2008:Q2 |

**Note:** This table shows a set of summary statistics (mean; standard deviation, abbreviated as St. Dev.; minimum; and maximum) for the financial stability sentiment (FSS) indices of the 24 countries in our sample. We also report the minimum and maximum dates when the FSS index takes on its lowest and highest values, respectively.

## Table 2. Financial Stability Governance Frameworks

| Country | Committee (Yes/No/De Facto) | Date | Committee with Powers | Date |
|---|---|---|---|---|
| Argentina | N | | NA | |
| Australia | Y | | N | |
| Austria | Y | 08-Sep-14 | Y | 08-Sep-14 |
| Belgium | N | 31-Jul-10 | N | |
| Canada | D | | N | |
| Chile | Y | 31-Jul-11 | N | |
| Czech Republic | N | | NA | |
| Denmark | Y | 28-Feb-13 | N | |
| Germany | Y | 31-Jan-13 | N | |
| Hong Kong | Y | | Y | |
| Hungary | N[1] | 16-Sep-13 | N | |
| Indonesia | Y[2] | 30-Dec-05 | N | |
| Netherlands | Y | 30-Nov-12 | N | |
| New Zealand | N | | NA | |
| Norway | Y | 01-Jan-06 | N | |
| Poland | Y[3] | 01-Oct-08 | Y | 01-Nov-15 |
| Portugal | N | | NA | |
| Singapore | N | | NA | |
| South Africa | D | 01-Jun-13 | N | |
| Spain | Y | 27-Feb-06 | N | |
| Sweden | Y[4] | 19-Dec-13 | N | |
| Switzerland | D | 23-Feb-10 | N | |
| Turkey | Y | 08-Jun-11 | N | |
| United Kingdom | D[5] | 28-Feb-11 | Y | 19-Dec-12 |

[1]De facto committee between 01/01/2010 and 09/16/2013. [2]Committee was de facto between 12/30/2005 and 11/30/2011. [3]Committee was de facto between 12/01/2008 and 11/01/2015. [4]Committee was de facto between 01/01/2012 and 09/01/2013. [5]Committee was de facto between 02/28/2011 and 12/19/2012.

**Note:** This table summarizes the financial stability governance frameworks for the central banks of the countries in our sample as of December 2019. "Y" ("N", respectively) denotes that the central bank of that country has (does not have, respectively) a particular governance characteristic. For central banks participating in an interagency financial stability committee, we specify whether this committee is official or established "de facto" ("D") through less formal memorandums of understanding. We also report the dates when changes to these frameworks have occurred within our sample period (in most cases, from not having a particular characteristic to having it). A more detailed description of this database can be found in Correa, Edge, and Liang (2019).

only four central banks in our sample participate in committees with powers.

**Financial Conditions.** We use the credit-to-GDP gap as the benchmark measure for the evolution of the financial cycle. This gap is calculated as the deviation of the credit-to-GDP ratio from its long-run trend and is expressed in percentages (Borio 2014). To assess the robustness of the effectiveness of financial stability communications, we use two other variables related to credit, namely the 12-quarter growth in credit to the non-financial private sector to GDP ratio and the debt-service ratio, where the latter is calculated as the ratio of interest payments plus amortizations to income for private non-financial borrowers. These variables are obtained from the Bank for International Settlements (BIS).

Table 3 shows a set of summary statistics for the credit-to-GDP gap in each country. There is substantial heterogeneity in the mean credit-to-GDP gap for the countries in our sample (by construction, the average gap is zero for large samples). The mean gap ranges from –9.90 (the United Kingdom) to 20.19 (Hong Kong). Standard deviations in the gap range from 4.0 (Austria) to 14.8 (Hong Kong). To characterize turning points in the financial cycle, we construct a dummy that takes the value of 1 whenever there is a local maximum in the credit-to-GDP gap followed by a decline in the gap over at least the next four quarters and zero otherwise. We use this definition of turning points in the financial cycle because our sample is relatively short and includes very few financial crises (as defined by Laeven and Valencia 2013, for instance). In our sample (60 quarters in total), there are no credit-to-GDP gap turning points in Germany but nine in both Hong Kong and Singapore, the most in the sample. We show the dates when turning points occurred for all countries in our sample. Many of these correspond to the key dates where FSS reaches maximum levels (as shown in Table 1).

### *3.2 Financial Stability Communications and the Evolution of the Financial Cycle*

Motivated by the hypotheses outlined in Section 2, we first test how financial stability governance frameworks affect the relation between

**Table 3. Credit-to-GDP Gap: Summary Statistics**

| Country | Mean | St. Dev. | Turning Points | Dates of Turning Points |
|---|---|---|---|---|
| Argentina | −3.49 | 6.27 | 2 | 2014:Q1, 2018:Q3 |
| Australia | −0.83 | 11.37 | 2 | 2007:Q3, 2016:Q2 |
| Austria | −4.27 | 4.04 | 2 | 2006:Q3, 2010:Q2 |
| Belgium | 1.28 | 10.08 | 4 | 2009:Q3, 2012:Q2, 2013:Q2, 2016:Q2 |
| Canada | 5.59 | 6.22 | 5 | 2009:Q4, 2011:Q3, 2013:Q2, 2016:Q3, 2018:Q2 |
| Chile | 0.19 | 10.32 | 3 | 2009:Q1, 2009:Q3, 2015:Q3 |
| Czech Republic | 9.60 | 7.22 | 5 | 2009:Q4, 2011:Q2, 2013:Q4, 2016:Q3, 2018:Q3 |
| Denmark | 2.28 | 24.43 | 4 | 2007:Q4, 2009:Q3, 2011:Q3, 2012:Q1 |
| Germany | −7.05 | 4.69 | 0 | |
| Hong Kong | 20.19 | 14.80 | 9 | 2005:Q2, 2007:Q3, 2008:Q3, 2011:Q2, 2012:Q1, 2014:Q2, 2015:Q1, 2017:Q2, 2017:Q4 |
| Hungary | 0.67 | 23.42 | 4 | 2006:Q2, 2009:Q1, 2010:Q2, 2011:Q3 |
| Indonesia | 3.13 | 7.68 | 7 | 2013:Q4, 2014:Q2, 2014:Q4, 2015:Q2, 2016:Q4, 2017:Q4, 2018:Q3 |
| Netherlands | −3.24 | 11.56 | 3 | 2005:Q2, 2012:Q2, 2015:Q1 |
| New Zealand | −7.96 | 13.69 | 2 | 2007:Q2, 2009:Q1 |
| Norway | 7.39 | 11.53 | 5 | 2005:Q4, 2009:Q2, 2010:Q2, 2012:Q1, 2016:Q3 |
| Poland | 0.42 | 5.97 | 6 | 2009:Q1, 2010:Q2, 2011:Q3, 2013:Q2, 2014:Q2, 2015:Q2 |
| Portugal | −7.35 | 26.92 | 4 | 2005:Q2, 2009:Q2, 2010:Q4, 2012:Q4 |
| Singapore | 3.55 | 12.41 | 9 | 2008:Q4, 2009:Q3, 2014:Q3, 2015:Q2, 2015:Q4, 2016:Q2, 2017:Q2, 2017:Q4, 2018:Q2 |
| South Africa | 1.01 | 5.45 | 2 | 2008:Q1, 2016:Q1 |
| Spain | −7.84 | 36.58 | 1 | 2007:Q2 |
| Sweden | 8.66 | 13.36 | 6 | 2009:Q3, 2012:Q1, 2012:Q3, 2013:Q2, 2014:Q1, 2015:Q1 |
| Switzerland | 5.46 | 7.46 | 4 | 2010:Q1, 2012:Q4, 2013:Q4, 2018:Q1 |
| Turkey | 8.43 | 5.09 | 7 | 2006:Q2, 2008:Q2, 2011:Q2, 2013:Q3, 2015:Q3, 2016:Q4, 2018:Q3 |
| United Kingdom | −9.90 | 14.02 | 4 | 2006:Q3, 2008:Q4, 2009:Q3, 2010:Q1 |

**Note:** This table reports a set of summary statistics for the credit-to-GDP gap, our benchmark financial cycle indicator, for the sample period from January 2005 to December 2019. We also report the number of turning points in the credit-to-GDP gap, which are defined as local maximums followed by a decrease in the gap over at least the next four quarters. The last column reports the dates (year and quarter) in which these turning points occur for each country.

central banks' communications and the evolution of the financial cycle, Hypothesis 1. In particular, we investigate how countries' financial stability governance characteristics influence the association between the FSS index and the (four-quarters-ahead) evolution of the selected financial cycle indicators using the following panel-data regression:

$$FC_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4})FSS_{i,t} + \beta_3 D_{i,t-4} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+h}, \tag{2}$$

where $FC_t$ is the credit-to-GDP gap, our benchmark financial cycle characteristic; $D_{i,t}$ is a dummy that takes the value of 1 when the country's central bank has one of the three characteristics in the governance framework database (see table 2) and zero otherwise; $FSS_t$ is the financial stability sentiment index; and $\mathbf{C_{i,t}}$ is a vector that includes the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. The dummy for the specific governance characteristic is lagged by one year to control for potential endogeneity between $FSS_t$ and $D_t$ (although, as noted, the time variation is limited for these characteristics).[8]

Table 4 presents the evidence as to the role of each of the three governance characteristics in explaining the differential effects of financial stability communication on the four-quarters-ahead credit-to-GDP gap. In all estimations, we use country fixed effects to account for other time-invariant country characteristics unrelated to governance and Huber-White standard errors.[9] For the purpose of brevity, we only show estimates of the coefficients associated with FSS.

The result in column 1 shows that the relation of the FSS index with the four-quarters-ahead credit-to-GDP gap is not statistically significant when we do not consider governance characteristics. The

[8]In Section 4.2, we control for policy actions in the regression setting in Equation (2).

[9]Clustering at the country level is not feasible, given the small number of countries in the sample.

**Table 4. Financial Stability Governance Frameworks and How Financial Stability Communications Relate to Financial Cycle Indicators**

| | Homogeneous (1) | Committee (2) | Official Committee (3) | Committee with Powers (4) |
|---|---|---|---|---|
| FSS ($\beta_1$) | 1.82 | 2.98 | 2.82 | 2.44 |
| | (1.80) | (2.02) | (1.62) | (1.78) |
| D*FSS ($\beta_2$) | | –2.03 | –3.68* | –4.40** |
| | | (1.60) | (1.39) | (1.45) |
| $R^2$ | 0.21 | 0.22 | 0.23 | 0.21 |
| N | 1,192 | 1,128 | 1,128 | 1,128 |

**Note:** This table reports the results for the following panel-data regression:

$$FC_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4})\, FSS_{i,t} + \beta_3 D_{i,t-4} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4},$$

where $FC_{i,t}$ is the credit-to-GDP gap and $D_{i,t}$ is a dummy that takes the value of 1 when the country has one of the characteristics in the financial stability governance framework database and zero otherwise, and is lagged by one year to control for endogeneity with $FSS_{i,t}$, the financial stability sentiment index calculated using the text in financial stability reports. $\mathbf{C_{i,t}}$ includes the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. In all estimations, we consider country fixed effects to account for other time-invariant country characteristics not related to governance. For the purpose of brevity, we only report estimates of the coefficients associated with FSS ($\beta_1$ and $\beta_2$).

specifications presented in the following columns, however, suggest material differences across governance characteristics. Specifically, financial stability communication by central banks participating in (interagency) committees is relatively more effective in limiting increases in the credit-to-GDP gap, as the coefficients associated with the interactions between these governance indicator variables and the FSS index, $\beta_2$, are negative. Interestingly, the coefficient associated with the interaction between FSS and the committee dummy is not significant if we consider both de jure and de facto committees (column 2). However, when we consider only official committees (column 3), $\beta_2$ becomes statistically significant, and its estimate becomes even more negative when we consider central banks participating in committees with powers (column 4).[10]

Table 5 assesses the robustness of our main results for the interaction between FSS and financial stability governance frameworks when we consider two alternative financial cycle measures. These alternative indicators are the 12-quarters growth rate in credit to the non-financial private sector (panel A) and the debt-service ratio (panel B). Our results for the negative coefficient associated with the interaction between FSS and the dummy for central banks participating in a financial stability committee with powers remain robust for these alternative financial cycle characteristics.

As an additional robustness check, Table 6 explores whether other country-specific characteristics unrelated to financial stability governance, but arguably proxying for the overall quality of a country's financial governance, can explain the differential effects of financial stability communication on financial cycle variables. In particular, we test for the relevance of the following institutional and banking system characteristics (in addition to the effect of participating in a financial stability committee with powers): the transparency index of Dincer and Eichengreen (2014), the central bank independence index of Garriga (2016), the financial openness index of Chinn and Ito (2006), the foreign bank ownership share of Claessens and van Horen (2014), and the ratio of total international banking claims to local bank claims obtained from the BIS. The results show that the coefficients associated with the interaction between all these additional variables and the FSS index, $\beta_3$, are not statistically significant at any standard confidence level. Importantly, the differential effect of participating in a committee with powers, $\beta_2$, remains negative and significant in all cases.[11] Overall, our results lead us to not reject Hypothesis 1 and suggest that

[10]There are only a handful of countries in which the central bank participates in a committee with powers, including Hong Kong, which is a financial center. In unreported results, which are available upon request, we show that our results remain robust when we exclude Hong Kong from the sample.

[11]Because there are only a few countries that have committees with powers, in Table A.1 in the appendix we confirm that these results remain robust if we use the indicator variable for official committees as the financial stability governance characteristic.

## Table 5. Financial Stability Governance Frameworks and How Financial Stability Communications Relate to Financial Cycle Indicators: Alternative Financial Cycle Indicators

| | Homogeneous (1) | Committee (2) | Official Committee (3) | Committee with Powers (4) |
|---|---|---|---|---|
| *A. Credit Growth* | | | | |
| FSS ($\beta_1$) | 1.5 | 1.3 | 1.52 | 1.78 |
| | (1.01) | (1.23) | (1.04) | (0.95) |
| D*FSS ($\beta_2$) | | –0.02 | –1.06 | –4.01*** |
| | | (2.01) | (2.34) | (0.99) |
| $R^2$ | 0.16 | 0.18 | 0.16 | 0.15 |
| N | 1,192 | 1,128 | 1,128 | 1,128 |
| *B. Debt-Service Ratio* | | | | |
| FSS ($\beta_1$) | 0.18 | 0.49 | 0.43 | 0.06 |
| | (0.33) | (0.42) | (0.32) | (0.35) |
| D*FSS ($\beta_2$) | | –0.73 | –1.35 | –1.00*** |
| | | (0.75) | (1.06) | (0.18) |
| $R^2$ | 0.06 | 0.07 | 0.10 | 0.07 |
| N | 877 | 831 | 831 | 831 |

**Note:** This table reports the results for the following panel-data regression:

$$FC_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4})\, FSS_{i,t} + \beta_3 D_{i,t-4} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4},$$

where $FC_{i,t}$ is one of the following alternative financial cycle indicators: the 12-quarter credit growth (panel A) and the debt-service ratio (panel B). $D_{i,t}$ is a dummy that takes the value of 1 when the country has one of the characteristics in the financial stability governance framework database and zero otherwise, and is lagged by one year to control for endogeneity with $FSS_{i,t}$, the financial stability sentiment index calculated using the text in financial stability reports. $\mathbf{C_{i,t}}$ includes the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. In all estimations, we consider country fixed effects to account for other time-invariant country characteristics not related to governance. For the purpose of brevity, we only report estimates of the coefficients associated with FSS ($\beta_1$ and $\beta_2$).

**Table 6. Other Country Characteristics and How Financial Stability Communications Relate to Financial Cycle Indicators**

| | Transparency (1) | Independence (2) | Financial Openness (3) | Foreign Bank Ownership (4) | Bank International Claims (5) |
|---|---|---|---|---|---|
| FSS ($\beta_1$) | 5.66 | –3.26 | 1.32 | 2.15 | 3.02 |
| | (6.60) | (2.24) | (2.24) | (2.35) | (4.38) |
| D*FSS ($\beta_2$) | –5.83* | –9.99** | –8.11*** | –6.48** | –8.82** |
| | (2.09) | (3.42) | (1.66) | (1.91) | (2.61) |
| X*FSS ($\beta_3$) | –0.19 | 6.08 | 0.06 | 0.00 | –0.90 |
| | (0.55) | (2.95) | (0.04) | (0.00) | (6.34) |
| $R^2$ | 0.13 | 0.23 | 0.21 | 0.21 | 0.22 |
| N | 816 | 980 | 1,100 | 1,128 | 1,076 |

**Note:** This table reports the results for the following panel-data regression setting:

$$FC_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4} + \beta_3 X_{i,t-4})\, FSS_{i,t} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4},$$

where $FC_{i,t}$ is the credit-to-GDP gap and $D_{i,t}$ is a dummy that takes the value of 1 when the country's central bank participates in an interagency financial stability committee with powers and zero otherwise, and is lagged by one year to control for endogeneity with $FSS_{i,t}$, the financial stability sentiment index calculated using the text in financial stability reports. $X_{i,t}$ is one of the following country-specific characteristics: the transparency index in Dincer and Eichengreen (2014), the central bank independence index in Garriga (2016), the financial openness index in Chinn and Ito (2006), the foreign bank ownership (source: BIS), and the ratio of bank international claims (source: BIS). $\mathbf{C_{i,t}}$ includes the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. In all estimations, we consider country fixed effects to account for other time-invariant country characteristics not related to governance. Because most additional characteristics are very slow moving, in this specification we do not include the governance characteristics in levels to reduce the possibility of multicollinearity. For the purpose of brevity, we only report estimates of the coefficients associated with FSS ($\beta_1$, $\beta_2$, and $\beta_3$).

the differential effects of communication by various central banks reported in Table 4 are not driven by any other related and observable country-specific characteristics.

### *3.3 Financial Stability Communications around Turning Points in the Financial Cycle*

Having examined how financial stability governance frameworks affect the mapping between central banks' communications and the evolution of financial cycle indicators, we now investigate how communication strategies and their effectiveness may vary over time. Specifically, we seek to address the following questions: Do governance characteristics affect how financial stability communication changes around turning points in the financial cycle? And if so, does this change in communication make some central banks relatively more effective at preventing these turning points?

We first explore whether the patterns documented in Table 4 change around turning points in the financial cycle. To do so, we use the following panel-data estimation setting:

$$FC_{i,t+4} = \alpha + (\beta_1 + (\beta_2 + \beta_3 TP_{i,t-4})D_{i,t-4} + \beta_4 TP_{i,t-4})FSS_{i,t} + \beta_5 D_{i,t-4} + \beta_6 TP_{i,t-4} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4}, \quad (3)$$

where $TP_{i,t}$ is a dummy that takes the value of 1 when the credit-to-GDP gap turns and decreases over at least the next four quarters (see Table 3).

Table 7 summarizes the results for the relation between the FSS index and the credit-to-GDP gap around turning points. Most estimates of the coefficients associated with the additional effects around turning points, $\beta_3$ and $\beta_4$, are not statistically significant. Nevertheless, the main takeaway is that a deterioration in sentiment by central banks participating in committees, especially committees with powers, is followed by a relative improvement in the credit-to-GDP gap, and that this relationship holds around turning points in the credit-to-GDP gap, as shown by $\beta_2$ and $\beta_2 + \beta_3$, respectively.

To further investigate the effectiveness of central banks' communications around turning points in the financial cycle, we use the following probit specification:

**Table 7. Financial Stability Governance Frameworks and How Financial Stability Communications Relate to Financial Cycle Indicators Around Turning Points**

| | Homogeneous (1) | Committee (2) | Official Committee (3) | Committee with Powers (4) |
|---|---|---|---|---|
| FSS ($\beta_1$) | 1.82 | 2.81 | 2.60 | 2.26 |
| | (1.80) | (2.13) | (1.66) | (1.81) |
| D*FSS ($\beta_2$) | | –1.96 | –3.54* | –4.11** |
| | | (1.90) | (1.50) | (1.35) |
| D*TP*FSS ($\beta_3$) | | –2.65 | 0.78 | 0.55 |
| | | (1.43) | (1.11) | (1.09) |
| TP*FSS ($\beta_4$) | | 2.90* | 1.77 | 1.98 |
| | | (1.38) | (1.35) | (1.50) |
| $R^2$ | 0.21 | 0.23 | 0.23 | 0.21 |
| N | 1,192 | 1,128 | 1,128 | 1,128 |

**Note:** This table reports the results for the following panel-data regression:

$$FC_{i,t+4} = \alpha + \left(\beta_1 + (\beta_2 + \beta_3 TP_{i,t-4}\right) D_{i,t-4} + \beta_4 TP_{i,t-4})FSS_{i,t}$$
$$+ \beta_5 D_{i,t-4} + \beta_6 TP_{i,t-4} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4}.$$

where $FC_{i,t}$ is the credit-to-GDP gap, $D_{i,t}$ is a dummy that takes the value of 1 when the country's central bank has one of the characteristics in the governance framework database and zero otherwise, $TP_{i,t}$ is a dummy that takes the value of 1 when there is a turning point in the credit-to-GDP gap followed by a decrease in the gap over at least the next four quarters, and $FSS_{i,t}$ is the financial stability sentiment index calculated using the text in financial stability reports. $\mathbf{C_{i,t}}$ includes the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. In all estimations, we consider country fixed effects to account for other time-invariant country characteristics not related to governance. For the purpose of brevity, we only report estimates of the coefficients associated with FSS ($\beta_1$, $\beta_2$, $\beta_3$, and $\beta_4$).

$$Pr[TP_{i,t+4} = 1] = \Phi[X_{i,t}\beta], \tag{4}$$

where the vector $X_{i,t}$ contains the demeaned FSS index.

Table 8 summarizes the estimates of Equation (4). The results show that an increase in the financial stability sentiment conveyed by central banks *not* participating in committees is followed by a significantly higher probability of a turning point in the financial cycle. This evidence is consistent with the results reported in Tables 4

**Table 8. Financial Stability Governance Frameworks and the Heterogeneous Predictive Power of Financial Stability Communications for Turning Points in the Financial Cycle**

| | Committee | | Official Committee | | Committee with Powers | |
|---|---|---|---|---|---|---|
| | **Yes (1)** | **No (2)** | **Yes (3)** | **No (4)** | **Yes (5)** | **No (6)** |
| FSS | 0.05 | 0.26** | –0.16 | 0.25** | –1.03*** | 0.21** |
| | (0.13) | (0.10) | (0.18) | (0.08) | (0.16) | (0.07) |
| $R^2$ | 0.00 | 0.03 | 0.01 | 0.02 | 0.13 | 0.01 |
| N | 1,140 | 906 | 729.00 | 1,317 | 174 | 1,872 |

**Note:** This table reports the results for the following probit regression:

$$Pr\,[TP_{i,t+4} = 1] = \Phi[X_{i,t}\beta]\,,$$

where $TP_{i,t}$ is a dummy that takes the value of 1 when there is a turning point in the credit-to-GDP gap followed by a decrease in the gap over at least the next four quarters and $X_{i,t}$ contains the demeaned financial stability sentiment index calculated using the text in financial stability reports, $FSS_{i,t}$. For each governance framework characteristic, we split the sample into central banks with that characteristic ("Yes") and those without it ("No"). *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively.

and 7—that is, for a central bank not participating in committees, the financial cycle is little affected by the central bank's communications, and the probability of a turning point in the financial cycle is higher than for other central banks. The coefficient associated with the FSS index is only negative and statistically significant—that is, a deterioration in sentiment lowers the probability of a turning point in the cycle—for central banks participating in a financial stability committee with powers (column 5). The evidence in Table 8 suggests that the results in CGLM, where it was found that central banks' communication is a useful predictor of crises and turning points in the financial cycle, are driven mostly by central banks not participating in a committee.[12]

[12]In Table A.2 in the appendix, we show that the main results in our probit specifications are robust to considering two alternative FSS indices, a "negativity" index, which is calculated using only negative words, and a "summary" index, which is calculated using only the text in FSR's summaries.

## 4. Communication Strategies

In this section, building again on the intuition introduced in Section 2, we test the second hypothesis related to financial stability communication strategies. In particular, we explore the extent to which governance frameworks and the policy tools available to central banks determine their communication strategies. First, we investigate whether central banks convey information that differs in its sentiment from that reflected in news articles depending on their governance characteristics. Second, we explore the trade-offs faced by central banks in their communication strategies when taking into account other tools at their disposal, such as macroprudential instruments and monetary policy.

### *4.1 Deviations between the Sentiment in FSRs and in News Articles*

In Section 3, we showed that some governance characteristics are associated with relatively more effective financial stability communications—that is, they are consistent with more limited increases in financial vulnerabilities (i.e., excess credit). We now explore whether central banks' communication strategies respond differently to information about the financial cycle that is publicly available depending on the governance framework in which they operate. To do so, we empirically test Hypothesis 2a in Section 2 by exploring the relation between the FSS index and the financial stability sentiment conveyed in news articles.

We calculate a financial stability sentiment index for each country using news articles related to financial stability instead of FSRs. Similar to the FSS index, the news index, which we call NS, is calculated as the proportion of negative to positive words in each quarter (as in Equation (1)). We use all news articles in the Refinitiv Machine Readable News (MRN) Reuters Daily News Feed database associated with financial stability topics. To select articles related to financial stability, we filter all articles in which the body of the article contains at least one of the top bigrams found in all FSRs in our sample. To link these articles to each country, we make sure that either the headline or the body of the article contains a country-name stem (for instance, "Argentin" for Argentina).

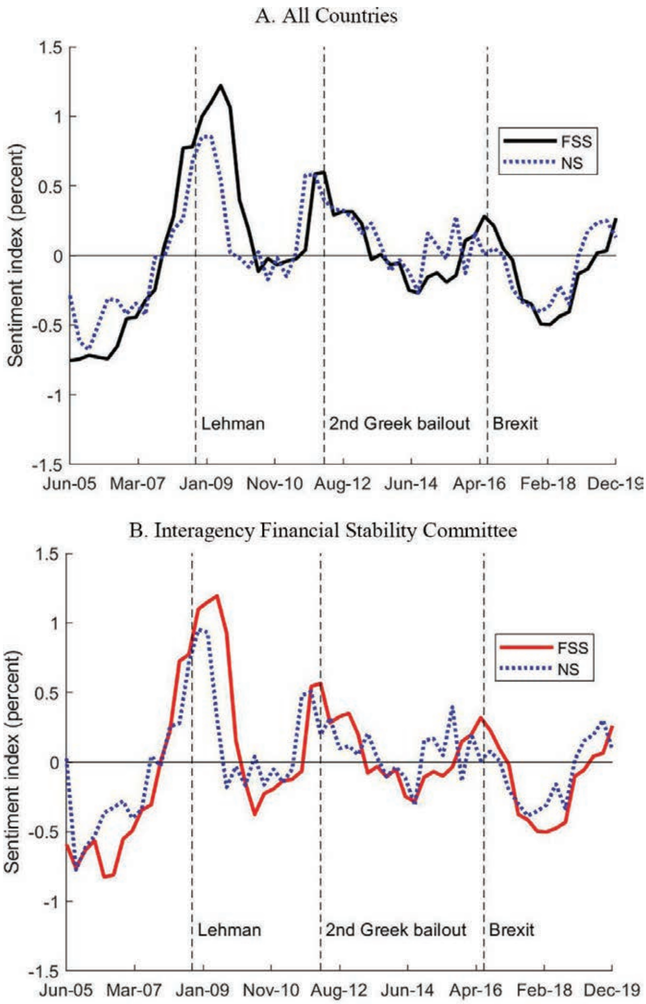
Figure 2 compares the evolution of the (demeaned at the country level) FSS and NS indices since 2005.[13] Panel A compares the time series for all countries, while panel B does the same for central banks in a financial stability committee. Irrespective of the governance characteristic, the NS and FSS indices follow similar dynamics and both tend to increase (that is, sentiment deteriorates) around episodes of heightened financial vulnerabilities or stress. As can be seen from the figures, however, NS tends to increase less than FSS in some of these key episodes.

We first confirm that news about financial stability is not strategically biased. To do so, we extend our main results about strategic central bank communication and its relative effectiveness by assessing whether the relation between the sentiment in news articles and the evolution of the financial cycle depends on the governance characteristics of the central bank. After all, the strategic communication considerations explained so far should not apply to the sentiment in news articles. Table 9 explores the relation between NS and the evolution of the financial cycle using the same setting as that used for Table 4. Our results suggest that an increase in the sentiment in news is followed by a deterioration in the credit-to-GDP gap ($\beta_1$ is positive and statistically significant in column 1), but this relation does not depend on whether the country's central bank participates or not in an interagency financial stability committee ($\beta_2$ is insignificant in columns 2–4).

To compare the dynamics of the FSS and NS indices, Table 10 presents the estimates for the contemporaneous and lead-lag coefficients of regression specifications alternating between the two sentiment indices as regressands and regressors. As can be seen in column 1, which reports the contemporaneous relation between the FSS and NS indices, the information from NS is reflected in the FSS index—the coefficient for NS is positive and statistically significant. Importantly, the association is lower for central banks participating in interagency financial stability committees with powers—that is, the estimate of $\beta_2$ is negative and significant in those cases. The results in column 2 confirm that NS is also strongly related to the one-quarter-ahead FSS, and that this relation is less strong for central

[13]The time series of NS can be found at Juan M. Londono's website: https://juanmlondono.wordpress.com/.

**Figure 2. Financial Stability Sentiment Indices from Financial Stability Reports and from News Articles: Averages across Countries**




**Note:** Panel A compares the sentiment from financial stability reports with that obtained from news articles. These indices are calculated as the proportion of negative to positive words in either financial stability reports (FSS) or financial stability news articles (NS). The time series shown are equally weighted averages of all countries' demeaned sentiment indices. Panel B shows the average across all countries for which the central bank participates in an interagency financial stability committee. For reference, we add vertical lines for the following key dates (quarterly equivalent): the collapse of Lehman Brothers (marked as October 2008), the second Greek bailout (marked as March 2012), and the Brexit referendum (marked as July 2016).

**Table 9. Strategic Communication: Sentiment in News Articles and Their Relation to Financial Stability Governance Frameworks**

| | Homogeneous (1) | Committee (2) | Official Committee (3) | Committee with Powers (4) |
|---|---|---|---|---|
| NS ($\beta_1$) | 3.03* | 1.76 | 2.26 | 3.82* |
| | (1.22) | (2.17) | (1.92) | (1.50) |
| D*NS ($\beta_2$) | | 4.49 | 4.08 | –7.28 |
| | | (4.33) | (4.85) | (4.06) |
| $R^2$ | 0.21 | 0.24 | 0.23 | 0.21 |
| N | 942 | 889 | 889 | 889 |

**Note:** This table reports the results for the following panel-data regression:

$$FC_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4})NS_{i,t} + \beta_3 D_{i,t-4} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4},$$

where $FC_{i,t}$ is the credit-to-GDP gap and $D_{i,t}$ is a dummy that takes the value of 1 when the country has one of the characteristics in the financial stability governance framework database and zero otherwise, and $NS_{i,t}$ is the sentiment from news articles, which is calculated as explained in Section 4.1. $\mathbf{C_{i,t}}$ includes the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. In all estimations, we consider country fixed effects to account for other time-invariant country characteristics not related to governance. For the purpose of brevity, we only report estimates of the coefficients associated with FSS ($\beta_1$ and $\beta_2$).

banks participating in financial stability committees with powers. Interestingly, however, the relation between the one-quarter-ahead sentiment in news and FSS does not change depending on whether central banks participate in committees or not, as shown in column 3, which confirms the evidence in Table 9 for the lack of strategic bias in news articles.[14]

Overall, consistent with Hypothesis 2a, this evidence suggests that central banks participating in a committee choose a communication strategy different from those institutions without such a financial stability governance arrangement. In particular, following

[14]In Table A.3 in the appendix, we show that these patterns hold when we consider official committees instead of committees with powers.

**Table 10. Strategic Communication: Deviations between the Sentiment in Financial Stability Reports and in News Articles**

| | Contemporaneous (1) | RHS: Lagged NS (2) | RHS: Lagged FSS (3) |
|---|---|---|---|
| RHS ($\beta_1$) | 0.42*** | 0.47*** | 0.20*** |
| | (0.06) | (0.06) | (0.05) |
| D*RHS ($\beta_2$) | –0.28* | –0.29* | 0.14 |
| | (0.11) | (0.14) | (0.16) |
| $R^2$ | 0.12 | 0.15 | 0.08 |
| N | 1,606 | 1,579 | 1,577 |

**Note:** This table reports the results for contemporaneous and lead-lag analyses between the financial stability sentiment index, FSS, and the financial stability sentiment from news articles, NS, where NS is calculated as explained in Section 4.1. Column 1 shows the results for a regression in which we explore how information from NS is contemporaneously correlated with the FSS index when the country's central bank participates (or not) in a committee with powers:

$$FSS_{i,t} = \alpha + (\beta_1 + \beta_2 D_{i,t-4}) NS_{i,t} + \beta_3 D_{i,t-4} + e_{i,t}.$$

Column 2 shows the results for a regression in which the right-hand-side (RHS) variable is the NS index, one-quarter lagged to the FSS index,

$$FSS_{i,t+1} = \alpha + (\beta_1 + \beta_2 D_{i,t-4}) NS_{i,t} + \beta_3 D_{i,t-4} + e_{i,t+1}.$$

Finally, column 3 shows the results for a regression in which the RHS variable is the FSS index, one-quarter lagged to the NS index,

$$NS_{i,t+1} = \alpha + (\beta_1 + \beta_2 D_{i,t-4}) FSS_{i,t} + \beta_3 D_{i,t-4} + e_{i,t+1}.$$

In all regressions, $D_{i,t-1}$ is a dummy that takes the value of 1 when the country's central bank participates in a committee with powers. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. For the purpose of brevity, we only report estimates of the coefficients associated with FSS or NS ($\beta_1$ and $\beta_2$).

a deterioration in financial conditions, central banks that are part of financial stability committees convey a calmer message, on average, compared with their counterparts that are not part of committees.

Our evidence is in line with the intuition that central banks might differ on how they convey their assessment of current or expected financial conditions because of one or more of the following strategic considerations: (i) communication by itself is effective at turning around the deterioration of financial vulnerabilities, (ii) revealing private information or alarming markets might accelerate the onset of a crisis, or (iii) they are confident about their ability to use tools, directly or indirectly, to prevent financial crises. We already tested the first consideration in Sections 3.2 and 3.3. The second consideration is difficult to test, at least with our data, as we cannot disentangle information that is publicly available from that available only to the central bank. In Section 4.2, we explore the third consideration, namely whether central banks can use or influence the use of tools to limit extreme events associated with the financial cycle.

### *4.2 Financial Stability Communications and Policy Actions*

As outlined in Hypotheses 2b and 2c, we explore the strategic considerations relating central banks' communication and the implementation of policy actions available to the central bank using the following equation:

$$PA_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4})FSS_{i,t} + \beta_3 D_{i,t-4} + \gamma \mathbf{C_{i,t}} + e_{i,t+4}, \tag{5}$$

where $PA_{i,t}$ is either the cumulative macroprudential policy index of (Cerutti et al. 2016) or the monetary policy rate targeted by the country's central bank, and $\mathbf{C_{i,t}}$ includes the macroeconomic control variables used in our previous estimations. Based on the intuition introduced in Section 2, we expect that central banks that have macroprudential tools or can influence other agencies that have those instruments are more likely to use them as their financial stability communications become more negative. The relation between financial stability communications and monetary policy is more ambiguous.

The results are presented in Table 11. The estimates in panel A show that communication by central banks in a committee with powers (column 4) appears relatively more "coherent," in the sense that a deterioration in sentiment is followed by a tightening in macroprudential policies ($\beta_2$ is positive and significant), whereas communication by central banks with none of the governance characteristics is followed by a relaxation in these tools—$\beta_1$ is negative, although statistically insignificant. This finding confirms the conjecture outlined in Hypothesis 2b.

**Table 11. Coherence in Communication: The Relation between Financial Stability Communications, Macroprudential Tools, and Monetary Policy**

| | Homogeneous (1) | Committee (2) | Official Committee (3) | Committee with Powers (4) |
|---|---|---|---|---|
| *A. Cumulative Macroprudential Policies* | | | | |
| FSS ($\beta_1$) | –0.01 | –0.24 | –0.14 | –0.13 |
| | (0.16) | (0.18) | (0.21) | (0.17) |
| D*FSS ($\beta_2$) | | 0.09 | 0.00 | 0.57** |
| | | (0.36) | (0.31) | (0.17) |
| $R^2$ | 0.02 | 0.17 | 0.10 | 0.03 |
| N | 764 | 700 | 700 | 700 |
| *B. Monetary Policy Rate* | | | | |
| FSS ($\beta_1$) | –0.34 | –0.09 | –0.08 | –0.30 |
| | (0.25) | (0.14) | (0.10) | (0.23) |
| D*FSS ($\beta_2$) | | –0.48 | –1.01 | –0.24 |
| | | (0.47) | (0.64) | (0.18) |
| $R^2$ | 0.06 | 0.09 | 0.11 | 0.07 |
| N | 860 | 982 | 982 | 982 |

**Note:** This table reports the results for the following panel-data regression:

$$PA_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4})FSS_{i,t} + \beta_3 D_{i,t-4} + \mathbf{C_{i,t}} + e_{i,t+4},$$

where $PA_{i,t}$ is either the cumulative macroprudential index from Cerutti et al. (2016) (panel A) or the monetary policy rate (panel B). $D_{i,t}$ is a dummy that takes the value of 1 when the country's central bank has one of the characteristics in the governance framework database and zero otherwise, $FSS_{i,t}$ is the financial stability sentiment index calculated using the text in financial stability reports, and $\mathbf{C_{i,t}}$ are the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. In all estimations, we consider country fixed effects to account for other time-invariant country characteristics not related to governance. For the purpose of brevity, we only report estimates of the coefficients associated with FSS ($\beta_1$ and $\beta_2$).

The results in panel B suggest that a deterioration in sentiment is not associated with a significant change in the policy rate, which rejects the premise of Hypothesis 2c. This result could be interpreted as lack of coherence between communication and actions, as monetary policy could be tightened to prevent a further expansion in the financial cycle. It could also indicate, however, that those central banks balance financial stability concerns and monetary policy objectives using different tools. The central bank may assess that it could fail to meet its monetary policy objectives (price stability and, in some cases, employment) if it acts just on financial stability considerations. At the same time, it may try to use macroprudential tools to curtail financial vulnerabilities, as suggested by the analysis presented in panel A.

Given that communication is more coherent for central banks participating in committees with powers to implement policy instruments, we next explore whether, for such central banks, communication complements other policy actions in preventing the deterioration of financial cycle conditions. This evidence helps gain insights into the governance and policy settings under which communication is effective in alleviating the deterioration in financial cycle conditions. To do so, we estimate the following augmented version of the panel-data specification in Equation (2):

$$FC_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4}) FSS_{i,t} + \beta_3 MP_{i,t} + \beta_4 IR_{i,t} + \beta_5 D_{i,t-4} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4},$$

where, again, $D_{i,t-1}$ is an indicator equal to 1 when the country's central bank participates in an interagency financial stability committee and zero otherwise, and where we control for lagged policy actions, with $MP_{i,t}$ the cumulative macroprudential index and $IR_{i,t}$ the monetary policy rate. The results, reported in Table 12, suggest that, after controlling for policy actions, sentiment in FSRs published by central banks participating in interagency financial stability committees with powers is more effective in limiting increases in the credit-to-GDP gap (column 4) than for central banks not participating in these committees.[15]

[15] Table A.4 in the appendix reports the results using the probit specification described in Equation (4), where we assess the predictive power of the FSS index for turning points in the financial cycle after controlling for policy actions. The results show that, after controlling for these actions, sentiment in FSRs by central banks not participating in committees remains a better predictor of turning points than the sentiment conveyed by other central banks.

**Table 12. Financial Stability Governance Frameworks and How Financial Stability Communications Relate to Financial Cycle Indicators: Controlling for Policy Actions**

| | Homogeneous (1) | Committee (2) | Official Committee (3) | Committee with Powers (4) |
|---|---|---|---|---|
| FSS ($\beta_1$) | 1.82 | 0.39 | 0.52 | 0.37 |
| | (1.80) | (1.41) | (1.39) | (1.35) |
| D*FSS ($\beta_2$) | | 0.12 | –1.46 | –2.97* |
| | | (1.46) | (2.23) | (1.38) |
| MP ($\beta_3$) | | –7.00 | –2.57 | –8.50** |
| | | (3.82) | (4.78) | (2.70) |
| IR ($\beta_4$) | | 0.78 | 0.43 | 0.31 |
| | | (0.84) | (0.84) | (0.76) |
| $R^2$ | 0.21 | 0.57 | 0.56 | 0.56 |
| N | 1,192 | 667 | 667 | 667 |

**Note:** This table reports the results for the following augmented version of the panel-data regression in Table 4:

$$FC_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4})FSS_{i,t} + \beta_3 MP_{i,t} + \beta_4 IR_{i,t} + \beta_5 D_{i,t-4} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4},$$

where $FC_{i,t}$ is the credit-to-GDP gap and $D_{i,t}$ is a dummy that takes the value of 1 when the country has one of the characteristics in the financial stability governance framework database and zero otherwise, and is lagged by one year to control for endogeneity with $FSS_{i,t}$, the financial stability sentiment index calculated using the text in financial stability reports. We control for lagged policy actions, specifically, $MP_{i,t}$, the cumulative macroprudential index from Cerutti et al. (2016), and $IR_{i,t}$, the monetary policy rate. $\mathbf{C_{i,t}}$ includes the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. In all estimations, we consider country fixed effects to account for other time-invariant country characteristics not related to governance. For the purpose of brevity, we only report estimates of the coefficients associated with FSS ($\beta_1$ and $\beta_2$) and with lagged policy actions ($\beta_3$ and $\beta_4$).

Together, these results suggest that for central banks not participating in financial stability committees, sentiment deteriorates more (they cry wolf) and fewer policy actions are implemented (less coherent communication) than for central banks with financial stability governance characteristics. Importantly, central banks without these governance characteristics are less likely to prevent the occurrence of a turning point in the financial cycle.

## 5. Conclusion

Financial stability communications and macroprudential policies have gained prominence and become part of the set of policy tools available to central banks worldwide. Yet, the interaction between central banks' financial stability communications and countries' financial stability governance frameworks, including the allocation of powers to use macroprudential tools, remains mostly unexplored in the literature.

We investigate how differences in governance frameworks across countries explain central banks' financial stability communication strategies and the effectiveness of these strategies in preventing turning points in the financial cycle. To do so, we propose a set of testable hypotheses to understand central bank communication strategies. In particular, our first hypothesis relates financial stability governance frameworks to the effectiveness of financial stability communications, while our second hypothesis relates these governance frameworks to differences in communication strategies and the use of other policy tools. We test these hypothesis empirically, and we show how these strategical aspects play a role in the evolution of the financial cycle. Using the sentiment in financial stability communications derived from text in FSRs published by the central banks of 24 countries and data on their respective countries' financial stability governance frameworks, we empirically test whether governance frameworks are important determinants of the effectiveness of financial stability communication strategies.

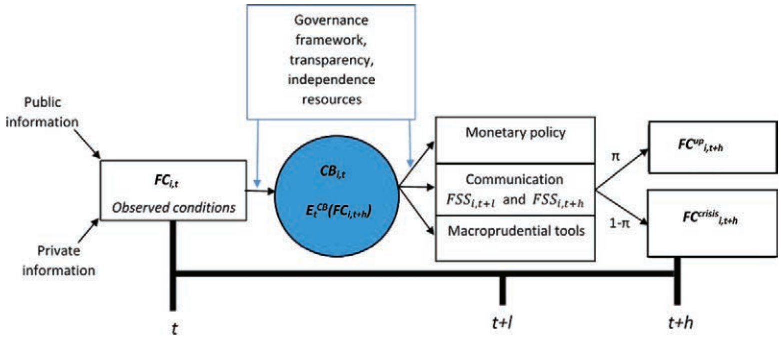
We find that communications by central banks participating in an interagency financial stability committee are relatively more effective in ameliorating the deterioration in financial vulnerabilities and the occurrence of turning points in the financial cycle. We then investigate what drives the effectiveness of communication by exploring how governance frameworks matter for central banks' communication strategies. After observing an increase in financial vulnerabilities or a worsening of the sentiment reflected in news articles, we find that central banks participating in financial stability committees transmit a calmer message than banks without this characteristic. To understand why central banks might decide to transmit a calmer message, we explore the relation between communication and other policy actions, and we find that governance characteristics affect the coherence between financial stability communications and actions—that is, changes in the implementation of policy actions follow a deterioration in sentiment for those central banks with direct or indirect access to macroprudential tools. Moreover, we find evidence that financial stability communications by central banks in financial stability committees are more effective in alleviating the deterioration of the financial cycle and the occurrence of crises, even after controlling for the implementation of policy actions. Overall, we can conclude that central banks' financial stability governance frameworks influence their financial stability communication strategies and their effectiveness in preventing a worsening of financial cycle conditions.

## Appendix

### *A.1 Conceptual Framework Relating Financial Stability Communications to Governance Arrangements*

This section develops a conceptual framework that outlines a central bank's decisionmaking process to communicate information about its financial stability assessments, potentially through a financial stability report. The framework describes actions that take place over three periods. Its main intuition is summarized in Figure A.1. In the first period, $t$, the central bank observes the initial financial conditions, $FC_{i,t}$, forms its expectations about the evolution of the financial cycle, $E_t^{CB}(FC_{i,t+h})$, and decides its general communication strategy. In the second period, $t+l$, the central bank communicates its views about the current financial conditions and, potentially, about the evolution of the financial cycle, $FSS_{i,t+l}$ and $FSS_{i,t+h}$, respectively. Besides communicating about financial stability, the central bank might, in this period, use other policy tools, including monetary policy and macroprudential tools. In the third period, $t+h$, financial stability conditions evolve depending on initial conditions, the decisions made by the central bank, including financial stability communication, and other shocks. For simplicity, we assume that only two states are possible in period $t+h$, a good

**Figure A.1. Central Bank Communication and Financial Stability Governance**




**Note:** This figure shows a diagram for the conceptual framework used to understand the interaction between financial stability governance frameworks and central bank communication.

state, with probability $\pi$, and a bad state (financial crisis or turning point in the cycle), with probability $1 - \pi$. From a financial stability perspective, the goal of the central bank is to decide the mixture of tools and communications that minimizes the probability of the bad state.

The financial and other information the central bank of country $i$ observes in the first period, $t$, is assumed to include not only the information available to the public, $I_t^{public}$, but also information available exclusively to the central bank, $I_t^{private}$, such as information obtained directly from financial institutions for supervisory purposes. Based on this information, the central bank forms expectations about the evolution of the financial cycle. In particular, the central bank will determine its expectations about time $t + h$ (final) financial cycle conditions,

$$E_{i,t}^{CB}(FC_{i,t+h}) = F_i^{CB}(I_{i,t}^{public}, I_{i,t}^{private}, C_{i,t}),$$

where $C_t$ is a set of characteristics of the country's central bank, including the financial stability governance framework in which it operates, its level of transparency and independence, its credibility, and its resources.

In the second period, the central bank uses its communication strategically to reveal some of its assessment of current financial conditions and, potentially, of the evolution of the financial cycle. Its communications about both current and future financial conditions, $FSS_{i,t+l}$ and $FSS_{i,t+h}$, depend on the set of information available to the central bank and the central bank's characteristics,

$$FSS_{i,t+l} = F_i^{current}(I_{i,t}^{public}, I_{i,t}^{private}, C_{i,t}), \tag{A.1}$$

$$FSS_{i,t+h} = F_i^{future}(I_{i,t}^{public}, I_{i,t}^{private}, C_{i,t}). \tag{A.2}$$

These assessments become part of the information set available to the public at time $l$, $I_{t+l}^{public}$.

The central bank's public assessments, $FSS_{i,t+l}$ and $FSS_{i,t+h}$, however, might differ from $FC_{i,t}$ and $E_{i,t}^{CB}(FC_{i,t+h})$, respectively—that is, the central bank does not necessarily reveal (all) its private information about current financial cycle conditions nor its (full) expectations about the evolution of the financial cycle, and it may reveal its private information in a (deliberately) biased manner.

There are three main reasons why $FSS_{i,t+l} \neq FC_{i,t}$ and/or $FSS_{i,t+h} \neq E_{i,t}^{CB}(FC_{i,t+h})$. The first one is institutional: The central bank does not reveal (all) information transparently because it is not fully independent or has other limits on being fully transparent. For example, legally, it cannot reveal certain institution-specific information. The second one is strategic: The central bank questions the value of full transparency. For example, it may have private information that points to a deterioration in financial stability conditions beyond what the set of information available to the public suggests, but revealing this could simply accelerate or exacerbate the occurrence of the bad state—for instance, lead to a financial crisis (see Cukierman 2009). The third reason is about coherence in communication: Given the other tools it has at its disposal and the confidence it has in them, it may convey risks differently. For example, if the central bank believes it has the tools to prevent a financial crisis (or financial boom) and is willing to use the tools, it may decide to transmit a message of calm even in the face of a deterioration (loosening) in financial conditions.

The first reason could make for a systematic bias or more noisy communication. The second reason would create a specific asymmetry in that bad information is not revealed. The third reason could imply that the bank's communication affects its use of other tools and vice-versa.

The final financial cycle conditions, $FC_{t+h}$, are then a function of time-$t$ conditions, the central bank communication strategy (FSS) and its policy actions (PA) at time $t+l$, its governance framework and other characteristics, and shocks to financial stability, $z_{i,t+h}$:

$$FC_{i,t+h} = F_i(I_{i,t}^{public}, I_{i,t}^{private}, FSS_{i,t+l}, PA_{i,t+l}, C_{i,t}) + z_{i,t+h}. \tag{A.3}$$

We assume that, in terms of financial stability—that is, setting aside its other mandates—the central bank decides its communication strategy, which in our framework is represented by $FSS_{i,t+l}$ and $FSS_{i,t+h}$, such that it minimizes $1-\pi$, the probability of the bad state. Our simple framework then implies that the central bank's communication strategy, and the extent to which it is effective at preventing the deterioration of financial cycle conditions, will differ by a number of central bank characteristics, including the governance framework in which it operates.

## A.2 Appendix Tables

### Table A.1. Other Country Characteristics and How Financial Stability Communications Relate to Financial Cycle Indicators: Official Committee as the Benchmark Governance Characteristic

| | Transparency (1) | Independence (2) | Financial Openness (3) | Foreign Bank Ownership (4) | Bank International Claims (5) |
|---|---|---|---|---|---|
| FSS ($\beta_1$) | 6.25 | –0.34 | 2.59 | 3.29 | 3.38 |
| | (6.69) | (2.13) | (2.02) | (1.98) | (3.97) |
| D*FSS ($\beta_2$) | –7.47* | –5.18* | –5.16* | –5.12* | –5.31* |
| | (2.86) | (2.17) | (2.06) | (2.06) | (2.18) |
| X*FSS ($\beta_3$) | –0.18 | 3.92 | 0.03 | 0.00 | –0.13 |
| | (0.54) | (2.74) | (0.03) | (0.00) | (5.69) |
| $R^2$ | 0.18 | 0.24 | 0.22 | 0.22 | 0.23 |
| N | 816 | 980 | 1,100 | 1,128 | 1,076 |

**Note:** This table reports the results for the following panel-data regression setting:

$$FC_{i,t+4} = \alpha + (\beta_1 + \beta_2 D_{i,t-4} + \beta_3 X_{i,t-4}) FSS_{i,t} + \gamma \mathbf{C_{i,t-1}} + e_{i,t+4},$$

where $FC_{i,t}$ is the credit-to-GDP gap and $D_{i,t}$ is a dummy that takes the value of 1 when the country's central bank participates in an official interagency financial stability committee and zero otherwise, and is lagged by one year to control for endogeneity with $FSS_{i,t}$, the financial stability sentiment index calculated using the text in financial stability reports. $X_{i,t}$ is one of the following country-specific characteristics: the transparency index in Dincer and Eichengreen (2014), the central bank independence index in Garriga (2016), the financial openness index in Chinn and Ito (2006), the foreign bank ownership (source: BIS), and the ratio of bank international claims (source: BIS). $\mathbf{C_{i,t}}$ are the following control variables: the change in real GDP with respect to the previous year, the change in the GDP deflator with respect to the previous year, and the unemployment rate. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. In all estimations, we consider country fixed effects to account for other time-invariant country characteristics not related to governance. Because most additional characteristics are very slow moving, in this specification, we remove the term for governance characteristics in levels to reduce the possibility of multicollinearity. For the purpose of brevity, we only report estimates of the coefficients associated with FSS ($\beta_1$, $\beta_2$, and $\beta_3$).

**Table A.2. Financial Stability Governance Frameworks and the Predictive Power of Financial Stability Communications for Turning Points in the Financial Cycle: Alternative FSS Indices**

| | Committee | | Official Committee | | Committee with Powers | |
|---|---|---|---|---|---|---|
| | **Yes (1)** | **No (2)** | **Yes (3)** | **No (4)** | **Yes (5)** | **No (6)** |
| *A. FSS Negativity* | | | | | | |
| FSS Negativity | 0.08 | 0.24* | –0.19 | 0.24** | –0.97** | 0.20* |
| | (0.13) | (0.12) | (0.18) | (0.09) | (0.35) | (0.09) |
| $R^2$ | 0.00 | 0.01 | 0.01 | 0.01 | 0.09 | 0.01 |
| N | 672 | 659 | 410 | 921 | 80 | 1,251 |
| *B. FSS Summary* | | | | | | |
| FSS Summary | 0.06 | 0.14*** | 0.02 | 0.13*** | –0.43*** | 0.13*** |
| | (0.07) | (0.04) | (0.12) | (0.03) | (0.05) | (0.03) |
| $R^2$ | 0.00 | 0.03 | 0.00 | 0.02 | 0.13 | 0.02 |
| N | 629 | 607 | 367 | 869 | 80 | 1,156 |

**Note:** This table reports the results for the following probit specification:

$$Pr\left[TP_{i,t+4} = 1\right] = \Phi[X_{i,t}\beta],$$

where $TP_{i,t}$ is a dummy that takes the value of 1 when there is a turning point in the credit-to-GDP gap followed by a decrease in the gap over at least the next four quarters and $X_{i,t}$ contains one of the following alternative (demeaned) financial stability sentiment index measures: the negativity index, in panel A, which is calculated as the proportion of negative to total words in financial stability reports, and the summary index, in panel B, which is calculated using only the text in the summaries of FSRs. For each governance framework characteristic, we split the sample into central banks with that characteristic ("Yes") and those without it ("No"). *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively.

**Table A.3. Strategic Communication: Deviations between the Sentiment in Financial Stability Reports and in News Articles: Official Committee as the Benchmark Governance Characteristic**

| | **Contemporaneous** | **RHS: Lagged NS** | **RHS: Lagged FSS** |
|---|---|---|---|
| RHS ($\beta_1$) | 0.48*** | 0.52*** | 0.23*** |
| | (0.07) | (0.08) | (0.06) |
| D*RHS ($\beta_2$) | –0.27* | –0.27* | –0.10 |
| | (0.10) | (0.12) | (0.08) |
| $R^2$ | 0.13 | 0.16 | 0.07 |
| N | 1,606 | 1,579 | 1,577 |

**Note:** This table reports the results for a lead-lag analysis between the financial stability sentiment index, FSS, and the financial stability sentiment from news articles, NS. NS is calculated as explained in Section 4.1. Column 1 shows the results for the following contemporaneous regression in which we explore how information from NS is contemporaneously correlated with the FSS index when the country's central bank participates in an official committee:

$$FSS_{i,t} = \alpha + (\beta_1 + \beta_2 D_{i,t-4}) NS_{i,t} + \beta_3 D_{i,t-4} + e_{i,t}.$$

Column 2 shows the results for a regression in which the right-hand-side (RHS) variable is the one-quarter-lagged NS index,

$$FSS_{i,t+1} = \alpha + (\beta_1 + \beta_2 D_{i,t-4}) NS_{i,t} + \beta_3 D_{i,t-4} + e_{i,t+1}.$$

Finally, column 3 shows the results for a regression in which the RHS variable is the one-quarter-lagged FSS index,

$$NS_{i,t+1} = \alpha + (\beta_1 + \beta_2 D_{i,t-4}) FSS_{i,t} + \beta_3 D_{i,t-4} + e_{i,t+1}.$$

In all regressions, $D_{i,t-1}$ is a dummy that takes the value of 1 when the country's central bank participates in an official committee. Huber-White standard errors (see Wooldridge 2002) are reported in parentheses. *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively. For the purpose of brevity, we only report estimates of the coefficients associated with FSS or NS ($\beta_1$ and $\beta_2$).

**Table A.4. Financial Stability Governance Frameworks and the Predictive Power of Financial Stability Communications for Turning Points in the Financial Cycle, Conditional on Policy Actions**

| | Committee | | Official Committee | | Committee with Powers | |
|---|---|---|---|---|---|---|
| | **Yes (1)** | **No (2)** | **Yes (3)** | **No (4)** | **Yes (5)** | **No (6)** |
| FSS | –0.05 | 0.29** | –0.48* | 0.25*** | –1.96*** | 0.18* |
| | (0.14) | (0.09) | (0.21) | (0.07) | (0.14) | (0.07) |
| MP | 0.05** | 0.03 | 0.05* | 0.05** | 0.21*** | 0.04** |
| | (0.02) | (0.04) | (0.02) | (0.02) | (0.02) | (0.02) |
| IR | 0.00 | 0.05** | 0.04* | 0.03 | 0.18* | 0.03 |
| | (0.01) | (0.02) | (0.02) | (0.02) | (0.08) | (0.01) |
| $R^2$ | 0.02 | 0.05 | 0.07 | 0.04 | 0.29 | 0.03 |
| N | 500 | 496 | 289 | 707 | 51 | 945 |

**Note:** This table reports the results for the following panel-data probit regression:

$$Pr\,[TP_{i,t+4} = 1] = \Phi[X_{i,t}\beta],$$

where $TP_{i,t}$ is a dummy that takes the value of 1 when there is a turning point in the credit-to-GDP gap followed by a decrease in the gap over at least the next four quarters and $X_{i,t}$ contains the demeaned financial stability sentiment index calculated using the text in FSRs, $FSS_{i,t}$, the cumulative macroprudential index from Cerutti et al. (2016), and the monetary policy rate. For each governance framework characteristic, we split the sample into central banks with that characteristic ("Yes") and those without it ("No"). *, **, and *** represent the usual 10 percent, 5 percent, and 1 percent significance levels, respectively.

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# The Economics of Central Bank Digital Currency*

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This paper provides a structured overview of the burgeoning literature on the economics of central bank digital currency (CBDC). We document the economic forces that shape the rise of digital money and review motives for the issuance of CBDC. We then study the implications for the financial system and discuss a number of policy issues and challenges. While the academic literature broadly echoes policymakers' concerns about bank disintermediation and financial stability risks, it also provides conditions under which such adverse effects may not materialize. We also point to several knowledge gaps that merit further work, including data privacy and the study of end-user preferences for attributes of digital payment methods.

JEL Codes: E41, E42, E51, E52, E58, G21.

## 1. Introduction

Traditionally, interest in the economics of money and payments has been largely confined to a narrow circle of experts in central banking, academia, and the financial industry. This has changed dramatically

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over the past 15 years or so, as technological innovation is disrupting the market for payments at an unprecedented scale, and the resulting changes are becoming tangible in citizens' everyday lives. Strong growth in e-commerce has led to a decline in the use of cash and increased demand for electronic payments. Technology-driven start-ups ("Fintech") and large digital platforms ("BigTech") are increasingly pushing into a market traditionally dominated by banks and credit card companies. At the same time, the development of distributed ledger technology (DLT) enables the decentralized settlement of electronic transactions, which has spurred the creation of fiat cryptocurrencies and stablecoins.

These developments have inspired central bankers to explore the merits of introducing a digital version of cash: central bank digital currency (CBDC). Notably, this debate has intensified considerably in recent years as policymakers have become unsettled by prospects for abrupt and potentially irreversible changes to the financial system due to the existence of strong network effects in both payments and digital services. Although ultimately not realized, the initial Libra proposal by Facebook (now Meta) was widely perceived as a significant wake-up call and led to an intensification of research efforts throughout the central banking community. According to a recent survey, 90 percent of 81 respondent central banks were actively investigating the potential for a CBDC at the end of 2021 (Kosse and Mattei 2022).

This paper provides a structured overview of the burgeoning literature on the economics of CBDC. It starts out with a review of the underlying economic drivers of the rise of digital money, namely the digitalization of economic activity and, consequently, payments. We then discuss how these developments give rise to concerns about the role of public money as anchor for the two-layer monetary system, monetary sovereignty, privacy in payments, and other frictions that motivate central banks to consider the issuance of CBDC.

Next, we study the implications of a CBDC introduction for the financial system. We first consider potential changes to the transmission and implementation of monetary policy, with a particular focus on the role of banks due to their central role in money creation and credit supply. We then discuss the consequences for financial stability, where we distinguish between effects affecting the asset and liability sides of intermediaries' balance sheets, as well as the implications for financial stabilization policies. For both monetary policy and financial stability, we also discuss the role of proposed safeguards in the CBDC design that aim to mitigate potential adverse effects.

The last section discusses several policy issues and challenges. First, we ask whether some of the key objectives that CBDCs aim to address could also be achieved through regulatory action. Then, we consider challenges related to end-user adoption (e.g., by consumers and merchants) on the basis of a pre-existing literature on the economics of payment instrument choice. And finally, we point towards several political economy issues.

In the conclusion, we highlight a few selected insights that arise from our review of the literature. While academics acknowledge policymakers' concerns about the potentially adverse effects of a CBDC issuance on bank lending and financial stability, they also point to mitigating forces. For example, credit supply may ultimately benefit from more competitive deposit markets. Similarly, more attractive deposit contracts could help limit the risk of bank runs. We also point to promising avenues for future research. Privacy in payments is a complex issue waiting to be explored further. And the proliferation of electronic payments raises interesting questions concerning the preferences of end users over the various attributes offered by new forms of digital money.

Our paper focuses on the economics of "retail CBDC," a digital central bank liability that is accessible to citizens and non-financial firms. We do not touch upon a parallel debate about "wholesale CBDC" intended for use by financial intermediaries, because it will entail a less significant change to the status quo of the financial system.[1] While we discuss technological innovations such as distributed ledger technology and the relationship between CBDC and stablecoins, our paper largely steers clear of the topics of cryptocurrencies and decentralized finance ("DeFi").

[1]Broadly speaking, wholesale CBDC and central bank reserves operate in very similar ways. However, wholesale CBDC may provide new benefits such as improved cross-border settlements or programmability; see Bank for International Settlements (2021a).

## 2. Digitalization in Business and Payments

This section provides an overview of the key drivers that have led to the debate about the potential introduction of central bank digital currency. We first review how the ongoing digitalization is reshaping the economy, and then discuss the rise of digital money.

### *2.1 The Economy in the Information Age*

The digitalization of the economy is progressing at breakneck speed. Firms are dramatically increasing investment into information and communication technologies (ICT) to reap the associated productivity gains. At the same time, the distribution of goods and services is steadily shifting towards online channels (Figure 1).

The ongoing digitalization is leading to rapid changes in the overall structure of the economy. Two driving forces stand out: digital platforms as dominant business model, and an increasing role for intangible inputs such as data and software. While both promise significant efficiency gains, concerns are mounting that they also give rise to market power and enable anti-competitive practices.

Digital platforms such as Google, Amazon, or Facebook are the signature business model of the digital economy. They operate as *two-sided markets*, which entails two key features (see Rysman 2009). First, they intermediate transactions between two groups of agents. Second, a *network externality* is present: the decisions of each group of agents affect those of the agents on the other side of the platform. For example, sellers will find an online marketplace more attractive if more buyers are present, and vice versa.[2]

Network externalities are a source of market power and thus play a key role for platform pricing and competition.[3] Platforms aim to strengthen network externalities by creating closed ecosystems (so-called walled gardens) with the aim of locking in one side of the market, which enables them to charge monopoly prices to the

[2]In addition to such a *cross-side* network externality, a *within-side* network externality may also exist. For example, users of social networks derive greater utility if more of their friends form part of the network.

[3]For example, the optimal price structure is asymmetric, with lower (often zero or even negative) prices prevailing on the side of the market where user demand is more elastic (Rochet and Tirole 2003; Armstrong 2006).

**Figure 1. The Evolution of ICT Usage and E-commerce in the Euro Area**


**Note:** The left panel (A) depicts various measures of ICT usage for the euro area over time. "Computer" refers to the percentage of employees that use a personal computer at work. "ERP software" denotes the share of firms that use Enterprise Resource Planning software. "Cloud" refers to the percentage of firms using cloud computing services. Countries: DE, FI, FR, GR, IE, IT, LU, NL, PT, ES. The right panel (B) illustrates the growth in e-commerce for the euro area over time. "Online purchases" represents the percentage of for individuals that have purchased at least one item online over the last 12 months. "Online sales" refers to the share of firms with online sales. Countries: AT, BE, DE, EE, FI, FR, IE, GR, ES, IT, CY, LV, LT, LU, MT, NL, PT, SI, SK. All series are aggregated using GDP weights. Source: Organisation for Economic Co-operation and Development (OECD) (panel A); Eurostat (panel B).

other side. In the extreme, this can give rise to a *winner-takes-it-all* outcome with a single dominant platform in a particular market segment.[4]

Beyond the dominance of digital platforms, an increased role for intangible inputs such as data and software is a defining feature of the digital economy. This gives rise to significant scale economies with increased fixed costs and reduced marginal costs, which favors large firms (Farboodi et al. 2019; Farboodi and Veldkamp 2021). The resulting shift in the economy's cost structure leads to a competitive edge for early technology adopters. While this boosts productivity

[4]Unlike in one-sided markets, a dominant player can—in principle—be beneficial to consumers because it allows to reap the benefits associated with network externalities, which can compensate for the potentially higher prices set by the platform.

in the short run, it deters entry by new firms and thus leads to lower growth in the long run (De Ridder 2021).[5]

Unlike traditional inputs, data is non-rival: It can be used multiple times, or by multiple parties (Jones and Tonetti 2020). Accordingly, a broad use of data on consumer preferences promises large social gains through more efficient matching and better goods and services. However, private incentives typically lead to data hoarding as firms aim to exert market power and fend off competitors.[6] Since network externalities and private access to data can be mutually reinforcing, such concerns become particularly acute in the case of digital platforms.

Empirical work supports the overall narrative of increasing concentration and market power. The evidence shows that markups are rising (De Loecker, Eeckhout, and Unger 2020) and a handful of "superstar firms" have emerged as dominant (Autor et al. 2020).[7] The breathtaking stock market performance of "BigTech" over the past decade speaks for itself.

### 2.2 The Transformation of Money and Payment Services

Money is crucial to economic activity because it enables the efficient exchange of goods and services. Without a widely accepted medium of exchange, transactions are limited to barter and credit arrangements, which can break down unless there is trust supported by long-term relationships, or perfect commitment.

Different types of money co-exist in our current monetary system, and there is a rather strict separation in their creation. Physical money—cash—is typically only issued by the central bank.[8] It is

[5] Aghion et al. (2022) reach broadly similar conclusions in a model based on the expansion of superstar firms.

[6] See, e.g., Bergemann, Brooks, and Morris (2015), Ichihashi (2020), Jones and Tonetti (2020), Hagiu and Wright (2021), Prüfer and Schottmüller (2021), and Kirpalani and Philippon (2021).

[7] While most the facts have established based on U.S. data, Cavalleri et al. (2019) document relatively stable markups for the four major European Union economies.

[8] One rare exception is the United Kingdom. Under the Banking Act of 2009, certain commercial banks in Scotland and Northern Ireland are permitted to issue physical banknotes. However, these must be fully backed by banknotes issued by the Bank of England.

public money in the sense that it is a direct liability of the monetary authority. By contrast, digital money available to the general public is created by commercial banks, usually in the form of bank deposits.[9] It is thus private money.

In practice, many citizens are not aware of any formal distinction between public and private (bank) money; they are deemed as equivalent in everyday use. However, this was not always the case. For example, private banknotes issued during the "free-banking era" in the United States typically traded at a discount depending on the issuer's creditworthiness.[10] Today, banks are subject to a carefully designed framework of bank regulation and supervision which aims to enforce prudent behavior. In combination with deposit insurance, this ensures that retail deposits are perceived as perfectly safe, and equivalent to public money.

To operate efficiently, a digital economy requires digital money. Since more and more business is conducted online, cash is losing its appeal as efficient means of payment. Consistent with this view, panel A of Figure 2 shows that the number of card payments in the euro area has increased more than fourfold over the past two decades. Over the same time, cash withdrawals at automated teller machines (ATMs) have fallen by around 20 percent, with evidence of an accelerating decline over recent years.[11] Panel B draws on data from payment diaries in Germany and the Netherlands and shows that the use of cash as means of payment (measured as percentage of transactions settled in cash) has declined strongly over the past decade.[12] It also reveals some significant cross-country variation, as the prevalence of cash payments differs substantially across those two economies.

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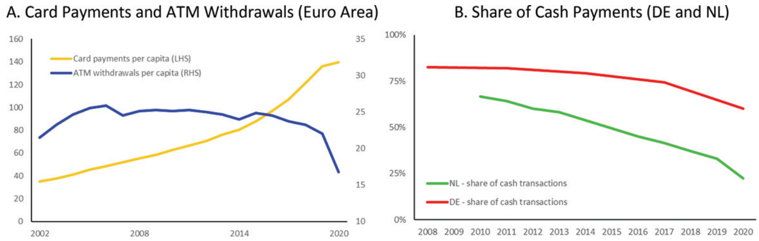
[9]Note that public digital money exists in the form of central bank reserves. However, these are only available to financial institutions with a reserve account.

[10]See Warren Weber's database on historical discounts of banknotes at https://researchdatabase.minneapolisfed.org/collections/2j62s4898?locale=en.

[11]Note that ATM withdrawals can be motivated by the need to obtain a means of payment or a store of value. The latter becomes economically more relevant in a negative interest rate environment.

[12]Card payments tend to be for higher amounts than cash payments. Nevertheless, the pattern over time is qualitatively similar when considering payment values instead of the number of payments.

**Figure 2. The Shift from Cash to Cashless Payments in the Euro Area**




**Note:** The left figure (A) depicts the evolution of card payments and ATM withdrawals per capita for the euro area over the period 2002–21. Countries: AT, BE, CY, DE, EE, ES, FI, FR, GR, IE, LU, LV, NL, PT, SI, SK. The right figure (B) plots the share of retail payments paid in cash, based on data from retail payment diaries in Germany and the Netherlands. Source: Eurosystem (panel A); Bundesbank and De Nederlandsche Bank/Betaalvereniging (panel B).

Despite its growing dominance over cash, today's digital money faces challenges. The current system of interbank payment rails has not fully caught up with technological change. Moreover, from the perspective of consumers, settlement remains slow: bank transfers, even within jurisdictions, continue to take one to two business days. More generally, retail payment systems are highly fragmented, and the development and adoption of instant payment systems continue to proceed at a muted pace.[13] While credit cards are well suited for the requirements of e-commerce, especially across borders, they remain expensive for merchants due to the dominance of a small number of card networks. Moreover, they ultimately also rely on the same legacy settlement systems.

The lack of innovation among incumbent institutions has created opportunities for market entrants. This has allowed new payment service providers to capture a significant and growing share of the market for online retail payments. Their success has been enabled by the ability to bundle digital payments with other services, including online marketplaces (PayPal/eBay, Alibaba/AliPay, Amazon),

[13]The Eurosystem launched its TARGET Instant Payment Settlement (TIPS) platform in November 2018, which enables instant payments 24/7/365. So far, the usage of TIPS has been limited. The U.S. Federal Reserve's FedNow Service is planned to go live in 2023.

lending (Klarna, Affirm), social networking (WeChat), ride-hailing (Go-Jek), and telecommunication (Apple Pay, Google Pay, M-Pesa).

Although the market for retail payments has undergone significant change, it continues to rely to a large extent on pre-existing infrastructures. Frequently, new payment solutions such as mobile wallets merely embed traditional products such as credit cards or deposit accounts into a new front end to increase user convenience and capture the client interface (together with the underlying data). Moreover, the customer balances of non-bank payment providers are ultimately "mirrored" as deposits in the traditional banking system.[14] While the internalization of payment flows within these new payment networks generates significant efficiency gains, a lack of interoperability gives rise to the need for multi-homing and a more fragmented payment system.

More fundamental change is looming with the advent of distributed ledger technology (DLT). Since digital money only exists in the form of computer code, in can in principle be duplicated and spent more than once (the so-called double-spend problem). In the traditional monetary system, this problem is mitigated by certification through trusted third parties such as banks. By contrast, DLT enables the direct exchange of digital claims (often referred to as "tokens") without the need for a trusted third party. The system relies on an immutable public transaction record (the "ledger"), which is maintained on different nodes of a peer-to-peer network and updated regularly by means of a consensus protocol. In the extreme case of full decentralization with a "permissionless" ledger, anyone who forms part of the network can certify transactions. Since the ledger's reconciliation process involves a large network of nodes, it is prohibitively expensive to "double spend."

DLT provides the basis for the development of cryptocurrencies, which could be used as a digital means of payment and

[14]Regulation typically requires non-bank providers of electronic money to hold customer balances in the form of bank deposits, and segregated from other assets. Depending on the jurisdiction, customer balances may enjoy the benefits of pass-through deposit insurance. Moreover, some payment providers have acquired a fully fledged banking license to reap the benefits of offering additional financial services (for example, PayPal's European subsidiary acquired a banking license in 2007).

support efficient contracting and decentralized settlement (including "smart contracts"). However, they are subject to significant challenges. In particular, fiat cryptocurrencies such as Bitcoin are subject to significant price volatility, which renders them inadequate as means of payment. Stablecoins—cryptocurrencies whose value is backed by a pool of reserve assets—have been proposed as a potential solution to this problem. However, the recent failure of the poorly designed stablecoin "Terra" shows that investor trust in such arrangements can deteriorate quickly and also spill over to other stablecoins.

Moreover, the full decentralization of cryptocurrencies comes at the cost of limited scalability and an excessive environmental footprint for consensus mechanisms such as "proof of work." This makes them particularly unattractive for retail payment systems which require a very large "throughput."[15] This issue can be addressed by moving away from a fully decentralized model towards a permissioned DLT where only specific network nodes can update the ledger. Facebook's Libra proposal—in particular, in its revised version—is a particular example in this direction (Libra Association 2020).[16]

The ability to bundle digital payments and services puts BigTech in a unique position to play a major role in the market for payments. In particular, the strong network externalities in both digital platforms and payment services create the scope for dominance by a small number of digital money issuers. These prospects have—at least in part—inspired a debate among central bankers about the potential benefits of introducing public digital money in the form of central bank digital currency.

[15] According to www.bitcoin.com, the Bitcoin blockchain records between three and seven transactions per second. By contrast, the Visa card network claims a capacity of 65,000 transactions per second. See https://www.visa.co.uk/dam/VCOM/download/corporate/media/visanet-technology/aboutvisafactsheet.pdf.

[16] Another example is the proof-of-stake consensus protocol, which selects validators in proportion to their stake (i.e., holdings of the relevant cryptocurrency). Buterin (2021) suggests that decentralized settlement creates a trilemma between decentralization, security, and scalability. See Auer, Monnet, and Shin (2021) for a formal analysis of the optimal ledger design in this context.

## 3. Motives for the Introduction of Central Bank Digital Currency

In this section, we highlight the key underlying motives for the issuance of "digital cash." We first discuss the role of public money as a monetary anchor against the background of an increasingly cashless world. We then examine monetary sovereignty, which was catapulted to the forefront of the debate by the publication of the first Libra white paper in 2019. We proceed to considering the role of privacy in payments, followed by a discussion of how CBDC can address frictions in the markets for payments and financial intermediation, among other potential benefits.

### *3.1 Public Money as Monetary Anchor in a Digital World*

Our current monetary system is based on the co-existence of public money ("cash") and private commercial bank money. Quantitatively, private money dominates the financial system. In the euro area, overnight bank deposits currently account for more than 85 percent of total money supply (as measured by the narrowest monetary aggregate M1). However, public money is crucial to the functioning of the two-layer monetary system. Due to its nature as a central bank liability, it is the safest form of money, and thus acts as an anchor for the monetary system (see Panetta 2021, and Brunnermeier and Landau 2022).

In the eyes of the consumer, commercial bank money is widely regarded as equivalent to public money. The combination of banking supervision and regulation, deposit insurance, and the central bank as lender of last resort ensure that it can always be converted, at par, into cash. The public safety net guarantees that bank deposits satisfy the "no-questions-asked" principle and can act as an effective medium of exchange.[17]

The ongoing digitalization of the economy poses a formidable challenge to the status quo. As the use of cash is declining, the promise of convertibility at par becomes less and less meaningful. To ensure that public money can perform its function as anchor

[17]The "no-questions-asked" principle requires money to be accepted at par without due diligence. See Holmstrom (2015) and Gorton and Zhang (2023).

of the monetary system, it must be widely accessible and used.[18] Accordingly, a digital update of cash in the form of CBDC could help ensure that the two-layer system of public and private money can prevail in the future.

### *3.2 Retaining Monetary Sovereignty*

Monetary sovereignty refers to the supremacy of domestic currency for fulfilling the three functions of money (unit of account, medium of exchange, store of value) in an economy. Whenever foreign currency takes on a significant role for at least one of these functions, monetary sovereignty is limited. This is often referred to as "currency substitution" or "dollarization/euroization." One example is Montenegro, where the euro is the official currency, but the domestic central bank is not part of the Eurosystem.[19]

Brunnermeier, James, and Landau (2019) warn that the rise of digital money could threaten monetary sovereignty. In the spirit of the original Libra proposal, dominant platform operators may strive to bundle their digital services with payment services. By exploiting their large customer base, they may quickly become dominant issuers of private digital money.[20] Once widely accepted as medium of exchange, these private digital currencies may also become enshrined as unit of account in contracts within the realm of their ever-expanding ecosystems, and possibly beyond.

This is consistent with the model of Doepke and Schneider (2017), where an economy's dominant unit of account is determined by agents that are large and generate lots of payments. This has ensured that government-issued currency, in which government debt is denominated, has emerged as the dominant unit of account in advanced economies. The introduction of a CBDC could ensure that

[18] However, Lagos and Zhang (2019) show that monetary policy can still have real effects in an almost cashless economy.

[19] A milder case is Poland, where around 50 percent of mortgage loans outstanding in 2013 were denominated in foreign currency (Brzoza-Brzezina, Kolasa, and Makarski 2017).

[20] See Guennewig (2021) for a model with currency-issuing firms.

public money remains used in practice, and thus help ensure that it retains its unit-of-account status.

The loss of monetary sovereignty can entail significant costs.[21] First, it limits the effective conduct of monetary policy. Monetary policy transmits to the economy because prices are sticky in terms of the domestic currency. This is crucial for a monetary expansion to generate an increase in output rather than just a bout of inflation (Gali 2015). If prices are quoted in a different unit of account, the transmission of monetary policy is impaired. Moreover, Benigno, Schilling, and Uhlig (2022) argue that the presence of alternative means of exchange in the economy, such as cryptocurrencies and private digital currencies, constrains monetary policy. They find that, for public money to be used in exchanges rather than hoarded, the central bank may not set its policy interest rate above the return on the alternative means of exchange, although this may be desirable to control inflation.

Limited monetary sovereignty also gives rise to financial stability risks. In particular, it impairs the central bank's ability to act as "lender of last resort." Theoretically, the monetary authority can "print" unlimited amounts of the domestic currency to support financial institutions in distress (Skeie 2008; Allen, Carletti, and Gale 2014). However, such liquidity support is no longer available if liabilities are denominated in foreign currency, which increases the risk of bank runs (even for solvent institutions). Consistent with this mechanism, Levy-Yeyati (2006) shows that dollarized economies are exposed to a greater risk of financial crises.

The reach of large digital ecosystems is global. Accordingly, any digital currency issued by "BigTech" would have an international flavor and its use would transcend national borders, such as the initial Libra proposal (Libra Association 2019). Accordingly, the threat of "digital dollarization" is particularly acute for open economies with a significant reliance on foreign digital players (Brunnermeier, James, and Landau 2019). The need to fend off competition for public money from abroad may pose an additional challenge since it may limit the ability to use domestic regulatory tools. This is vividly

[21] Limited monetary sovereignty can be beneficial in economies with high inflation (Barro and Gordon 1983) or poor bank supervision (Gale and Vives 2002).

illustrated by ongoing transatlantic disagreements concerning the regulation of large U.S.-based digital platforms.[22]

### *3.3 Preserving Privacy*

The concept of privacy spans various dimensions, depending on the context or subject matter. Economists, however, typically focus on its informational aspects (Acquisti, Taylor, and Wagman 2016). From this perspective, Westin's (1967) classical definition is useful, according to which privacy is "the claim of individuals, groups, or institutions to determine for themselves when, how, and to what extent information about them is communicated to others."

The proliferation of personal data as lubricant of the digital economy gives rise to privacy concerns. While user awareness of data collection efforts by technology firms was low in the early days of the Internet, sentiment has shifted markedly in recent years. The results from the Eurosystem's public consultation on a digital euro suggest that consumers have become sensitive to the use of data derived from digital payments.[23] This raises two important questions. First, what level of privacy should electronic payments offer? And second, can we trust the market to provide digital money with adequate levels of privacy, or is there a need for policy intervention?

To answer the first question, one must first establish reasons for people to demand privacy in payments. One set of motives includes illegal activities such as drug trafficking, tax evasion, arms trade, etc. To combat those, commercial banks are subject to strict anti-money laundering and "know-your-customer" regulations.[24] It is crucial that innovative digital means of payments are compliant with these safeguards.

Abstracting from illicit behavior, people may also value privacy in payments for legitimate reasons. Kahn, McAndrews, and Roberds (2005) argue that the privacy provided by cash helps to mitigate

[22]See "US Warns EU against Anti-American Tech Policy," *Financial Times*, June 15, 2021.

[23]Forty-three percent of all respondents named privacy as the most important feature (European Central Bank 2021). It is important to note, however, that the survey was not representative.

[24]They also motivate upper limits on cash payments in many countries, and the discontinuation of the EUR 500 bill by the Eurosystem. See "ECB Ends Production and Issuance of €500 Banknote," ECB press release, May 4, 2016.

moral hazard issues (modeled as the risk of theft). Ahnert et al. (2022) develop a related argument in a theoretical model that captures key features of the digital economy. They study the joint choice of payment methods and distribution channels by merchants in need of financing. Online distribution generates high sales but requires the acceptance of digital payments. This provides information to the monopolist bank and exposes the merchant to rent extraction. While offline distribution results in lower sales, it allows the merchant to accept cash and hide some of the proceeds from the bank. In some cases, the merchant will opt for cash because the associated value of privacy exceeds the gains from more efficient distribution.

Importantly, Westin's definition of privacy also involves an element of control ("determination"). While the withholding of information can be economically efficient in some settings, its disclosure can be efficient in others (Acquisiti, Taylor, and Wagman 2016). Consistent with this view, Ahnert at al. (2022) show that digital payments with optional data-sharing features can increase welfare. When borrowers face multiple potential lenders, they will want to reveal their type to all of them in order to reap the benefits from competition. By contrast, they may prefer to stay anonymous when facing a monopolist, as discussed previously. This inverse relationship between the value of anonymity and the degree of credit market competition is illustrated in Figure 3.

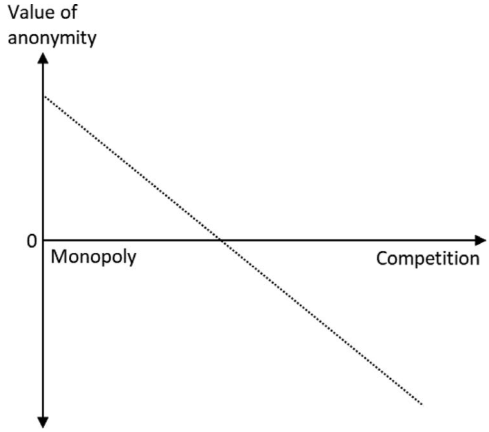
The perception that data hoarding by private entities presents an obstacle to innovation and competition is reflected in several recent policy and infrastructure initiatives aimed at promoting data-sharing and interoperability in the digital world. For example, the EU's Digital Markets Act aims at reducing exclusive control of data collected by digital platforms.[25] And Stack India, a major digital infrastructure project in India, aims to build an integrated platform for digital identities, payments, and data sharing.[26]

We next turn to the question whether one can rely on market forces to satisfy the demand for digital money with socially desirable levels of privacy. The analysis by Garratt and van Oordt (2021) answers this question with a resounding "No." Their model rests

[25]See https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/690589/EPRS_BRI(2021)690589_EN.pdf.

[26]See https://www.indiastack.org.

**Figure 3. The Relationship between the Value of Privacy and Competition in Financial Intermediation**




**Note:** This figure illustrates the relationship between the value of privacy (vertical axis) and the degree of competition in financial intermediation (horizontal axis) in the model of Ahnert et al. (2022).

on the observation that consumers share certain observable attributes that are related to their willingness to pay. Accordingly, the collection of payments data from current customers enables merchants to engage in price discrimination against future customers. While agents can protect their privacy at a cost, they only reap part of the social benefit, since they may not return to the same merchant. Accordingly, there is too little privacy protection in equilibrium, which results in a welfare loss. This is the case of a classic externality that calls for policy intervention.

The so-called privacy paradox raises additional concerns. While consumers tend to attribute a high importance to privacy in surveys, they tend to give away their data for free, or in exchange for very small rewards in practice (e.g., Norberg, Horne, and Horne 2007; Athey, Catalini, and Tucker 2017; Chen, Huang et al. 2021). Analyzing the roots for this apparent dichotomy, researchers point to various contributing factors such as asymmetric information, bounded rationality, and heuristics in decisionmaking (Acquisti, Taylor, and Wagman 2016). From a public policy perspective, these observations warrant further skepticism concerning the ability of market forces to reach efficient levels of privacy protection.

### *3.4 CBDC as a Tool to Address Market Imperfections*

Existing research shows that a retail CBDC could lead to better economic outcomes by reducing pre-existing market imperfections. The most prominent examples in this direction are inefficiencies in payment services and frictions in the financial intermediation process. However, the reach of CBDC potentially extends further, as we shall see below.

First, a retail CBDC could help reduce the cost of making payments. Williamson (2022b) and Keister and Sanches (2023) study settings in which means of payment are not perfectly substitutable, and agents use both currency and bank deposits. The introduction of CBDC as an additional means of payment can increase welfare by lowering the liquidity premium on bank deposits. Another channel for improving payment efficiency could be a reduction in the cost of making cross-border payments (Bank for International Settlements 2021a), which have experienced considerable growth due to increased travel and remittances.[27] At the same time, cross-border payments are often very expensive, which is often blamed on limited competition. Most CBDC designs are at the national (or currency-union) level, but there are efforts (e.g., at the G-20 level) to link such schemes through multi-CBDC arrangements (Auer, Haene, and Holden 2021). This could reduce the effective cost of making cross-border (and cross-currency) payment, both by offering a new service to consumers and by introducing competition among financial intermediaries.[28]

Second, a CBDC could address frictions in financial intermediation, such as market power in deposit markets, moral hazard, impediments to liquidity provision, and information flows to policymakers. Andolfatto (2020) and Chiu et al. (2022) show that the introduction of CBDC reduces the effective market power of banks in

[27]Remittances alone were USD 720 billion in 2019 (BIS 2021a). Moreover, the cost of remittances can be high: a EUR 140 payment from Germany to India incurs a fee of 0.5–3 percent (Bindseil and Pantelopoulos 2022).

[28]Part of the cost of cross-border payments comes from AML/CFT (Anti-Money Laundering and Countering the Financing of Terrorism) regulation, which is not directly related to the payments technology.

deposit markets by providing an outside option to depositors. This forces banks to compete and raise deposit rates. Moreover, to the extent that (remunerated) CBDC induces depositors to substitute away from bank deposits, the moral hazard friction of the bank is reduced and welfare increases (Williamson 2022a).

Keister and Monnet (2022) show that CBDC can also improve the information flow to policymakers (such as the lender of last resort) and thus improve the efficiency of interventions. A common concern is that CBDC provides a safe alternative to bank deposits and thus induces depositors to withdraw, which increases bank fragility (see Section 5). Since withdrawals are converted into CBDC during a bank run, the central bank learns about the state of the economy and responds more quickly. This reduces costly liquidation and the misallocation of resources. This information channel reduces the ex ante incentives of investors to withdraw, so that CBDC can have a beneficial impact on bank stability.

A CBDC may also improve the liquidity transformation services available to consumers (Fernández-Villaverde et al. 2021). If bank runs are possible, CBDC holdings are superior to bank deposits because the central bank (i) cannot be forced into liquidation and (ii) is better than a commercial bank at committing to illiquid investments. Effectively, the central bank takes over as financial intermediary and offers more liquidity to consumers than commercial banks could.

Finally, a CBDC may also have other benefits outside the financial sector. For example, Brunnermeier and Payne (2022) develop a model where digital platforms issue tokens as a means of payment and extract rents (e.g., fees or seigniorage). Customers accept tokens because of a network externality: using the token to sell today is acceptable because it can be used in the future to buy. CBDC, as widely accepted means of payments, competes with the private tokens and reduces platforms' market power.

Similarly, a CBDC introduction may allow governments to improve their control over payment infrastructures. This may be particularly valuable if the current system is dominated by foreign entities, which is the case for the European Union at the moment.[29]

[29]Another political economy consideration is how CBDC issuance and its effect on the size of the balance sheet may affect central bank independence (vis-à-vis

Further, a CBDC may provide a more efficient channel for governments to disburse fiscal transfers directly to citizens (unlike mailing checks). Additional features such as programmability may enhance the efficiency of fiscal policy—for example, through transfers with an expiration date that yield an increased marginal propensity to consume in crisis times.[30]

Finally, CBDC has been lauded as an opportunity for financial inclusion. However, survey evidence suggests that the share of unbanked households in the euro area is less than 5 percent (Ampudia and Ehrmann 2017). This suggests that the resulting benefits may be relatively small, at least compared to those expected for developing economies (Boar and Wehrli 2021).

## 4. Implications for Monetary Policy

This section studies the implications of a potential CBDC introduction on monetary policy. We first examine the effects on the transmission of monetary policy through the credit channel. We then discuss the role of a remunerated CBDC as a tool for monetary policy, and potential challenges for monetary policy implementation.

### *4.1 The Credit Channel*

The credit channel places banks at the heart of the monetary policy transmission mechanism. Since a CBDC can be considered as an alternative to bank deposits for households and firms, it is likely to affect the liability side of banks' balance sheets. This, in turn, may affect the supply of credit and thus the transmission of monetary policy.

One can differentiate between three determinants of CBDC's effect on credit: the impact on banks' funding costs, the impact on their capital, and changes to potential synergies between different bank activities. For the first two channels, the effect crucially

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the political system) and trust in the public institution (vis-à-vis consumers and citizens).

[30]For an analysis of digital cash with an expiration date to facilitate consumer loss recovery, see Kahn, van Oordt, and Zhu (2021). For the role of programmability for monetary policy, see Davoodalhosseini (2022).

depends on banks' response to the prevailing market structure in terms of competition and market discipline. We discuss these issues in turn.

The analysis by Keister and Sanches (2023) is consistent with the widespread concern among policymakers that a CBDC could reduce bank credit supply through "disintermediation" (e.g., Bindseil 2020). In their model, banks raise funds in a perfectly competitive deposit market. In this setting, the introduction of a CBDC crowds out deposits, raises banks' funding costs, and leads to a decline in bank lending. While Agur, Ari, and Dell'Ariccia (2022) study a slightly different framework, they also assume a perfectly competitive deposit market and come to broadly similar conclusions. These results raise the question whether the central bank could close banks' funding gap through lending operations. This is formally examined by Brunnermeier and Niepelt (2019), who provide conditions for CBDC neutrality in this context.

Crucially, models with imperfect competition in deposit markets come to different conclusions. In Andolfatto (2021) and Chiu et al. (2022), market power enables banks to artificially restrain deposit supply and keep funding costs low. In this setting, a remunerated CBDC presents consumers with a potential outside option, and thus forces banks to compete more fiercely by raising deposit rates. As long as the CBDC remuneration is not too high, this increases deposit volumes and, ultimately, bank lending.[31] This mechanism is consistent with empirical work which shows that banks increase deposit rates significantly in response to greater competition (Drechsler, Savov, and Schnabl 2017). Garratt and Zhu (2021) study the resulting implications in a setting with heterogeneous banks. Since deposits in smaller banks provide less convenience to depositors (e.g., through smaller branch and ATM networks), their deposit base is more vulnerable to an increase in CBDC remuneration. This may lead to a more concentrated banking sector.

The second key factor affecting the effects of CBDC on credit supply is bank capital. Banks hold equity to comply with regulation (Van den Heuvel 2008) and to align the incentives of owners and

[31]In Whited, Wu, and Xiao (2022), banks exert market power but also face an external financing friction when raising wholesale funding. In this environment, a CBDC leads to a moderate decline in bank lending.

managers through "skin in the game" (Gertler and Kiyotaki 2010). Hence, an insufficient level of capital constrains bank lending.[32] The empirical evidence suggests that banks predominantly accumulate capital through retained earnings (Cohen 2013). However, the effect of CBDC on banks' profit-retention decisions is ambiguous. On the one hand, CBDC is likely to put pressure on banks' profits through a loss of market power in deposit markets, which leaves fewer earnings to retain. On the other hand, the ability of bank creditors to switch from bank debt to perfectly safe CBDC can force banks to compete on safety, and thus sharpen their incentives to accumulate capital. This can induce banks to retain a larger share of their profits. The latter effect is likely more powerful in a scenario in which CBDC leads to a shift in banks' funding mix towards more uninsured debt, which is particularly associated with market discipline (Calomiris and Kahn 1991; Diamond and Rajan 2001).

Banks bundle multiple financial activities under one roof because of the existence of synergies. A classic example is the synergies between deposit-taking and lending through credit lines (Kashyap, Rajan, and Stein 2002). Since deposit withdrawals and credit-line drawdowns are imperfectly correlated, the joint provision of both services enables banks to economize on costly liquid asset holdings. Building on this intuition, Piazzesi and Schneider (2020) show that a CBDC-induced decline in deposit funding implies a loss of synergies and thus a decline in credit provision.

Banks also reap synergies between deposit-taking and lending in their management of interest rate risk. In particular, since deposit rates are sticky (Neumark and Sharpe 1992; Driscoll and Judson 2013), increases in interest rates only translate gradually into higher interest expenses for banks, if at all. The long-effective duration of deposit funding allows banks to insure borrowers against interest rate risk through long-term fixed-rate loans without incurring exposure to interest rate risk (Hoffmann et al. 2019; Drechsler, Savov, and Schnabl 2021). If a CBDC renders deposit markets more

[32] Eren, Jackson, and Lombardo (2021) argue that CBDC issuance allows banks to engage in more productive lending per unit of capital. As the central bank balance sheet absorbs more relatively safe assets (e.g., government bonds or mortgage-backed securities), this frees up space on bank balance sheets for business loans.

competitive, it may increase banks' exposure to interest rate risk (Whited, Wu, and Xiao 2022).[33]

### *4.2 CBDC Remuneration as Monetary Policy Tool*

Major central banks have expressed the view that the use of CBDC as a monetary policy tool is not the main focus of their explorations. Accordingly, the introduction of a CBDC aims to complement cash, not to replace it (Group of Central Banks 2020). While this is often also understood to mean that CBDC should be available like banknotes, i.e., supplied elastically and without remuneration, it need not necessarily follow. Importantly, an unremunerated CBDC with elastic supply would limit monetary policy space by introducing a hard zero lower bound on interest rates.[34]

Instead, a remunerated CBDC could be an option to overcome the effective lower bound (ELB) on interest rates (Bordo and Levin 2017, Lilley and Rogoff 2021). The remuneration could be adjusted with policy rates over the business cycle and potentially become negative, thereby eliminating the potential for a liquidity trap. However, this would require phasing out banknotes to prevent cash hoarding when interest rates on digital currency become negative, which major central bank have already committed not to do (Group of Central Banks 2020).[35]

Bindseil (2020) notes that in a negative interest rate environment demand for CBDC would be potentially unlimited if it were remunerated at a zero interest rate. At the same time, a CBDC carrying a negative interest rate might face adoption obstacles, as users would perceive cash as a less costly means of payment. To steer demand, Bindseil therefore proposes a tiered remuneration system, in which a first tier of CBDC holdings would be remunerated at

[33] Alternatively, banks could demand greater compensation for interest rate risk in the form of higher term premiums.

[34] In contrast to banknotes, CBDC can be held at no cost and without risk of loss or theft, which would prevent central banks from lowering policy rates into negative territory.

[35] Lilley and Rogoff (2021) list a number of other approaches to discourage cash hoarding in the presence of a negative remuneration on a digital currency—among others, phasing out larger banknotes (Rogoff 2016) or creating a crawling peg between paper and electronic money (see also Agarwal and Kimball 2019 or Assenmacher and Krogstrup 2021).

a non-negative interest rate whereas a second tier would bear an unattractive penalty rate, and the remuneration on both tiers would potentially move in tandem with policy rates. Such a scheme, however, would be difficult to explain to the public and might impede adoption as well as usability of CBDC for the average consumer, in particular in the presence of alternative private digital means of payment. Moreover, CBDC holdings could be more responsive to changes in policy rates than cash and probably also than bank deposits that currently react to policy rate changes only partially and with a lag. This would potentially strengthen the transmission of policy rate changes to bank funding rates and might thereby also increase the transmission to bank lending rates (Whited, Wu, and Xiao 2022).[36]

Beyond strengthening monetary policy transmission, a remunerated CBDC could give the central bank an additional tool that it could use for targeting other objectives, such as the exchange rate or the liquidity premium on bank deposits. By operating as a means of exchange, CBDC opens up new channels for monetary policy to affect output and inflation. Assenmacher, Bitter, and Ristiniemi (2022) link a New Monetarist model to a New Keynesian model with financial frictions and show that the central bank can separately target the store-of-value and the means-of-exchange function of money by steering the supply of CBDC. This offers an additional channel for stabilizing the economy by exploiting a trade-off between payments efficiency, bank funding conditions, and the opportunity cost of holding money. This is in line with Keister and Sanches (2023), who conclude that welfare is often maximized when the central bank uses the CBDC interest rate to increase total real money balances and lower the equilibrium liquidity premium, although this results in some bank disintermediation. George, Xie, and Alba (2020) use a slightly different modeling setup in an international context and find that the existence of CBDC allows monetary policy to target both the domestic price level and the exchange rate, analogous to sterilized foreign exchange interventions.

The implications of CBDC for monetary policy implementation and transmission will largely depend on the characteristics of CBDC

[36]See Jiang and Zhu (2021) for an analysis of the interactions between the potentially different interest rates on reserves and CBDC.

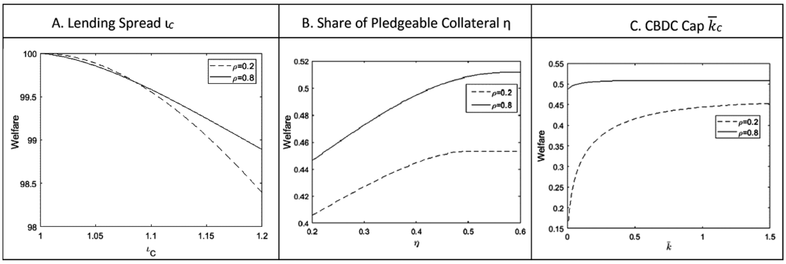
and the design choices that will be made. Amongst the key choices, central banks will need to decide who should be able to use CBDC, whether and how it would be remunerated, and whether its use would be subject to holding or transaction limits (Auer, Cornelli, and Frost 2020). As stated in the introduction, we abstract from wholesale considerations and only consider the implications of a retail CBDC accessible to citizens and firms. One question is whether the use should be confined to domestic users or whether non-residents also would be allowed to transact with a domestic CBDC. While CBDC could increase the efficiency of cross-border payments significantly, it could potentially lead to large cross-border financial flows and create new international arbitrage conditions between domestic and foreign interest rates and the exchange rate. Large holdings of a foreign CBDC could potentially lead to stronger international spillovers and complicate monetary policy trade-offs for economies not issuing a CBDC (Ferrari Minesso, Mehl, and Stracca 2022).

Remuneration has been identified as one important attribute that affects the potential demand for CBDC (see Li 2021). While a tiered remuneration would allow a central bank to influence demand and use the CBDC rate as an additional policy tool, it is less clear whether changes in the remuneration would be sufficient to control demand also during crisis episodes. Fegatelli (2021) proposes to deal with large shifts in CBDC demand by using reserve requirements as a tool for macroeconomic stabilization instead of only changing policy rates.

Alternatively, holding or transaction limits have been proposed as an additional safeguard to steer demand for CBDC (European Central Bank 2020) and avoid CBDC crowding out bank deposits, thereby interfering with monetary policy transmission and financial stability objectives (see also Section 5.1). While holding limits would be highly effective in constraining the overall amount of CBDC in circulation, they come with certain drawbacks. First, it is difficult to calibrate a holding limit that can be applied equally to different users of CBDC, such as households and firms with potentially very different payment needs.[37] Second, constraining holdings to a

[37]This problem remains even if holding limits could be differentiated for different users, as the limit would need to be based on an objective and easily observable statistics.

**Figure 4. The Welfare Effects of CBDC in the Model of Assenmacher et al. (2021)**




**Note:** This figure depicts welfare as a function of the lending spread, the share of pledgeable collateral, and the CBDC cap for different degrees of substitutability $\rho$.

maximum amount may give rise to a shadow price of CBDC compared to other forms of money. Third, as holding limits could constrain the ability of a payee to accept payment in CBDC, it might conflict with declaring CBDC legal tender. A possible solution could be to combine such limits with a waterfall approach that transfers amounts exceeding the maximum holding amount to a bank account (Bindseil, Panetta, and Terol 2021). This, however, would make CBDC less financially inclusive, as its use would be tied to the possession of a bank account. Finally, limits may give rise to commitment problems similar to the ones known from the optimal monetary policy literature (see, e.g., Woodford 2003), as the central bank may find it difficult to enforce or tighten these limits when they are needed most (e.g., in the case of a bank run).

Overall, it can be concluded that although safeguards allow the central bank to better control the amount of CBDC in circulation, they also give rise to wedges that increase the liquidity premium on CBDC and therefore limit the associated welfare gains (Assenmacher et al. 2021, Burlon et al. 2022, Keister and Sanches 2023).

This is illustrated in Figure 4, which is based on Assenmacher et al. (2021). As the interest rate spread between the central bank's lending rate for CBDC relative to the rate for holding CBDC increases, welfare is reduced (panel A). Conversely, welfare increases when more collateral is available or when the central bank raises the maximum amount of CBDC that it is willing to issue (panels B and C). The figure also demonstrates that the welfare effects depend on the degree of substitutability between CBDC and bank deposits. The higher the degree of substitution, the smaller is the welfare loss from restricting the availability of CBDC, suggesting that such tools are less costly if the risk of bank disintermediation is high.

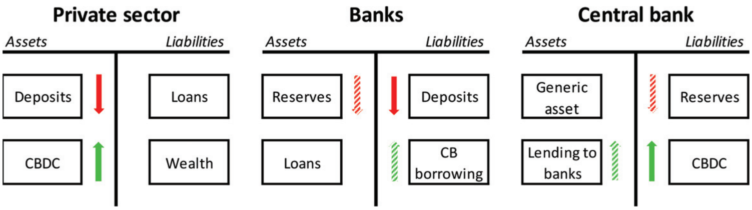
### *4.3 CBDC and Implications for Monetary Policy Implementation*

A CBDC introduction will have implications for monetary policy operations as well as the size and structure of the central bank's balance sheet that depend, on the one hand, on the amount of CBDC that would be in circulation, and, on the other hand, on how the central bank reacts to this demand. Brunnermeier and Niepelt (2019) and Niepelt (2020a, 2020b) argue that the introduction of CBDC would be neutral with respect to bank funding if the central bank undoes the effects resulting from a substitution of deposits for CBDC by lending more to banks. Figure 5 depicts the resulting balance sheet adjustments. When a CBDC becomes available, households may decide to substitute some of their deposits for CBDC. If banks have sufficient reserves to accommodate the deposit outflow, their balance sheet size would decrease and reserves would be substituted for CBDC on the central bank's balance sheet (hatched red arrows in Figure 5). If banks' reserve holdings were insufficient, they would need to obtain additional reserves by borrowing from the central bank, which would imply a lengthening of the central bank's balance sheet (hatched green arrows in Figure 5).[38]

To ensure that the capital allocation and prices are not affected by the introduction of CBDC, central bank loans to banks would have to replicate the characteristics of deposits lost by banks. In particular, they would have to be uncollateralized. As long as the central bank maintains its collateral standards, equivalence of CBDC and deposits can therefore not be ensured. Williamson (2022b) notes that the central bank may have to take on private assets in its portfolio if CBDC significantly displaces privately supplied means of

[38]As an alternative to the usual liquidity-providing repo operations, the central bank could also decide to conduct outright purchases, i.e., acquiring securities from the banking sector.

**Figure 5. The Balance Sheet Effects of CBDC**




**Note:** This figure illustrates the balance sheet implications of a CBDC introduction for the private sector, banks, and the central bank.

payment. Fernández-Villaverde et al. (2021) argue that the equivalence result is fragile and will break down in an economy that is prone to financial crises because a central bank is more stable than commercial banks. As depositors would anticipate this, CBDC would crowd out deposits completely. Fraschini, Somoza, and Terracciano (2021) investigate the equivalence result with a particular focus on the efficiency in the provision of CBDC. If CBDC is provided more efficiently than bank deposits, the central bank's balance sheet will lengthen and seigniorage revenues will increase. This may allow for a reduction in taxes if the effect is quantitatively important.[39] Kahn, Singh, and Alwazir (2022) argue that, to the extent that a CBDC increases the usefulness of central bank money and draws demand away from private monetary assets, it has the potential to increase the central bank's control over monetary policy and its ability to reap seigniorage.

The impact of CBDC on monetary policy implementation depends on the size of CBDC demand and the policy environment at the time of the CBDC introduction. Volatility in the demand for CBDC could make interest rate control in a corridor system more challenging. This might be easier to handle in a floor system where excess reserves are sufficiently large (see Malloy et al. 2022). In this case, a CBDC introduction in an environment with large excess liquidity would allow banks to satisfy CBDC demand by running down their excess reserves. Whenever excess reserves face a negative interest rate, such a conversion could affect bank profitability

[39]Note that the effect on seigniorage depends on the level of CBDC remuneration.

positively, although it needs to be recognized that the distribution of excess reserves is not homogeneous across banks (Fegatelli 2021, Adalid et al. 2022).

The emergence of new forms of digital money may also require the central bank to rethink its counterparty framework. If non-bank entities were to distribute CBDC to the public, they might require direct access to the central bank's balance sheet in order to manage CBDC distribution efficiently.[40] If a CBDC existed, private stablecoin issuers could also consider holding it as a part of their reserve (Libra Association 2019).

In sum, a CBDC would require the central bank to rethink its monetary policy implementation framework. Besides the question of how a potential CBDC remuneration would fit into the set of key policy rates, a sufficiently large CBDC take-up would have implications for the size and structure of the central bank's balance sheet that could affect the operational framework, i.e., corridor or floor, and the type and maturity of operations (refinancing operations versus outright purchases).

## 5. Implications for Financial Stability

Financial stability considerations feature prominently in the policy discussion on CBDC (see BIS 2021b). The concerns primarily focus on the safety and remuneration of CDBC claims relative to bank deposits, and the resulting implications for bank stability.[41]

The financial stability implications of CBDC are likely to operate through several different channels. Ultimately, bank stability is the result of banks' and creditors' decisions, which are further intertwined with the effectiveness of prudential regulation and the lender-of-last-resort policy in place. One way to illustrate this is to differentiate between the effects of CBDC on the liability and asset

[40] Similarly, the central bank may also consider broadening its collateral framework.

[41] Despite the presence of deposit insurance, a large fraction of bank deposits in the United States and Europe are uninsured (see, e.g., Egan, Hortaçsu, and Matvos 2017 for U.S. data). Furthermore, the lack of a pan-European deposit insurance scheme has undermined the credibility and effectiveness of national deposit insurance schemes during the sovereign debt crisis. Accordingly, financial stability risks due to bank runs remain economically important.

sides of the bank balance sheet. The former refers to the impact on funding costs and short-term liquidity through creditors' withdrawal decisions. The latter, instead, encompasses the implications for banks' risk-taking incentives. In addition, as we illustrate in detail below, separate considerations on the effect of CBDC on the ability of authorities to intervene and enhance stability are also relevant to financial stability.

### *5.1 The Liability Side: Fragility and (Digital) Bank Runs*

On the liability side, bank fragility is rooted in banks' role as liquidity providers (Diamond and Dybvig 1983; Goldstein and Pauzner 2005). Banks raise funds in the form of demandable deposits and invest them in illiquid and risky assets. While this structure enables them to provide liquidity insurance to risk-averse depositors, the resulting maturity mismatch exposes them to the risk that depositors withdraw their funds before the maturity of their assets (a "bank run").

Bank runs occur either because (i) depositors panic and withdraw early out of the self-fulfilling belief that other depositors will do the same and the bank will fail (Diamond and Dybvig 1983) or (ii) due to a deterioration of economic conditions (Gorton 1988; Allen and Gale 1998, 2004). Irrespectively, depositors choose to withdraw early because they expect to receive a higher repayment from doing so. The value of the available outside investment opportunity when running is then crucial in determining depositors' withdrawal incentives and, in turn, the probability of a bank run.

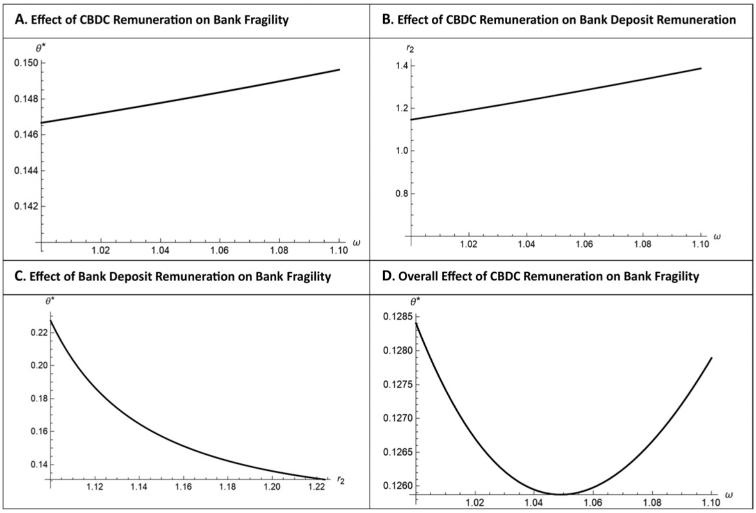
This logic captures policymakers' concern that the introduction of a CBDC could lead to an increase in bank fragility (see, e.g., Broadbent 2016; Callesen 2017). Given its safety (plus the potential to carry interest), CBDC is considered to increase run incentives relative to an economy where cash holdings are the only alternative to bank deposits. This is especially true when depositors have low expectations about bank health, because converting bank deposits into CBDC shields them from the risk associated with a bank failure. Since the central bank can always honor its debts by printing currency, it is perceived as a safe investment and not subject to runs. Consistent with this flight-to-safety view, Williamson (2022a) shows that the introduction of CBDC increases the set of parameters for which runs on bank deposits can occur in a multiple equilibrium model.

The above flight to safety argument hinges on the fact that CBDC holdings are shielded from runs. This point is explored in Skeie (2020), where CBDC eliminates the bank run problem: The central bank prints money and this implies that nominal deposit claims are always honored, although the real value of these claims falls. This aspect is also present in Schilling, Fernández-Villaverde, and Uhlig (2022), where the introduction of CBDC confronts the central bank with a trilemma between the central bank's traditional price stability objective, the attainment of the efficient allocation of resources, and the maintenance of trust in the value of currency. However, their analysis does not feature commercial bank runs, since CBDC fully crowds out bank deposits (as in Fernández-Villaverde et al. 2021).

Allowing for runs on commercial banks, Ahnert et al. (2022) study the implications of CBDC remuneration for bank fragility. They model an economy in which investors can either hold their funds in bank deposits or in CBDC accounts with the central bank. In their global-games framework, the probability of a bank run is endogenous and depends on the level of CBDC remuneration and the terms of the deposit contract set by profit-maximizing banks. In this setting, a change in CBDC remuneration has two countervailing effects on the probability of a bank run. On the one hand, a higher CBDC remuneration increases the incentive for depositors to run into CBDC, since it enables higher consumption in the future. This mechanism is illustrated in Figure 6 (panel A), which shows that, all else equal, an increase in the remuneration of CBDC leads to a higher probability of a bank run. On the other hand, an increase in CBDC remuneration induces banks to counter a potential outflow of deposits by adjusting the deposit contract. To compensate depositors for the more valuable outside option and the associated higher fragility, banks raise the promised repayment to depositors, as shown in panel B of Figure 6. This, in turn, decreases the incentive to withdraw early and thus the probability of a bank run (Figure 6, panel C).

Since the two effects described operate in different directions, the relationship between CBDC remuneration and bank stability need not be monotonic. In particular, if bank lending is sufficiently profitable, it will be U-shaped as illustrated in panel D of Figure 6.

**Figure 6. CBDC Remuneration and Bank Fragility**




**Note:** The variable $\omega$ captures the gross CBDC remuneration, so the economy without CBDC corresponds to the case where $\omega = 1$. Financial fragility is measured by the variable $\theta^*$, which represents the endogenous probability of a bank run. The remuneration of bank deposits is denoted by $r_2$. The graphs are based on the following parameter values: liquidation value $L = 0.9$, date-2 project return $R = 15$. Source: Ahnert et al. (2022).

In this case, some positive but not too high CBDC remuneration reduces financial fragility relative to an economy with only cash.

The analysis above focuses on the effect that CBDC has on financial stability, through the impact it has on depositors' incentives to run. It abstracts from changes in the type of funding banks raise and in the amount of bank deposits, both of which may have implications for financial stability. However, the introduction of CBDC may also have an impact on both the costs of retail deposits and their quantity. As retail deposits become more expensive following the introduction of CBDC, banks may have incentives to substitute retail deposits with less stable, but cheaper, sources of funding, like wholesale deposits, thus increasing bank fragility.[42] Similarly, by

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[42]Evidence of a similar substitution between (stable) retail and (unstable) wholesale deposits following a monetary policy tightening is provided in Choi and Choi (2020).

representing a safe and valuable investment opportunity, the introduction of CBDC may induce investors to (partially) replace bank deposits with CBDC accounts. This reduction in bank deposits can also have negative implications for financial stability: as the supply of private credit is reduced, the nominal interest rate rises and banking panics can occur for a larger set of parameters (Kim and Kwon 2023).

The potential negative consequences for financial stability associated with the introduction of CBDC can be curbed by design features such as CBDC remuneration or holding limits (see the discussion in Section 4.2). Holding limits aim to prevent CBDC from crowding out bank deposits, although they do not curb depositors' incentives to run into CBDC, especially when there are concerns about banks' health. Similarly, a recalibration of liquidity requirements for banks to account for the higher risk of deposit outflow could be implemented to reduce the consequences of runs into CBDC. A remuneration of CBDC below short-term market rates has been proposed as a way to limit the attractiveness of CBDC relative to bank deposits to minimize both the risk of a run and bank disintermediation. In the context of the Eurosystem's digital euro project, pros and cons of introducing a quantitative cap on digital euro holdings or a tiered remuneration are investigated (Panetta 2022).

### *5.2 The Asset Side: Profits Margin and Risk-Taking Incentives*

On the asset side of their balance sheet, banks' risk-taking decisions are a key driver of fragility. Traditionally, changes in risk-taking incentives have been associated with changes in profit margins. Since lowering risk on the asset side entails costly screening and monitoring, banks are only willing to exercise such effort if they expect to accrue sufficiently large gains in return. This is the reason why increased risk-taking has been traditionally linked to more competitive banking markets (Keeley 1990), or accommodative monetary policy (Dell'Ariccia, Laeven, and Marquez 2014; Martinez-Miera and Repullo 2017; and Heider and Leonello 2021).

Building on these arguments, a CBDC introduction may lead to increased risk-taking due to reduced bank profitability and compressed interest margins. This may operate through different channels. First, as discussed in the previous section, banks may respond to the introduction of CBDC by increasing deposit rates. Unless they are able to compensate for this increase in funding costs through higher lending rates, interest margins will decline and give rise to excessive risk-taking and financial instability. Second, even if banks can pass on the increase in funding costs to borrowers, they are likely to face a reduction in lending volumes. However, Monnet, Riva, and Ungaro (2021) challenge this view. In their model, an increase in the interest paid on CBDC lowers the real price of capital. This allows banks to lend more, and to increase their profits despite the associated increase in funding costs. As a result, the incentives to engage in risk-taking decline.

CBDC may also affect banks' risk-taking incentives by affecting market discipline. This argument closely relates to the impact of CBDC on depositors' withdrawal incentives, since the probability of a run determines banks' expected profits and also captures the extent of discipline that depositors exercise on banks (Calomiris and Kahn 1991). Thus, changes in the threat of a run triggered by the introduction of CBDC also affects banks' incentives to take risk. Two mechanisms are at play. On the one hand, a stronger threat of a run translates into more discipline for banks. Banks anticipate that depositors are ready to react to their risk choices and so, in the attempt to avoid the losses associated with early liquidation, banks take less risk. On the other hand, when the run probability is high, banks are confronted with lower expected profits, thus reducing their incentives to behave prudently. Whether CBDC fosters banks' risk-taking incentives, then, depends on how it affects runs, as well as on the impact of a change in the run probability on banks' profits.

### *5.3 Impact on Financial Stabilization Policies*

Thus far, our discussion has abstracted from the role played by prudential policies and interventions (bailouts, deposit insurance, lender-of-last-resort support) for curbing distorted incentives and enhancing financial stability. Their design is crucial for their effectiveness, as well as for minimizing the potential side effects in terms of moral hazard (Gale and Vives 2002; Keister 2016; Allen et al. 2018). Crucial features include the timing of the intervention, the information the policy authority has on banks' health and the fundamentals of the economy, and its commitment to a specific size and type of intervention.

Given their role in enhancing financial stability, it is important to understand whether and how the introduction of CBDC may interact with prudential policies. In particular, can CBDC help prudential authorities in supporting financial stability? If so, which design features of CBDC may play an important role?

Keister and Monnet (2022) study the role of CBDC on policy interventions by a public authority which lacks commitment and learns the state of the economy with a lag. In their framework, the following trade-off is at play. On the one hand, a CBDC leads to more runs because it provides a more profitable outside option to bank depositors. On the other hand, a CBDC enables the policymaker to acquire real-time information on banks' health by monitoring the flow of resources in and out the CBDC accounts. This allows for more timely interventions. Depending on which of these two effects dominates, the introduction of CBDC may decrease or increase financial stability. The analysis also speaks to the debate on design features. From a financial stability perspective, an account-based CBDC would be preferable to a token-based system where such information is impossible to obtain. Furthermore, the introduction of limits would reduce the precision of the information that can be obtained by the public authority.

Finally, the introduction of CBDC can also improve financial stability by reducing the moral hazard problem associated with implicit support guarantees for the banking sector. Part of the rationale for support from policymakers is banks' essential role in the payment system. With the introduction of CBDC, banks become less special, which reduces the social case for preferential treatment and the associated distortions.

## 6. Policy Issues and Challenges

This section discusses a number of issues and challenges that are of first-order significance in the policy debate on CBDC. First, we discuss potential alternatives for reaching some of the objectives that CBDCs aim to achieve. We then discuss issues related to end-user adoption, followed by political economy considerations.

### 6.1 Regulatory Alternatives

While many central banks are actively engaged in researching the potential of CBDCs, they have thus far only been launched in two countries, namely the Bahamas (Sand Dollar) and Nigeria (e-Naira). At the same time, some prominent policymakers have voiced concerns that CBDC is "a solution in search of a problem."[43] While survey data show that central bankers view a CBDC introduction as an increasingly realistic scenario (Kosse and Mattei 2022), it is natural to ask whether some of the key objectives (outlined in Section 3) could be reached through alternative approaches.

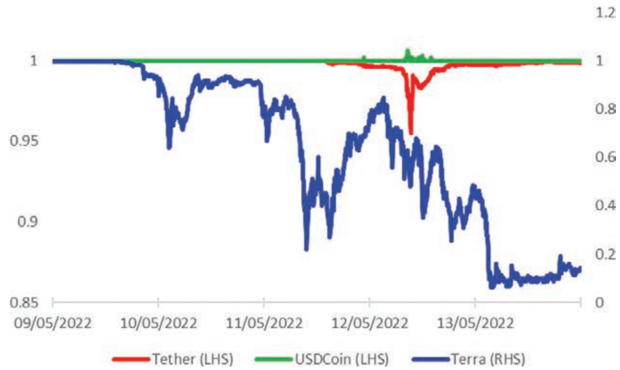
There is no regulatory alternative that promises to eliminate the threat to the two-layer monetary system. Since cash is only available in physical form, it is by construction not "fit" for the digital age. Regulations that aim at maintaining its large-scale use are likely to imply large economic costs without clear benefits. Accordingly, the introduction of digital cash in the form of a CBDC appears to be the only solution to guarantee a smooth continuation of the current monetary system.

The threat to monetary sovereignty is a major one. The explosive mix of BigTech and cryptocurrencies—especially stablecoins—is at the center of attention, and the strength of network externalities in payments and digital services implies that public policy must act decisively and in a forward-looking manner. Absent regulatory action, stablecoins are subject to the same financial stability risks as other forms of weakly regulated private money, such as banknotes during the "free-banking era" or money market mutual funds before the 2007–08 financial crisis (Kacperczyk and Schnabl 2013; Gorton and Zhang 2023). These concerns became very tangible in May 2022, when the then fifth-largest stablecoin Terra was wiped out in a matter of days following a crash in its major reserve asset, the cryptocurrency Luna.[44] Concerns about the quality of the reserve

[43] See https://www.federalreserve.gov/newsevents/speech/waller20210805a.htm and https://www.fnlondon.com/articles/ex-boe-governor-mervyn-king-calls-britcoin-a-solution-without-a-problem-20220118.

[44] Notably, Terra was a so-called algorithmic stablecoin, which typically rely on hard-wired exchange rate policies implemented through smart contracting on a blockchain. In principle, such arrangements have the potential to solve commitment problems (see Routledge and Zetlin-Jones 2021). However, in this case the

**Figure 7. Price Evolution of Selected Stablecoins around the Terra/Luna Crash in May 2022**




**Note:** This figure depicts the price evolution (in USD) of three major stablecoins (Tether, USDCoin, and Terra) from May 9 to May 12, 2022. Source: Refinitv.

asset pool also induced a significant temporary price drop in Tether, the world's largest stablecoin (see Figure 7).[45]

At the same time, our current monetary system is the result of carefully designed regulation. It is therefore not obvious that adjustments to the regulatory framework are not a viable alternative to a CBDC. Lawmakers in advanced economies are currently drawing up regulatory proposals to this end. For example, the EU Markets in Crypto-Assets Regulation (MICA) aims to restrict the issuance of stablecoins to banks and so-called e-money institutions.[46] In the United States, the President's Working Group has published a report that recommends even tighter rules, including limits on the affiliation with commercial entities (such as "BigTech"). In the meantime, at

value of the backing collateral became essentially worthless, which rendered the mechanism ineffective and exposed the design flaws in Terra.

[45]In an interview held during the same week, Tether's chief technology officer declined to provide detailed information about the collateral pool. See "Crypto Industry Shaken as Tether's Dollar Peg Snaps," *Financial Times*, May 12, 2022.

[46]Broadly speaking, e-money institutions are payment providers without a banking license. They face capital requirements, are subject to supervision, and typically are required to hold customer funds in the form of commercial bank deposits (which may or may not enjoy the benefits of pass-through deposit insurance, depending on the regulatory framework).

least one major stablecoin issuer (Circle/USDCoin) has announced plans for obtaining a U.S. banking license.[47]

These proposals would bring new forms of digital money into the regulatory perimeter and help to address some of the major concerns related to monetary sovereignty and financial stability. Moreover, strict limitations on the universe of eligible reserve assets (e.g., short-dated government bonds) could curb incentives for risk-taking.[48] However, Gorton and Zhang (2022) point out that stablecoins constitute "circulating money" (i.e., token-based money) and argue that protecting them through the public safety net—especially deposit insurance—may be infeasible because it only applies to account-based money (at least in its current form). Accordingly, they advocate to strengthen the public monopoly on circulating currency.

Some of the issues related to privacy in electronic payments could be addressed by expanding upon existing regulatory frameworks, such as the General Data Protection Regulation (GDPR) and the Revised Payment Services Directive (PSD2) in the European Union. However, the proliferation of data not only creates privacy concerns but also promises significant efficiency gains. Accordingly, a blanket prohibition of the use of payments data is unlikely to be a socially optimal solution. At the same time, disparities between public and private values of privacy (Garratt and van Oordt 2021) and the "privacy paradox" imply that market forces alone will not lead to desirable outcomes in terms of data sharing, so that regulatory intervention may be required.

Finally, central bankers expect CBDCs to increase the efficiency of payment systems (Boar and Wehrli 2021). The key question is whether upgrades of the current infrastructure towards "fast payment systems" could attain similar benefits without making major

[47]See https://www.forbes.com/sites/stevenehrlich/2022/04/05/ceo-behind-50-billion-stablecoin-explains-why-not-all-digital-dollars-are-created-equal/?sh=198ca7f67972.

[48]In the extreme, regulators could even require stablecoins to be backed one-for-one with central bank reserves. Such "synthetic CBDC" (Adrian and Mancini-Griffoli 2021) arrangements would provide the broader public with indirect access to central bank money, even though they represent private-sector liabilities. At the same time, they would broadly lead to the same concerns regarding bank disintermediation and financial stability as a fully fledged CBDC.

changes to the overall financial system. This is of particular relevance for the euro area, where payment systems remain fragmented along national borders, so that progress towards a better infrastructure has progressed in an uneven manner.[49] The European Payment Initiative (EPI) is a private-sector attempt to build a pan-European retail payment system in order to increase efficiency and lower the dependence on large non-European providers such as Visa, Mastercard, and PayPal. However, progress has stalled and a significant number of banks have left the consortium in the meantime in order to retain focus on existing national solutions, citing a lack of public financial backing in the light of significant setup costs.[50] Similarly, the Eurosystem's instant payments services TIPS has not led to a proliferation of fast retail payments. Brazil's successful launch of "Pix" suggests that regulatory intervention may be a powerful tool in establishing the sufficient network effects required for widespread adoption of such services (Duarte et al. 2022).

### *6.2 Too Much vs. Too Little: Ensuring Adoption of CBDC*

Much of our discussion has highlighted the risk of "excessive" CBDC take-up and the resulting implications for monetary policy and financial stability. At the same time, central banks will also be keen to avoid introducing a product that is not used in practice. While some theoretical models stress the value of CBDC as an "outside option" for disciplining private actors, a low take-up would likely signal low user demand, and at least lead to a public perception of "failure." Moreover, a lack of adoption may also diminish the ability of CBDC to act as a public anchor for the monetary system. Accordingly, it is important to understand the determinants of users' choices in the market for payments.

Due to the existence of strong network externalities, the barriers to entry in the market for payments are extremely high. To be successful, a new means of payment must attract a critical mass of both merchants and consumers simultaneously. Consistent with

[49] Examples of successful transitions to more efficient payments systems, including P2P (peer-to-peer) transfers, include Swish in Sweden and Bizum in Spain.

[50] See "New European Payments Project Hits Major Snag," Reuters, December 23, 2021.

the asymmetric pricing structure predicted by theoretical models, merchants typically face relatively high interchange fees.[51] Accordingly, a CBDC based on cost recovery could aim at ensuring widespread adoption by merchants, which would be a necessary condition for becoming a successful means of payment. It would also be consistent with previous efforts to regulate interchange fees as a tool to increase merchant acceptance (Valverde, Chakravorti, and Fernández 2016).[52] However, as digital payments can be bundled with other services such as data analytics (e.g., PayPal Marketing Solutions) or consumer credit (e.g., Klarna, Affirm), merchant adoption may no longer be exclusively driven by cost considerations. Accordingly, a successful CBDC must be embedded into an infrastructure that facilitates such bundling, since it otherwise risks being supplanted by private payment solutions.

Success, however, also requires uptake by the consumer. There is an extensive empirical literature analyzing the determinants of payment choices in retail markets. Most studies find that consumers tend to make small payments in cash and resort to electronic payments such as debit and credit cards for larger amounts (Klee 2008; Chen, Rysman et al. 2021). This behavior is consistent with the classical Baumol-Tobin view of opportunity costs (in terms of foregone interest) as key determinant for money demand (Baumol 1952; Tobin 1956; Alvarez and Lippi 2009). This is also supported by Li (2021), who predicts that a 0.1 percent increase in CBDC remuneration would increase demand by 8 percent to 18 percent. More broadly, the empirical evidence suggests that consumers act cost-consciously: they avoid payment methods that incur additional fees and indulge those that grant rebates such as bonus points (Ching and Hayashi 2010; Simon, Smith, and West 2010; Carbó-Valverde and Liñares-Zegarra 2011).

The secular shift from cash to electronic payments has also revealed a non-trivial role of non-monetary factors such as

[51]Interchange fees refer to the payment that the merchant's bank makes to the consumer's bank whenever a purchase is settled using a card, both debit and credit. These fees are then transferred by the merchant's bank to the retailer, which, in turn, may pass the fees on to consumers by charging higher prices.

[52]In the European Union, interchange fees are regulated under EU Directive 2015/2366. They are currently capped to 0.2/0.3 percent of the transaction value for consumer debit/credit cards.

convenience and transaction speed. While card payments used to be relatively cumbersome and slow (Klee 2008), innovations such as contactless payments are tilting the balance away from cash even for smaller amounts (Brown et al. 2021). Moreover, consumers tend to develop habits in their payment behavior: Once they settle for a preferred payment method, they exhibit a significant aversion to adopting other alternatives (Van der Cruijsen, Hernandez, and Jonker 2017; Berg et al. 2021). In a recent study commissioned by the European Central Bank (ECB), consumers express a strong preference for seamless one-stop solutions that avoid the inconvenience associated with multi-homing, such as having to deal with different cards/devices (Kantar Public 2022).

Privacy is a central aspect of the debate on digital money. Die-hard fans of cryptocurrencies view the ability to transact in full anonymity in the digital world as a key feature.[53] In the context of digital retail payments, survey evidence suggests that consumers are aware of privacy issues, but do not consider them to be primary concerns (Kantar Public 2022). While Li (2021) finds that reduced levels of anonymity would lead to a decline in the demand for CBDC, her estimates are based on survey data and thus subject to the "privacy paradox," which has also been documented in the context of digital payments (Chen, Huang et al. 2021). Accordingly, modest monetary incentives may be sufficient to compensate consumers for the reduced levels of privacy of private payment solutions, at the expense of depressed CBDC demand. This is a source of concern, since the wedge between the public and private values of privacy (Garratt and van Oordt 2021) may entail a social welfare loss that can only be avoided through additional regulation of rebate schemes. Moreover, as shown in Ahnert, Hoffmann, and Monnet (2022), user preferences in terms of privacy may differ depending on the particular environment. This is also corroborated in recent survey evidence from Kantar Public (2022). Accordingly, a fixed privacy regime may jeopardize CBDC adoption.

Finally, little is known about the value that users attach to the bundling of payments and other services. Traditionally, money is

[53] Another feature highlighted by proponents of cryptocurrencies is the ability to escape "excessive" government control, especially in the case of authoritarian regimes and economies with strong capital controls.

both a means of payment and a store of value. However, current CBDC design proposals aim to separate these functions through the introduction of holding limits or tiered remuneration (Bindseil, Panetta, and Terol 2021). While such restrictions may be successful at preventing potential adverse effects on bank lending and financial stability, their implications for user demand are not well understood. However, the success of large digital players in bundling payments with digital services suggests that these effects may be economically significant (Brunnermeier, James, and Landau 2019). It therefore appears crucial that a successful CBDC is built on an architecture that allows for the seamless bundling with financial and non-financial services.

In summary, a successful CBDC introduction requires central banks to strike the right balance. While "too much" adoption may have adverse effects on credit supply and financial stability, "too little" adoption also poses a significant risk. The market for payment services has changed considerably in recent years, as cash has become increasingly supplanted by electronic payments. Accordingly, additional research could shed light on how features such as bundling and privacy affect the choices of both merchants and consumers, and thus help policymakers in "getting it right."

### *6.3 Political Economy Considerations*

Issuance of CBDC exposes the central bank to operational risks, which may damage the central bank's reputation. These are highly impactful risks, since the central bank's reputation with the public is key to successfully achieving its primary objective of price stability.[54] The largest of these operational risks is represented by cybersecurity. Kahn, Rivandeneyra, and Wong (2021) point out that a tension exists between convenience and security of digital currencies, and report that theft of private digital currencies is quite common.[55]

[54]With survey data, Christelis et al. (2020) find that higher trust in the ECB moves inflation expectations closer to the central bank's inflation target. Ehrmann, Soudan, and Stracca (2013) show that unfavorable macroeconomic and financial developments are reflected in reductions in the public's trust in the ECB.

[55] Aldasoro et al. (2022) also find that cryptocurrencies are particularly vulnerable to cyber-attacks.

More generally, with the central bank taking direct responsibility for a larger payment system, also regular disservices and malfunctions, for which intermediaries are currently held accountable, may be pinned on to the central bank, reducing trust in the institution. Operational risks can be mitigated by giving a large role to intermediaries in the handling and onboarding of customers.

Currently, the interest rates set by the central bank affect households only indirectly, which may imply limited public attention to monetary policy. Introducing a remunerated CBDC with direct interest payments to retail depositors may make monetary policy measures more tangible for households. A seminal paper by Rogoff (1985) finds that, if central banks come under increased political pressure and adopt the preferences of the general public, they implement policies that lead to excessive inflation. This theoretical argument is the foundation for central bank independence. Goncharov, Ioannidou, and Schmalz (2023) find evidence consistent with this conflict between the public and the central bank. In light of this literature, greater political pressure may reduce central banks' ability to stabilize the economy. Moreover, since all households are net creditors in their CBDC balance, political pressure may become not only stronger but also more skewed towards advocating higher rates of interest. The resulting resistance to interest rate cuts would be an additional constraint on monetary policy, potentially leading to suboptimal outcomes.

Fernández-Villaverde et al. (2021) caution that a successful introduction of CBDC would lead to a large flow of resources to the central bank and thereby empower political decisionmakers to pursue wasteful policies. According to the paper, the advantages enjoyed by CBDC over bank deposits in terms of safety could give the central bank a position of monopoly in the market for deposits and therefore considerably increase its economic power. Conceivably, political pressure could leverage this economic power to pursue ends that are socially wasteful, such as subsidies for borrowing by well-connected firms. However, two considerations assuage this concern. First, it is unlikely that CBDC will completely take over the market for deposits as discussed in Section 4.1. Banks are likely to react to CBDC introduction by offering better conditions to depositors in order to retain market share. Second, central banks such as the ECB are independent exactly to avoid their economic heft being misused.

Indeed, the opposite argument can be made: should the central bank come to enjoy monopoly rents, it may well end up deploying them in a socially beneficial manner. It could invest them in public goods, such as a resilient payment system.

## 7. Conclusion

The debate on the merits and drawbacks of CBDC is moving rapidly. While some aspects are well understood, the implications for monetary policy and financial stability often depend on the economic environment and specific design features. Moreover, several issues merit further analysis to improve our understanding of policymakers' options going forward.

Several conclusions emerge from our review of the literature. First, due to the digital nature of CBDC and resulting accumulation of payment data, privacy is a complex issue that needs to be addressed. Externalities and private-sector profit motives suggest that the public sector has a comparative advantage at the provision of privacy in payments. However, a one-size-fits-all solution with full anonymity (know-your-customer/anti-money laundering issues aside) need not be optimal because users can also derive benefits from data sharing.

Second, the literature suggests that policymakers' concerns about a contraction of credit supply following a CBDC introduction need not materialize when banks are able to exert market power in retail deposit markets. Issuing CBDC in such a situation would improve competition and increase welfare. Moreover, central banks could in principle cover the funding gap that would arise from a large-scale substitution of bank deposits into CBDC. However, frictions in current operational frameworks such as collateral requirements may impose limits on banks' recourse to the central bank.

Third, theoretical models suggest that the financial stability implications may be less severe than what conventional wisdom dictates. While the emergence of an attractive storage technology increases the risk of bank runs, banks will react and offer more attractive deposit contracts, which can alleviate, or even overturn, adverse effects on bank fragility.

Finally, central banks face a tension between too much and too little adoption. While safeguards such as holding limits or tiered remuneration have the potential to avoid excessive use and reduce the risk of disintermediation, it is important to understand their effects on user adoption. More generally, the rapid rise in electronic payments implies that user preferences are shifting rapidly as new means of payment are becoming available. However, relatively little is known regarding the value end users attribute to certain features, including privacy and the convenience from bundling payments with other services.

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# Real-Time Forecasting with a (Standard) Mixed-Frequency VAR During a Pandemic*

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We resuscitated the mixed-frequency vector autoregression (MF-VAR) developed in Schorfheide and Song (2015) to generate macroeconomic forecasts for the United States during the COVID-19 pandemic in real time. The model combines 11 time series observed at two frequencies: quarterly and monthly. We deliberately did not modify the model specification in view of the COVID-19 outbreak, except for the exclusion of crisis observations from the estimation sample. We compare the MF-VAR forecasts to the median forecast from the Survey of Professional Forecasters (SPF). While the MF-VAR performed poorly during 2020:Q2, subsequent forecasts were at par with the SPF forecasts. We show that excluding a few months of extreme observations is a promising way of handling VAR estimation going forward, as an alternative of a sophisticated modeling of outliers.

JEL Codes: C11, C32, C53.

## 1. Introduction

Vector autoregressions (VARs) are widely used in empirical macroeconomics. A VAR is a multivariate time-series model that can be used to forecast individual time series, to predict co-movements of

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macroeconomic or financial variables, to analyze sources of business cycle fluctuations, or to assess the effects of monetary or fiscal policy interventions on the macro economy. The recent COVID-19 pandemic triggered long-lasting mobility restrictions in the form of stay-at-home orders across the United States and the world in 2020 and beyond. As a consequence, economic activity collapsed in many sectors and unemployment soared. The unprecedented decline of economic activity created a tremendous challenge for macroeconomic modeling and forecasting, including the use of VARs and related state-space models.

In response to this challenge we resuscitated the mixed-frequency VAR, henceforth MF-VAR, developed in Schorfheide and Song (2015). MF-VARs have been shown to be competitive with other forecasting approaches, including surveys of professional forecasters, by, for instance, Schorfheide and Song (2015), Brave, Butters, and Justiniano (2019), and McCracken, Owyang, and Sekhposyan (2020). They are preferable, in particular at shorter forecast horizons, to single-frequency VARs that use time-aggregated data. Rather than modifying the MF-VAR in real time or ex post to accommodate idiosyncrasies of the economic downturn triggered by the COVID-19 pandemic, we decided to leave the model unchanged, except for the consideration of several forms of excluding or discounting extreme observations during the estimation stage. We summarized a first set of real-time forecasts in the working paper version Schorfheide and Song (2020) and subsequently published monthly real-time forecasts at www.donghosong.com from April 30, 2020 until August 31, 2021.

The contribution of the current paper is to evaluate the 17 months of real-time MF-VAR forecasts and compare them to median forecasts from the Survey of Professional Forecasters (SPF) conducted by the Federal Reserve Bank of Philadelphia.[1] The paper focuses on the effect of outliers in the context of an MF-VAR, rather than on the advantages of a modeling strategy that mixes time series sampled at various frequencies. State-space models are more flexible in handling outliers than models in which all variables are treated as observed, such as standard VARs. We contrast two

[1] See https://www.philadelphiafed.org/surveys-and-data.

approaches of capturing outliers: inflating the scale of the measurement errors to capture observation outliers, and inflating the scale of the state-transition innovations to capture innovation outliers. The first approach downweights extreme observations without propagating them through the system. Lagged values of extreme observations are effectively replaced by forecasts from the state-transition equation. The second approach downweights the likelihood increment associated with extreme observations, but uses them as lagged values to predict subsequent "normal" observations. We use the first approach for parameter estimation and the second approach to generate forecasts conditional on parameter draws from the posterior distribution. Letting the scale tend to infinity is equivalent to dropping observations from the system.

Instead of modeling the occurrence of outliers through a fat-tailed distribution or a mixture distribution, we simply scale the innovation variances or drop observations based on an inspection of the data prior to the MF-VAR estimation. This approach is convenient and practical in situations in which observations are so extreme that they are easily recognizable as outliers, such as the COVID-19 pandemic. Our approach is also easy to implement on other model classes and less demanding in terms of time and human resources than the explicit modeling of outliers.

The SPF is a widely used benchmark in forecast comparisons. From our perspective, the SPF has two important features: first, as our MF-VAR forecasts, the SPF forecasts were made in real time as the pandemic was unfolding and they are not based on ex post model optimization. Second, the professional forecasters had the opportunity to make real-time judgmental adjustments to model-based forecasts in view of the evolving pandemic which cannot be reproduced in pseudo-out-of-sample forecast comparisons with other model classes. Our sample is too short for a formal comparison of forecasts to be informative. Numerical evaluation statistics are likely to be dominated by a few large forecast errors. Instead, we focus on visual comparisons of ex post realizations and forecast paths generated at different origins.

We draw three main conclusions from our analysis. First, during the first three months of the pandemic in the United States, in 2020:Q2, we deliberately did not exert any effort in adapting our MF-VAR to the idiosyncrasies of the pandemic, except for ending the estimation sample on January 31, 2020, nor did we make judgmental adjustments to the model-based forecasts. We find that the MF-VAR forecasts are substantially worse than the SPF forecasts during this period. In April 2020 the data for the MF-VAR estimation did not yet contain information about the severity of the downturn and the model did not anticipate the magnitude of the recession. By June 2020, the model had identified large shocks to the economy. Propagating these large shocks through a very persistent VAR law of motion led to an overly pessimistic forecast. In short, the model performed poorly in 2020:Q2.

Second, without any modifications or adjustments the MF-VAR model generated remarkably accurate forecasts from July 2020 onward. These forecasts are at par with the median SPF forecasts. Many pundits initially expected the pandemic to be relatively short-lived and the recession to be followed by a strong recovery once the mobility restrictions were lifted. From this perspective, the cards were stacked ex ante against the MF-VAR, which is estimated based on macroeconomic time series that exhibit unit-root behavior and thereby implies that shocks tend to have long-lived effects. Ex post it turned out that mobility restrictions could only be lifted gradually and that the economic effects of the pandemic were long-lasting, just as the effects of previous recessionary shocks had been long-lasting and recoveries have often been slow.

Third, going forward, an important question for users of VARs is how to handle the extreme data points observed in the second quarter of 2020. One option is to increase the complexity of the VAR model by explicitly allowing for outliers, either specifically during the COVID-19 pandemic or in every period with some small probability. Our findings suggest that the alternative and rather simple approach of excluding observations from the first few months of the pandemic works remarkably well and provides an attractive alternative in situations in which a more sophisticated modeling of outliers is impractical. Our approach ensures that the MF-VAR performs as well after the initial downturn as it did prior to the pandemic. The real-time forecasts published at www.donghosong.com were generated by ending the estimation sample on January 31, 2020. As time has progressed, it has become desirable to start including new observations in the estimation sample. Based on our findings, we recommend dropping observations from March to June

2020 but including the subsequent data points when estimating a VAR.

Since the beginning of the pandemic, many papers have been written contemporaneously on how to adjust forecast models to cope with the unprecedented economic downturn. The two papers most closely related to our work are Lenza and Primiceri (2022), henceforth LP, and Carriero et al. (2022), henceforth CCMM. Just as in our paper, CCMM and LP propose adjustments to a baseline VAR specification. While our baseline model features mixed-frequency observations, LP use a homoskedastic VAR as a starting point, and CCMM start from a VAR with stochastic volatility (SV).

LP propose to deterministically scale the innovation covariance for the duration of the pandemic to capture the increased shock sizes. Specifically, the authors recommend estimating separate scale factors for the first months of the pandemic and then letting the last of these scale factors decay geometrically at an estimated rate. To the extent that the estimated scale factors are large, the method has a similar effect on the parameter estimates as dropping observations. However, rather than abruptly including new observations after a certain period, the method gradually increases the weight of these observations.

While VARs with SV are designed to adapt to time-varying volatility and have shown to improve density and interval forecasts (see, for instance, Clark 2011), the estimated volatility processes are typically highly persistent. This implies that large COVID-19 shocks over two to three months would raise SV for multiple years to levels that are ex ante implausible and ex post counterfactual. As a remedy, CCMM modify the SV specification to allow for Student-$t$ distributed (instead of Gaussian) innovations as well as outliers that do not trigger a persistent increase in volatility. The authors show that the outlier-augmented SV-$t$ specification substantially improves the forecast performance of a standard VAR with SV.

Our approach of essentially dropping observation after a casual inspection of the data and CCMM's approach of explicit outlier modeling can be viewed as the two endpoints of a continuum of empirical strategies. LP's approach of inflating the error variance at a pre-specified point in time and then estimating a decay rate lies in between the two endpoints. While the CCMM approach can handle outliers in an automated way and potentially adapt to future outliers caused by non-COVID-related economic disruptions, our approach provides a low-tech alternative in situations in which a more sophisticated modeling is impractical. We adapt the Lenza and Primiceri (2022) approach to our mixed-frequency framework. We find in our application that, compared to our approach of excluding observations, the LP approach creates similar point forecasts but ex post unreasonably large predictive intervals because the estimated scale factor implies a relatively slow decay.

Alvarez and Odendahl (2021) use an outlier modeling approach similar to CCMM, but with the feature that the reduced-form errors rather than the structural errors are stochastically rescaled, so that the contemporaneous correlation of the reduced-form errors is preserved. Antolin-Diaz, Drechsel, and Petrella (2021) and Bobeica and Hartwig (2022) use fat-tailed error distributions to discount extreme observations—the former in the context of a dynamic factor model (DFM) and the latter in a VAR. Foroni, Marcellino, and Stevanovic (2020) explore COVID-19 adjustments of econometric model forecasts that are based on the forecasting experience during the Great Recession. Either the forecast model is exclusively estimated based on observations surrounding the Great Recession (similarity-based estimation) or its forecasts are corrected by forecast errors made during the Great Recession (intercept correction).

We are not alone in exploring the behavior of a time-series models during the pandemic without explicitly modeling outliers or tailoring the model specification to the COVID observations. For instance, Diebold (2020) studies the performance of the Aruoba-Diebold-Scotti (ADS) economic activity index, which is based on a low-dimensional dynamic factor model and has been published by the Federal Reserve Bank of Philadelphia for more than a decade. Lewis, Mertens, and Stock (2020) developed a weekly economic index (WEI) to track the rapid economic developments triggered by the coronavirus pandemic. Their principal component analysis, which uses observations from 2008 onward, does not treat the observations from the second quarter of 2020 as outliers.

Ng (2021) uses COVID indicators, such as the number of current documented infections, and the number of hospitalizations and deaths, either as exogenous controls or as endogenous variables in VARs regressions to "de-COVID" the data so that economic factors and shocks can be identified, or as additional predictors to account for the persistent nature of COVID. Because the COVID indicators are zero before the pandemic, their behavior is very non-Gaussian. Davis and Ng (2022) develop methods for the estimation of multivariate models with heavy-tailed and thin-tailed variables, using independent component analysis to identify disaster/pandemic shocks. While all of the previous approaches treat the pandemic as large unobserved shocks that propagate through the dynamic system, Primiceri and Tambalotti (2020) adapt a VAR to the COVID-19 pandemic by assuming that also the propagation (persistence and co-movements) of the COVID shocks is potentially different from typical business cycle shocks. While their approach is useful for scenario analysis, it is difficult to accurately estimate the COVID shock propagation mechanism in real time.

There is another strand of literature that has a slightly different objective, namely to introduce non-linearities into time-series models such as VARs or DFMs. A side benefit, though not the key modeling motivation, is that these models, without further adjustments, may be more robust to the occurrence of outliers than linear models. Huber et al. (2022) develop Bayesian econometric methods for posterior parametric mixed-frequency VARs using additive regression trees. Goulet Coulombe, Marcellino, and Stevanovic (2021) document that some ML methods capture non-linearities that can improve forecasts during the COVID-19 crisis. However, it is important to note that the same adjustments that we, LP, and CCMM make to a linear VAR could be made to the non-linear time-series models.[2]

The remainder of this paper is organized as follows. In Section 2 we provide an example that illustrates how outliers can be handled in a state-space model by robustifying either the measurement equation or the state-transition equation. Section 3 reviews the specification of the MF-VAR and discusses how we drop observations from the estimation sample and implement the LP approach of scaling the

[2]This includes growth-at-risk models building on Adrian, Boyarchenko, and Giannone (2019). While the assessment of tail risk is particularly important at the onset of the COVID-19 pandemic, during the pandemic and in its aftermath the same question remains: does including the pandemic observations distort the recursive estimates of these models?

innovation covariance matrix. The real-time data set is discussed in Section 4 and the empirical results are presented in Section 5. Finally, Section 6 concludes. Additional information about the construction of our data set is provided in the appendix. Real-time forecasts from April 30, 2020 to August 31, 2021, were published and remain available at www.donghosong.com.

## 2. Outliers in State-Space Models—An Example

In order to examine the effect of outliers on filtering and parameter estimation in state-space models, consider the following example:

$$\begin{aligned} (ME) &: y_\tau = s_\tau + u_\tau, \quad u_\tau \sim N(0, \chi_{u,\tau}) \\ (ST) &: s_\tau = \theta_{\tau-1} s_{\tau-1} + \epsilon_\tau, \quad \epsilon_\tau \sim N(0, \chi_{\epsilon,\tau}), \quad \tau = 1, 2, \ldots, T. \end{aligned} \tag{1}$$

The observables $y_\tau$, the latent states $s_\tau$, and the unknown parameters $\theta_\tau \in \Theta$ are scalars. We assume that there is a pandemic in period $\tau = t$ and that the sample ends one period later in period $\tau = t + 1 = T$. In normal times

$$\chi_{u,\tau} = 1, \quad \chi_{\epsilon,\tau} = 1, \quad \theta_\tau = \theta$$

and the observations are generated from (1). During the pandemic period $t$, nature replaces the innovations $(u_t, \epsilon_t)$ with the values $(\tilde{u}_t, \tilde{\epsilon}_t)$ to determine $(y_t, s_t)$. Moreover, nature sets $\theta_t = \tilde{\theta}$ to generate $(y_{t+1}, s_{t+1})$ from (1). Following the taxonomy in Gandhi and Mili (2010), we refer to $\tilde{u}_t$ as observation outlier, $\tilde{\epsilon}_t$ as innovation outlier, and $\tilde{\theta}_t$ as structural outlier.

The econometrician uses (1) to make inference about the latent state $s_\tau$, the parameter $\theta$, and forecast $y_\tau$. She considers robustifying the econometric model to the presence of outliers by inflating the scale of the error distributions in period $t$. Rather than considering fat-tailed distributions, this is done by simply switching the values of the constants $\chi_{u,t}$ and $\chi_{\epsilon,t}$ from one to a large value. We refer to an increase of $\chi_{u,\tau}$ as robustifying the measurement equation (ME). Similarly, an increase of $\chi_{\epsilon,t}$ is regarded as robustifying the state-transition (ST) equation. We compare the effect of both approaches on filtering and parameter estimation. If we set $\chi_{u,\tau} = 0$, then the model reduces to an AR(1).

Let $\chi_\tau = [\chi_{u,\tau}, \chi_{\epsilon,\tau}]'$. Suppose that the Kalman filter (KF) delivers the time $t-1$ state distribution $s_{t-1}|Y_{1;t-1} \sim N(s_{t-1|t-1}, P_{t-1|t-1})$. The predictive distribution for the time $t$ observation is $y_t|Y_{1:t-1} \sim N\big(y_{t|t-1}, F_{t|t-1}(\chi_t)\big)$, where

$$y_{t|t-1} = \theta s_{t-1|t-1}, \quad F_{t|t-1}(\chi_t) = \theta^2 P_{t-1|t-1} + \chi_{\epsilon,t} + \chi_{u,t}. \tag{2}$$

Define

$$\lambda(P, \chi, \theta) = \left( \frac{\theta^2 P + \chi_\epsilon}{\theta^2 P + \chi_\epsilon + \chi_u} \right). \tag{3}$$

The updating step yields $s_t|Y_{1:t} \sim N\big(s_{t|t}(\chi_t), P_{t|t}(\chi_t)\big)$, where

$$\begin{aligned} s_{t|t}(\chi_t) &= \lambda(P_{t-1|t-1}, \chi_t, \theta) y_t + \big[1 - \lambda(P_{t-1|t-1}, \chi_t, \theta)\big] \theta s_{t-1|t-1} \\ P_{t|t}(\chi_t) &= \lambda(P_{t-1|t-1}, \chi_t, \theta) \chi_{u,t}. \end{aligned} \tag{4}$$

Thus, the filtered state in period $t$ is a linear combination of $y_t$ and the forecast $\theta s_{t-1|t-1}$, obtained by iterating ST one period forward. The weight $\lambda(\cdot)$ in (3) is a function of $\chi_t$. Iterating the KF one more period forward, we obtain the following mean and variance for the predictive distribution of $y_{t+1}$:

$$y_{t+1|t}(\chi_t) = \theta s_{t|t}(\chi_t), \quad F_{t+1|t}(\chi_t) = \theta^2 P_{t|t}(\chi_t) + 2. \tag{5}$$

The updating step yields the moments

$$\begin{aligned} s_{t+1|t+1}(\chi_t) &= \lambda\big(P_{t|t}(\chi_t), 1, \theta\big) y_{t+1} + \big[1 - \lambda\big(P_{t|t}(\chi_t), 1, \theta\big)\big] \theta s_{t|t}(\chi_t) \\ P_{t+1|t+1}(\chi_t) &= \lambda\big(P_{t|t}(\chi_t), 1, \theta\big). \end{aligned} \tag{6}$$

Letting $\chi_{u,t}$ or $\chi_{\epsilon,t}$ tend to infinity can be viewed as an extreme way of robustifying the filtering, likelihood evaluation, and forecasting in the presence of the period $t$ outliers. Maintaining that $\chi_\tau = 1$ for $\tau \neq t$, define the log-likelihood function as

**Table 1. Limits of KF Moments**

| Moment | Robust ME $\chi_{u,t} \longrightarrow \infty, \chi_{\epsilon,t} = 1$ | Robust ST $\chi_{u,t} = 1, \chi_{\epsilon,t} \longrightarrow \infty$ |
|---|---|---|
| $y_{t\|t-1}$ | $\theta s_{t-1\|t-1}$ | $\theta s_{t-1\|t-1}$ |
| $F_{t\|t-1}(\chi_t)$ | $\infty$ | $\infty$ |
| $s_{t\|t}(\chi_t)$ | $\theta s_{t-1\|t-1}$ | $y_t$ |
| $P_{t\|t}(\chi_t)$ | $\theta^2 P_{t-1\|t-1} + 1$ | $1$ |
| $y_{t+1\|t}(\chi_t)$ | $\theta^2 s_{t-1\|t-1}$ | $\theta y_t$ |
| $F_{t+1\|t}(\chi_t)$ | $\theta^4 P_{t-1\|t-1} + \theta^2 + 2$ | $\theta^2 + 2$ |
| $s_{t+1\|t+1}(\chi_t)$ | $\left(\frac{\theta^4 P_{t-1\|t-1}+\theta^2+1}{\theta^4 P_{t-1\|t-1}+\theta^2+2}\right) y_{t+1} + \left(\frac{1}{\theta^4 P_{t-1\|t-1}+\theta^2+2}\right) \theta^2 s_{t-1\|t-1}$ | $\left(\frac{\theta^2+1}{\theta^2+2}\right) y_{t+1} + \left(\frac{1}{\theta^2+2}\right) \theta_{yt}$ |
| $P_{t+1\|t+1}(\chi_t)$ | $\frac{\theta^4 P_{t-1\|t-1}+\theta^2+1}{\theta^4 P_{t-1\|t-1}+\theta^2+2}$ | $\frac{\theta^2+1}{\theta^2+2}$ |

$$\ln p(Y_{1:T}|\theta, \chi_t) = -\frac{T}{2}\ln(2\pi) - \frac{1}{2}\sum_{\tau=1}^{T}\left[\ln|F_{\tau|\tau-1}(\chi_t)| + \frac{(y_\tau - y_{\tau|\tau-1}(\chi_t))^2}{F_{\tau|\tau-1}(\chi_t)}\right], \tag{7}$$

with the understanding that $y_{\tau|\tau-1}(\chi_t)$ and $F_{\tau|\tau-1}(\chi_t)$ do not vary with $\chi_t$ for $\tau < t$.

Table 1 summarizes the $\chi_{u,t} \longrightarrow \infty$ (robust ME) and $\chi_{\epsilon,t} \longrightarrow \infty$ (robust ST) limits of the KF moments for periods $t$ and $t+1$. The time $t$ limits of the forecasts are identical. In both cases $y_{t|t-1} = \theta s_{t-1|t-1}$ and $F_{t|t-1} = \infty$, which implies that the log-likelihood increment for the outlier observation $y_t$ drops out. While the time $t$ likelihood increment diverges, the limit of any log-likelihood ratio $\ln p(Y_{1:T}|\theta, \chi_t) - \ln p(Y_{1:T}|\tilde{\theta}, \chi_t)$ remains well defined. The robust ME and ST limits start to differ with the time $t$ updating step. Notice from (3) that

$$\lim_{\chi_{u,t}\longrightarrow\infty} \lambda(P, \chi_t, \theta) = 0, \quad \lim_{\chi_{u,t}\longrightarrow\infty} \lambda(P, \chi_t, \theta)\chi_{u,t} = \theta^2 P + \chi_{\epsilon,t},$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} \lambda(P, \chi_t, \theta) = 1.$$

Under robust ME the time $t$ filtered state is solely based on the forward iteration of the ST, $\theta s_{t-1|t-1}$. In turn, neither the time $t$ forecast of $y_{t+1}$ nor the filtered value of $s_{t+1}$ is affected by the outlier $y_t$. Under robust ST, on the other hand, $y_{t+1|t}$ and $s_{t+1|t+1}$ are functions of the extreme observation $y_t$ instead of the forward iteration $\theta s_{t-1|t-1}$.

In the empirical part of this paper we conduct Bayesian inference, which is based on the posterior distribution

$$p(\theta|Y_{1:T}, \chi_t) \propto p(Y_{1:T}|\theta, \chi_t)p(\theta), \tag{8}$$

where $\propto$ denotes proportionality and $p(\theta)$ is the prior. In large samples the log-likelihood function is approximately quadratic around the maximum likelihood estimator (MLE)

$$\hat{\theta}(\chi_t) = \text{argmax}_{\theta\in\Theta} \ \ln p(Y_{1:T}|\theta, \chi_t).$$

Denoting $\hat{V}(\chi_t)$ the negative inverse Hessian of the log-likelihood function evaluated at the posterior mode, we can approximate the posterior as

$$\begin{aligned} p(\theta|Y_{1:T}, \chi_t) \propto\ & (2\pi)^{-1/2}|\hat{V}(\chi_t)|^{-1/2} \\ & \times \exp\left\{ -\frac{\left(\theta - \hat{\theta}(\chi_t)\right)^2}{2\hat{V}(\chi_t)} + \text{small} \right\} p(\theta). \end{aligned} \tag{9}$$

We proceed by examining the sensitivity of the MLE to $y_t$ as a function of $\chi_t$. Recall that $T = t + 1$ and let $Y_{(-t)} = (Y_{1:t-1}, y_{t+1})$. Then define

$$\ell(\theta, y_t; Y_{(-t)}, \chi_t) = \ln p(Y_{1:T}|\theta, \chi_t)$$

and its first- and second-order derivatives $\ell_\theta(\theta, y_t; \cdot)$, $\ell_y(\theta, y_t; \cdot)$, $\ell_{y\theta}(\theta, y_t; \cdot)$, $\ell_{\theta\theta}(\theta, y_t; \cdot)$. Assuming that the MLE lies in the interior, it satisfies the first-order condition $\ell_\theta(\hat{\theta}, y_t; Y_{(-t)}, \chi_t) = 0$. We deduce from the implicit function theorem that

$$\frac{\partial\hat{\theta}}{\partial y_t} = -\left[\ell_{\theta\theta}(\hat{\theta}, y_t; Y_{(-t)}, \chi_t)\right]^{-1} \ell_{\theta y}(\hat{\theta}, y_t; Y_{(-t)}, \chi_t). \tag{10}$$

We show in the appendix that

$$\lim_{\chi_{u,t} \longrightarrow \infty} \ell_{y\theta}(\hat{\theta}, y_t; Y_{(-t)}, \chi_t) = 0$$

$$\lim_{\chi_{\epsilon,t} \longrightarrow \infty} \ell_{y\theta}(\hat{\theta}, y_t; Y_{(-t)}, \chi_t) = -\frac{\hat{\theta} y_t}{\hat{\theta}^2 + 2} + \frac{y_{t+1} - \hat{\theta} y_t}{\hat{\theta}^2 + 2}\left(1 - 2\frac{\hat{\theta}^2}{\hat{\theta}^2 + 2}\right).$$

The observation $y_t$ affects inference about $\theta$ in two ways. First, the model needs to explain the observation $y_t$ based on $t-1$ information. Second, $\theta$ affects the error that the model makes predicting $y_{t+1}$ based on information that includes the observation $y_t$. If we let $\chi_{u,t} \longrightarrow \infty$, then the influence of $y_t$ on $\hat{\theta}$ is eliminated because the increment $\ln p(y_t|Y_{1:t-1}, \theta, \chi_t)$ is removed from the likelihood function. Moreover, as can be seen from Table 1, the forecast of $y_{t+1}$ also no longer depends on $y_t$. It is well known in the state-space model literature that the $\chi_{u,t} \longrightarrow \infty$ limit corresponds to dropping time $t$ observation from the measurement equation using the selection matrix (here just $1 \times 1$):

$$y_\tau = M_\tau(s_\tau + u_\tau), \quad M_\tau = \begin{cases} 1 & \text{for } \tau \neq t \\ \emptyset & \text{otherwise.} \end{cases}$$

On the other hand, if we let $\chi_{\epsilon,t} \longrightarrow \infty$, then $y_t$ continues to affect the estimator $\hat{\theta}$ because it is used in the prediction of $y_{t+1}$. If after the pandemic, in period $t+1$, $y_{t+1}$ is determined in the same way as before the pandemic, i.e., $\tilde{\theta}_t = \theta$, then a large value of $y_t$ is very beneficial, because it generates, correctly, a lot of information about $\theta$. If on the other hand, post-pandemic dynamics are somewhat different from pre-pandemic dynamics, i.e., $\tilde{\theta}_t \neq \theta$, then the information generated by $y_t$ will distort inference about $\theta$ and forecasts for future periods.

In view of these considerations, we adopted the following strategy to generate the baseline real-time forecasts: we estimate $\theta$ using a Gibbs sampler with a simulation smoother that is based on the previously described Kalman filter algorithm. We set $M_\tau = \emptyset$ during part of the pandemic, which removes the influence of the extreme pandemic observations on the parameter estimation. This generates posterior draws $\theta^i$, $i = 1, \ldots, N$. When generating out-of-sample forecasts, in the notation of the example, we bring back observation

$y_t$ to forecast $y_{t+1}$. For each posterior draw $i$, we use the filter to compute draws from $s_{t+1}|(Y_{1:t}, \theta^i, \chi_{u,t} = 1, \chi_{\epsilon,t} = 1)$. The VAR-based forecasts of Carriero et al. (2022) and Lenza and Primiceri (2022) can be interpreted as setting $\chi_{u,\tau} = 0$ for all $\tau$ and $\chi_{\epsilon,t}$ equal to a large estimated value. Primiceri and Tambalotti (2020) try to estimate $\tilde{\theta}_t$.

## 3. MF-VAR Specification and Estimation

We consider an MF-VAR that utilizes monthly and quarterly observations. The MF-VAR can be conveniently represented as a state-space model, in which the state-transition equations are given by a VAR at monthly frequency and the measurement equations relate the observed series to the underlying, potentially unobserved, monthly variables that are stacked in the state vector. To cope with the high dimensionality of the parameter space, the MF-VAR is equipped with a Minnesota prior and estimated using Bayesian methods. In Section 3.1 we reproduce the model description and estimation strategy from Schorfheide and Song (2015), referring the reader to our original paper for a detailed discussion of the Bayesian computations. In Section 3.2 we discuss two modifications that we consider in the empirical application: (i) dropping of observations and (ii) a break in volatility as in LP.

### *3.1 Baseline Version*

**Model Specification.** We assume that the economy evolves at monthly frequency according to the following VAR(p) dynamics:

$$x_t = \Phi_1 x_{t-1} + \ldots + \Phi_p x_{t-p} + \Phi_c + u_t, \quad u_t \sim iidN\big(0, \Sigma\big). \quad (11)$$

The $n \times 1$ vector of macroeconomic variables $x_t$ can be composed into $x_t = [x'_{m,t}, x'_{q,t}]'$, where the $n_m \times 1$ vector $x_{m,t}$ collects variables that are observed at monthly frequency, e.g., the consumer price index and the unemployment rate, and the $n_q \times 1$ vector $x_{q,t}$ comprises the unobserved monthly variables that are published only at quarterly frequency, e.g., GDP. Define $z_t = [x'_t, \ldots, x'_{t-p+1}]'$ and $\Phi = [\Phi_1, \ldots, \Phi_p, \Phi_c]'$. Write the VAR in (11) in companion form as

$$z_t = F_1(\Phi) z_{t-1} + F_c(\Phi) + v_t, \quad v_t \sim iidN\big(0, \Omega(\Sigma)\big), \quad (12)$$

where the first $n$ rows of $F_1(\Phi)$, $F_c(\Phi)$, and $v_t$ are defined to reproduce (11) and the remaining rows are defined to deliver the identities $x_{q,t-l} = x_{q,t-l}$ for $l = 1, \ldots, p-1$. The $n \times n$ upper-left submatrix of $\Omega$ equals $\Sigma$ and all other elements are zero. Equation (12) is the state-transition equation of the MF-VAR.

We proceed by describing the measurement equation. To handle the unobserved variables, we vary the dimension of the vector of observables as a function of time $t$ (e.g., Durbin and Koopman 2001). Let $T$ denote the forecast origin and let $T_b \leq T$ be the last period that corresponds to the last month of the quarter for which all quarterly observations are available. The subscript $b$ stands for *balanced* sample. Up until period $T_b$ the vector of monthly series $x_{m,t}$ is observed every month. We denote the actual observations by $y_{m,t}$ and write

$$y_{m,t} = x_{m,t}, \quad t = 1, \ldots, T_b. \tag{13}$$

Assuming that the underlying monthly VAR has at least three lags, that is, $p \geq 3$, we express the three-month average of $x_{q,t}$ as

$$\tilde{y}_{q,t} = \frac{1}{3}(x_{q,t} + x_{q,t-1} + x_{q,t-2}) = \Lambda_{qz} z_t. \tag{14}$$

For variables measured in logs, e.g., $\ln GDP$, the formula can be interpreted as a log-linear approximation to an arithmetic average of GDP that preserves the linear structure of the state-space model. For flow variables such as GDP, we adopt the national income and product accounts (NIPA) convention and annualize high-frequency flows. As a consequence, quarterly flows are the average and not the sum of monthly flows. This three-month average, however, is only observed for every third month, which is why we use a tilde superscript. Let $M_{q,t}$ be a selection matrix that equals the identity matrix if $t$ corresponds to the last month of a quarter and is empty otherwise. Adopting the convention that the dimension of the vector $y_{q,t}$ is $n_q$ in periods in which quarterly averages are observed and empty otherwise, we write

$$y_{q,t} = M_{q,t}\tilde{y}_{q,t} = M_{q,t}\Lambda_{qz} z_t, \quad t = 1, \ldots, T_b. \tag{15}$$

For periods $t = T_b + 1, \ldots, T$ no additional observations of the quarterly time series are available. Thus, for these periods the dimension of $y_{q,t}$ is zero and the selection matrix $M_{q,t}$ in (15) is empty.

However, the forecaster might observe additional monthly variables. Let $y_{m,t}$ denote the subset of monthly variables for which period $t$ observations are reported by the statistical agency after period $T$, and let $M_{m,t}$ be a deterministic sequence of selection matrices such that (13) can be extended to

$$y_{m,t} = M_{m,t} x_{m,t}, \quad t = T_b + 1, \ldots, T. \tag{16}$$

Notice that the dimension of the vector $y_{m,t}$ is potentially time varying and less than $n_m$. The measurement equations (13) to (16) can be written more compactly as

$$y_t = M_t \Lambda_z z_t, \quad t = 1, \ldots, T. \tag{17}$$

Here, $M_t$ is a sequence of selection matrices that selects the time $t$ variables that have been observed by period $T$ and are part of the forecaster's information set. In sum, the state-space representation of the MF-VAR is given by (12) and (17).

**Bayesian Estimation.** The starting point of Bayesian inference for the MF-VAR is a joint distribution of observables $Y_{1:T}$, latent states $Z_{0:T}$, and parameters $(\Phi, \Sigma)$, conditional on a presample $Y_{-p+1:0}$ to initialize lags. The distribution of observables and latent states conditional on the parameters is implied by the above state-space representation of the MF-VAR. For the marginal distribution of the parameters $(\Phi, \Sigma)$ we use a conjugate Minnesota prior. This prior dates back to Litterman (1980) and Doan, Litterman, and Sims (1984). We use the version of the Minnesota prior described in Del Negro and Schorfheide (2011)'s handbook chapter, which in turn is based on Sims and Zha (1998). The main idea of the Minnesota prior is to center the distribution of $\Phi$ at a value that implies a random-walk behavior for each of the components of $x_t$ in (11). We implement the Minnesota prior by mixing artificial (or *dummy*) observations into the estimation sample. The artificial observations are computationally convenient and allow us to generate plausible a priori correlations between VAR parameters. The variance of the prior distribution is controlled by a low-dimensional vector of hyperparameters $\lambda$.

We generate draws from the posterior distributions of $(\Phi, \Sigma)|Z_{0:T}$ and $Z_{0:T}|(\Phi, \Sigma)$ using a Gibbs sampler. Based on these draws, we are able to simulate future trajectories of $y_t$ to characterize the predictive distribution associated with the MF-VAR and to calculate point, interval, and density forecasts.

### *3.2 Modifications*

**Robustifying Estimation and Forecasting.** As discussed in Section 2, we distinguish between the handling of outliers at the estimation stage and when we run the filter to infer the latent states at the forecast origin, conditional on parameter draws from the posterior distribution. Let $T$ denote the forecast origin. For the estimation, we will consider three approaches. Approaches E1 and E2 were labeled as robustifying ME in Section 2.

- E1: Estimation with observations from $t = 1, \ldots, t_*$, where $t_* < T$ is a pre-pandemic period. In the notation of Section 2 we will set the measurement error variance to infinity, i.e., $\chi_{u,t} = \infty$, for $t > t_*$, which is equivalent to setting the selection matrix $M_t = \emptyset$ in (17); or simply ending the estimation sample in period $t = t_*$.
- E2: Rather than ending the estimation sample at the onset of the pandemic, we drop a sequence of extreme observations during the early phase of the pandemic and retain subsequent observations from $t = t_{**} + 1, \ldots, T$. This is implemented by setting $M_t = \emptyset$ for $t = t_* + 1, \ldots, t_{**}$.
- E3: Finally, we consider an estimation based on the full sample $t = 1, \ldots, T$ that includes the extreme observations during the early part of the pandemic.

To determine the latent states at the forecast origin $T$ conditional on a draw $(\Phi^i, \Sigma^i)$ from the posterior distribution, we consider three different filtering strategies. In each case the filter is run from $t = 1, \ldots, T$, but we potentially use $M_t$ (equivalently $\chi_{u,t}$) or $\chi_{\epsilon,t}$ to robustify the filter against outliers.

- F1: We keep $\chi_{u,t} = \chi_{\epsilon,t} = 1$ and leave $M_t$ unchanged.
- F2: Set $M_t = \emptyset$ for $t > t_*$. This means that the latent state estimates for period $t = t_* + 1, \ldots, T$ are generated by simulating ST forward.

- F3: From period $t_*$ onward, increase the innovation variance by setting $\chi_{\epsilon,t}$ to a large value.

The baseline forecasts reported in Section 5 are generated by combining estimation E1 with filtering F1. The determination of $t_*$ is discussed in Section 4.3 below.

**Volatility Breaks and Discounting.** LP propose allowing for a break in volatility, which is modeled through a variable $s_t$ that scales up the residual covariance matrix during the period of the pandemic. Following their specification, we replace (11) with

$$x_t = \Phi_1 x_{t-1} + \ldots + \Phi_p x_{t-p} + \Phi_c + s_t u_t, \quad u_t \sim iidN\big(0, \Sigma\big). \quad (18)$$

It is assumed that $s_t = 1$ before time period $t = t_*$ in which the pandemic begins. Subsequently $s_t$ evolves according to

$$\begin{aligned} &s_{t_*} = \bar{s}_0, \quad s_{t_*+1} = \bar{s}_1, \quad s_{t_*+2} = \bar{s}_2, \quad \text{and} \\ &s_{t_*+j} = 1 + (\bar{s}_2 - 1)\rho^{j-2}. \end{aligned} \quad (19)$$

The quadruplet $\vartheta = (\bar{s}_0^2, \bar{s}_1^2, \bar{s}_2^2, \rho)$ needs to be estimated. This flexible parameterization allows for this scaling factor to take three (possibly) different values in the first three periods after the outbreak of the disease, and to decay at rate $\rho$ after that. Note that $\vartheta$ uniquely determines the sequence $S_{1:T} = \{s_1, \ldots, s_T\}$.[3]

## 4. Real-Time Data

We generated and published the forecasts presented in Section 5 in real time as the pandemic unfolded.[4] Section 4.1 summarizes the monthly and quarterly series used for the MF-VAR and the timing convention for the estimates and forecasts. The timing of the real-time SPF forecasts is described in Section 4.2.

[3] One can easily modify the specification to allow for more or fewer exceptional periods.

[4] Diebold (2020) distinguishes between “pseudo-real-time” analysis, meaning the use of expanding sample estimation and vintage *data*, and “real-time” analysis, meaning the use of real-time *information* rather than hindsight. We did the latter.

### *4.1 Monthly and Quarterly Time Series*

We consider an MF-VAR for 11 macroeconomic variables, of which 3 are observed at quarterly frequency and 8 are observed at monthly frequency. The quarterly series are GDP, fixed investment (INVFIX), and government expenditures (GOV). The monthly series are the unemployment rate (UNR), hours worked (HRS), consumer price index (CPI), industrial production index (IP), personal consumption expenditures (PCE), federal funds rate (FF), 10-year Treasury-bond yield (TB), and S&P 500 index (SP500). Precise data definitions are provided in the appendix. Series that are observed at a higher than monthly frequency are time aggregated to monthly frequency. The variables enter the MF-VAR in log levels with the exception of UNR, FF, and TB, which are divided by 100 to make them commensurable in scale to the other log-transformed variables.

Our forecasts are based on real-time data sets, assuming that the econometric analysis is conducted on the last day of each month.[5] The timing convention and the data availability for each forecast origin are summarized in Table 2. A forecaster on April 30 has access to monthly observations from March; an initial release of Q1 GDP, investment, and government spending; as well as the April observations for the average federal funds rate, the Treasury-bond yield, and the S&P 500 index. In May, monthly non-financial observations on the April unemployment rate, hours worked, inflation, industrial production, and personal consumption expenditures become available. On June 30, two monthly observations for each non-financial variable are available for the second quarter. This pattern of information repeats itself every quarter. In the remainder of the paper we will refer to the forecast origins only by month and year, with the understanding that estimates and forecasts are based on the information available on the last day of the month.

### *4.2 Survey of Professional Forecasters*

We compare the MF-VAR forecasts to median forecasts from the SPF. The timing of the SPF is summarized in Table 3. The

[5] Due to data revisions by statistical agencies, observations of $Y_{1:T-1}$ published in period $T$ are potentially different from the observations that have been published in period $T-1$. Moreover, some series are published with a delay of several periods.

**Table 2. Information at MF-VAR Forecast Origin**

| | | UNR | HRS | CPI | IP | PCE | FF | TB | SP500 | GDP | INVFIX | GOV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **April 30** | | | | | | | | | | | | |
| Q1 | M3 | X | X | X | X | X | X | X | X | QAv | QAv | QAv |
| Q2 | M4 | ∅ | ∅ | ∅ | ∅ | X | X | X | X | ∅ | ∅ | ∅ |
| **May 31** | | | | | | | | | | | | |
| Q1 | M3 | X | X | X | X | X | X | X | X | QAv | QAv | QAv |
| Q2 | M4 | X | X | X | X | X | X | X | X | ∅ | ∅ | ∅ |
| Q2 | M5 | ∅ | ∅ | ∅ | ∅ | ∅ | X | X | X | ∅ | ∅ | ∅ |
| **June 30** | | | | | | | | | | | | |
| Q1 | M3 | X | X | X | X | X | X | X | X | QAv | QAv | QAv |
| Q2 | M4 | X | X | X | X | X | X | X | X | ∅ | ∅ | ∅ |
| Q2 | M5 | X | X | X | X | X | X | X | X | ∅ | ∅ | ∅ |
| Q2 | M6 | ∅ | ∅ | ∅ | ∅ | ∅ | X | X | X | ∅ | ∅ | ∅ |

**Note:** ∅ indicates that the observation is missing. X denotes monthly observation and QAv denotes quarterly average.

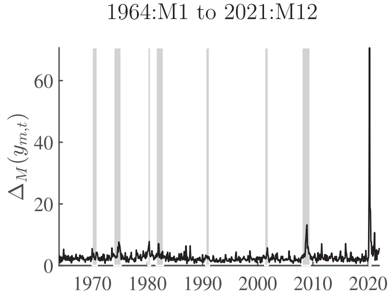
**Table 3. Timing of Survey of Professional Forecasters**

| Survey Name | Questionnaires Sent to Panelists | Submission Deadline | Last Quarter in Info Set | Quarterly Forecasts |
|---|---|---|---|---|
| 1st Quarter | End of January | Middle of February | Y–1:Q4 | Y:Q1 to Y+1:Q1 |
| 2nd Quarter | End of April | Middle of May | Y:Q1 | Y:Q2 to Y+1:Q2 |
| 3rd Quarter | End of July | Middle of August | Y:Q2 | Y:Q3 to Y+1:Q3 |
| 4th Quarter | End of October | Middle of November | Y:Q3 | Y:Q4 to Y+1:Q4 |

**Note:** The questionnaires are sent after the NIPA advance report. The submission deadline is in the second or third week of the month. "Y" refers to the year of the survey.

quarterly survey forecasts are comparable to our first-month-within-a-quarter forecasts (January, April, July, October). Because the survey respondents in principle have two more weeks after our end-of-month MF-VAR forecast origin, this comparison generates a slight

**Figure 1. Extreme Monthly Observations: Mahalanobis Distance**




**Note:** Based on our eight monthly series, we compute the Mahalanobis distance $\mathcal{D}(\Delta y_{m,t})$ defined in (20). The plot is based on the January 2022 vintage.

informational advantage for the SPF. On the other hand, a comparison with our third-month-within-a-quarter predictions (March, June, September, December) puts the SPF forecasts at a clear informational disadvantage against the MF-VAR because the most recent monthly data used in the MF-VAR forecasts are released well after the SPF submission deadline.

## *4.3 Outliers*

Unlike in CCMM, we do not explicitly model the occurrence of outliers in our MF-VAR through fat-tailed error distributions. The outlier-robust estimation and forecasting methods described in Section 3.2 rely on the researcher to pre-specify the cut-off periods $t_*$ and $t_{**}$. In view of the unprecedented mobility restrictions imposed by governments around the world in March 2020, there was no doubt that starting from 2020:M3 macroeconomic data would look very different from their pre-pandemic values and the COVID outliers were easily detectable in real time.

We are plotting the Mahalanobis distance for the eight monthly variables (converted into growth rates) in Figure 1. The distance is defined as

$$\mathcal{D}(\Delta y_{m,t}) = \sqrt{(\Delta y_{m,t} - \hat{\mu})'\hat{\Sigma}^{-1}(\Delta y_{m,t} - \hat{\mu})}. \quad (20)$$

Note that if $\Delta y_{m,t} \sim N(\hat{\mu}, \hat{\Sigma})$, then $\mathcal{D}^2(\Delta y_{m,t})$ has a $\chi^2$ distribution with degrees of freedom equal to the dimension of $y_{m,t}$. Thus, $\mathcal{D}(\Delta y_{m,t})$ measures how far $\Delta y_{m,t}$ lies in the tail of its distribution if it were normally distributed. To generate the figure, we estimate $\hat{\mu}$ and $\hat{\Sigma}$ based on observations up to 2020:M1. In the plot we are simply using the January 2022 vintage, but the pattern is very similar with the real-time vintages. The left panel provides a historical perspective, plotting $\mathcal{D}(\Delta y_{m,t})$ from 1964 onward, whereas the right panel zooms into the last 16 years.

The values of $\mathcal{D}(\Delta y_{m,t})$ from 2020:M3 to 2020:M6 are unprecedented. Between February and March the distance measure jumped from 3.3 to 23.3 and it reached 70.6 in April. From June to July it dropped again from 17.8 to 7.7. For comparison, the largest value during the Great Recession was 13.2 in 2008:M11. Thus, in real time and also with hindsight, the monthly observations from 2020:M3 to 2020:M6 are clearly outliers. In the subsequent analysis we consider three types of estimation samples. For the baseline estimation, E1 in the terminology of Section 3.2, we use the January 2020 vintage which includes the 2020:M1 financial variables, the 2019:M12 monthly macroeconomic variables, and the 2019:Q4 quarterly macroeconomic variables.[6] For the estimation approach E2, we drop observations for periods in which $\mathcal{D}(\Delta y_{m,t})$ exceeds the value 16. This means that observations 2020:M1 and 2020:M2 are included in the estimation sample, the observations 2020:M3 to M6 and 2020:Q1 and Q2 are excluded from the estimation sample, and subsequent observations are included.[7] Finally, we consider the full-sample estimation E3, which includes all observations available at the forecast origin.

[6] Rather than re-estimating the MF-VAR month-by-month using the most recent vintage but keeping the estimation sample fixed, we simply freeze the parameter estimates.

[7] Maroz, Stock, and Watson (2021) estimate a dynamic factor model on a large set of macroeconomic and financial variables and show that including an additional factor for the COVID period improves the fit substantially. This new COVID factor takes on large values from 2020:M3 to 2020:M6, which is the period we drop from the estimation sample, but was less important afterward.

## 5. Empirical Results

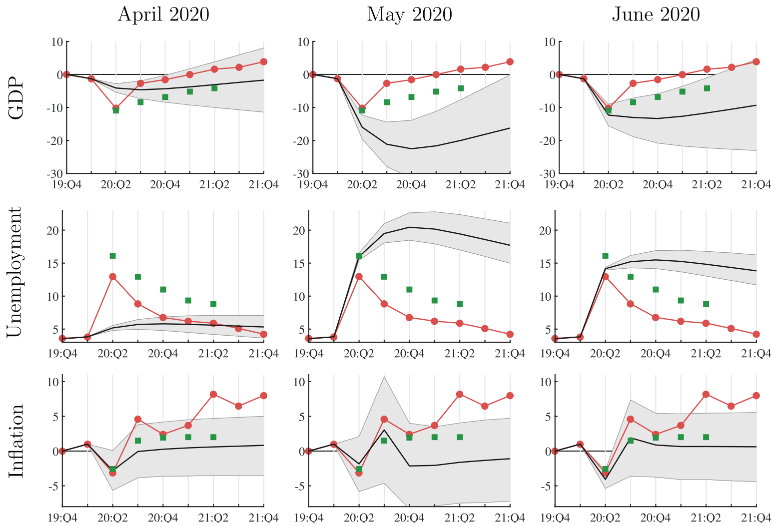
The pre-COVID forecast performance of the MF-VAR model used in this paper was documented in Schorfheide and Song (2015). We showed that the MF-VAR generates more accurate nowcasts and short-run forecasts than a VAR estimated on time-aggregated quarterly data. The improvement tempers off in the medium and long run. The short-run accuracy gain is largest in the third month of the quarter, when a lot of monthly data are available for the current quarter. We also documented that the monthly information helped the MF-VAR track the economic downturn during the 2008-09 (Great) recession period more closely in real time than a VAR estimated on quarterly data only. Similar results for other MF-VAR specifications have been obtained by Brave, Butters, and Justiniano (2019) and McCracken, Owyang, and Sekhposyan (2020).

We estimate the MF-VAR using $p = 6$ lags based on various 2020 and 2021 real-time data vintages and generate forecasts of quarterly averages of the 11 variables that appear in the VAR. All of our estimation samples start in 1964. The hyperparameter settings are the same as in Schorfheide and Song (2015). We subsequently examine the MF-VAR forecasts in chronological order: the COVID-19 outbreak in the United States in 2020:Q2 (Section 5.1), the continuation of the pandemic throughout the second half of 2020 (Section 5.2), and the first three quarters of 2021 (Section 5.3). Because our sample only spans 17 MF-VAR forecast origins and six quarters of SPF forecasts, we examine plots of forecasts and actuals, rather than computing forecast evaluation summary statistics.

### *5.1 The First Months of the COVID-19 Pandemic*

April, May, and June forecasts for GDP, the unemployment rate, and CPI inflation are plotted in Figure 2. The panels show actual values from the January 2022 vintage (solid red), posterior median forecasts (solid black), and 90 percent posterior predictive intervals (light grey). Moreover, we also plot the median forecasts from the SPF. The MF-VAR forecasts are constructed from the real-time vintages available on the date of the forecast, as described in Section 4. Unless otherwise noted, we use the baseline approach of combining

**Figure 2. Forecasts in 2020:Q2**




**Note:** We forecast quarterly averages. Actual values (solid red, January 2022 vintage) and forecasts: median (solid black) and 90 percent bands (light grey) constructed from the posterior predictive distribution. Green squares represent median forecasts from the SPF. For GDP we depict percentage change relative to December 2019. The MF-VAR is estimated based on the January 2020 vintage; filtering uses the vintage available at the forecast origin (baseline, E1 and F1).

parameter estimation approach E1 with full-sample filtering F1; see Sections 3.2 and 4.3.

We are reporting forecasts of quarterly averages (see tick marks on the x-axes of the plots), which are obtained by averaging the within-quarter monthly values simulated from the MF-VAR. Depending on the forecast origin, actual values for some variables might be available for the first one or two months of the first quarter to be forecast. In this case, we generate the quarterly forecast by averaging actual and simulated values. While unemployment and inflation forecasts are plotted directly, we make the following adjustment for the graphical presentation of the GDP forecasts. First, we convert the level forecasts from the MF-VAR and the SPF into growth rate forecasts. Second, we add the level of GDP at the forecast origin according to the January 2022 vintage to the cumulative growth rate forecasts. This is equivalent to adjusting the level of GDP forecasts by the difference between the GDP value at the forecast origin as measured in the January 2022 vintage and the real-time value at the forecast origin.[8]

**Forecasts.** In regard to the treatment of the latent states at the forecast origin conditional on the parameter estimates, the April forecasts are, with the exception of the April financial variables (federal funds rate, Treasury-bond yield, and S&P 500 index) based on Q1 and March data. The economic downturn started in the second half of March when the mobility restrictions became effective. According to the January 2022 vintage, quarter-on-quarter (Q-o-Q) GDP growth in Q1 was −1.3 percent, which is approximately 1.5 times the historical standard deviation in the estimation sample. Industrial production in March 2020 dropped by 3.9 percent and the unemployment rate increased from 3.5 percent to 4.4 percent. At an annualized rate, consumer prices fell by 3.9 percent. Recall from Figure 1 that the Mahalanobis distance for the monthly variables jumped from 3.3 to 23.3 in March.

Because the severity of the pandemic was not yet fully reflected in the observations available for the forecast origin, the April MF-VAR forecasts did not capture the unprecedented magnitude of the downturn. While the posterior median forecast for Q2 GDP growth was −2.8 percent, the actual drop was −9.4 percent. Likewise, the Q2 unemployment forecast was 5.2 percent, whereas the actual average unemployment rate in Q2 was 13.1 percent. The SPF forecasters had an additional week or two to gather information about the economic consequences of the pandemic and the freedom to make judgmental adjustments to model-based forecasts. The figure shows that the median SPF forecasts for GDP and inflation for Q2 were more pessimistic and thereby much closer to the respective actuals than the MF-VAR forecasts. In terms of inflation, the Q2 forecasts of MF-VAR and SPF essentially agree, but over the medium run the SPF forecasters correctly predicted a rise in inflation, whereas the median-run MF-VAR forecast stayed close to zero.

[8] Abstracting from publication lags, denote the time $\tau$ release of $y_t$ by $y_t^\tau$, $\tau = t, t+1, \ldots$. We would like to compare the forecasts $y_{t+h|t}$, $h = 1, \ldots, H$ to the end-of-sample values $y_{t+h}^T$. However, the real-time forecast origin value $y_t^t$ ($h = 0$) does not match the final vintage value $y_t^T$. Thus, we correct the level of the forecasts by $y_t^T - y_t^t$.

We now turn to the May forecasts of GDP and unemployment, which use observations on the April monthly non-financial variables to quantify lagged values at the forecast origin. Under F1 filtering, the MF-VAR requires very large "COVID-19" shocks in the state-transition equation to be able to rationalize the April data. Because historically macroeconomic shocks have had very persistent effects on the time series included in the MF-VAR specification, the model predicts long-lasting adverse effects of the COVID-19 shocks: until the end of 2021 GDP will stay 15 percent to 20 percent below its December 2019 value and the unemployment rate will remain above 13 percent. A comparison to the actuals shows that these forecasts were overly pessimistic: over the forecast period, GDP reverts back to its 2019:Q4 level and the unemployment rate falls below 6 percent. The June information leads to slightly more favorable MF-VAR forecasts, but the model continues to predict long-lasting macroeconomic effects of the pandemic.

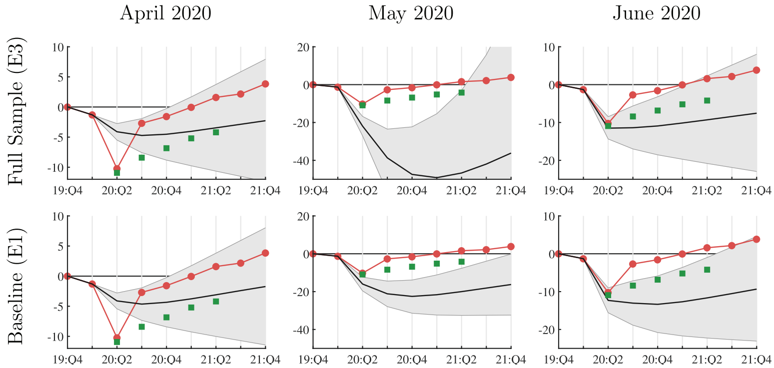
Recall that the survey underlying the SPF forecasts is only conducted quarterly. Thus, the May and June SPF forecasts plotted in Figure 2 are the same as the April forecasts.[9] As we have seen before, the SPF predicts a much faster recovery than the MF-VAR and, ex post, its median forecasts turned out to be much more accurate than the MF-VAR forecasts. Overall, the forecast performance of the MF-VAR during the first three months of the pandemic is poor, compared to the SPF, which presumably incorporates other data sources and judgment about the idiosyncratic nature of the COVID-19 recession.

**Effect of Estimation Sample.** We proceed by examining the effect of choosing the endpoint of the estimation sample on the forecasts. To construct the baseline forecasts, we used the approach E1 and excluded observations that became available after January 2020 from the estimation.[10] This is a sensible strategy if the pandemic was a shock to the economy that was unusually large, indeed several standard deviations in magnitude, but did not change the

[9]The plotted values can be slightly different within the quarter, because we are converting level forecasts into growth rate forecasts and add the growth rates to the level at the origin which may get revised from month to month.

[10]Recall from Section 2 that in a state-space setting this approach is equivalent to setting the measurement error variance to infinity.

**Figure 3. Effect of Estimation Sample on GDP Forecasts**



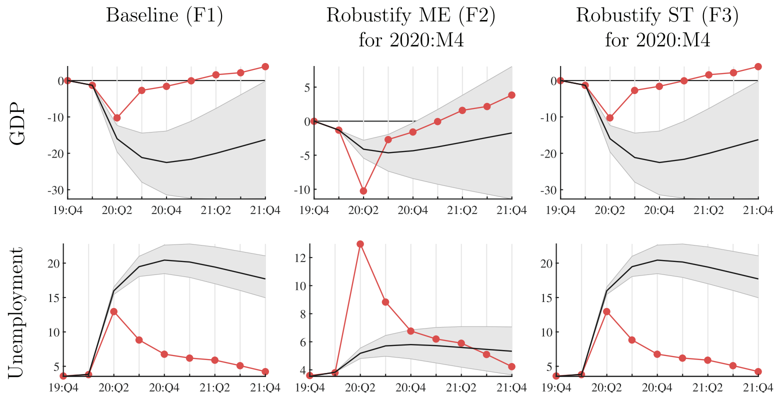

**Note:** We forecast quarterly averages. Actual values (solid red, January 2022 vintage) and forecasts: median (solid black) and 90 percent bands (light grey) constructed from the posterior predictive distribution. Green squares represent median forecasts from the SPF. We depict percentage change relative to December 2019. Full Sample (E3): The MF-VAR is estimated based on data up to the forecast origin. Baseline (E1): The MF-VAR is estimated based on the January 2020 vintage. Estimates are combined with filtering approach F1.

fundamental workings of the aggregate economy. Unless explicitly modeled, the COVID-19 outliers simply distort the parameter estimates. On the other hand, if the pandemic fundamentally changed macroeconomic dynamics, then the most recent observations should be included in the estimation, and earlier observations should possibly be discounted.

In Figure 3 we compare GDP forecasts from a full-sample estimation (top row) that includes data up to the forecast origin (but does not downweight pre-pandemic observations)—estimation approach E3 combined with filtering approach F1 in the terminology of Section 3.2—to the baseline forecasts. For April 2020 the two sets of forecasts are very similar, because the estimation sample ends with the Q1 and March non-financial variables which are not yet severely affected by the pandemic, as discussed previously.

The difference between the forecasts is most pronounced for the May 2020 forecast origin. Here the 90 percent bands under the full-sample estimation are considerably wider than the bands under the baseline estimation. Moreover, the median forecasts drop below

**Figure 4. Effect of Filtering on Forecasts in May 2020**




**Note:** We forecast quarterly averages. Actual values (solid red, January 2022 vintage) and forecasts: median (solid black) and 90 percent bands (light grey) constructed from the posterior predictive distribution. For GDP we depict percentage change relative to December 2019. The MF-VAR is estimated based on the January 2020 vintage (baseline estimation, E1).

−40 percent in 2020:Q4, whereas under the baseline estimation the median forecasts only fall to about −20 percent. The increase in forecast interval width is mainly driven by the estimates of $\Sigma$ which increased due to the extreme observations in April 2020. The discrepancy among the forecasts shrinks again for the June 2020. In general, after the initial adjustment of the economy to the COVID-19 pandemic, we expect the magnitude of subsequent shocks to be more similar to the pre-2020 experience. For 2020:Q2 we find no upside in including post-January observations in the estimation sample.

**Effect of Filtering to Extract States at Forecast Origin.** In the subsequent experiment we revert to the baseline parameter estimation approach E1, excluding 2020 observations from the estimation sample. Instead, we vary the post-estimation filtering to infer the states at the forecast origin. The results are summarized in Figure 4. The plots in the first column of the figure reproduce the baseline May forecasts in Figure 2. The second column is generated using filtering approach F2. We set $M_t = \emptyset$ for 2020:M4, which means that the lagged values needed for the May forecasts are obtained by iterating the state-transition equation forward from the March data onward. This has a drastic effect on the real activity forecasts. The F2 approach completely misses the Q2 drop in GDP and spike in unemployment. However, for Q3 onward it generates less pessimistic forecasts that turned out ex post to be closer to the actual path of the economy. Under F1 the ST propagates the large shock to rationalize the April observations, whereas F2 attributes the outliers to measurement errors and does not propagate them forward.

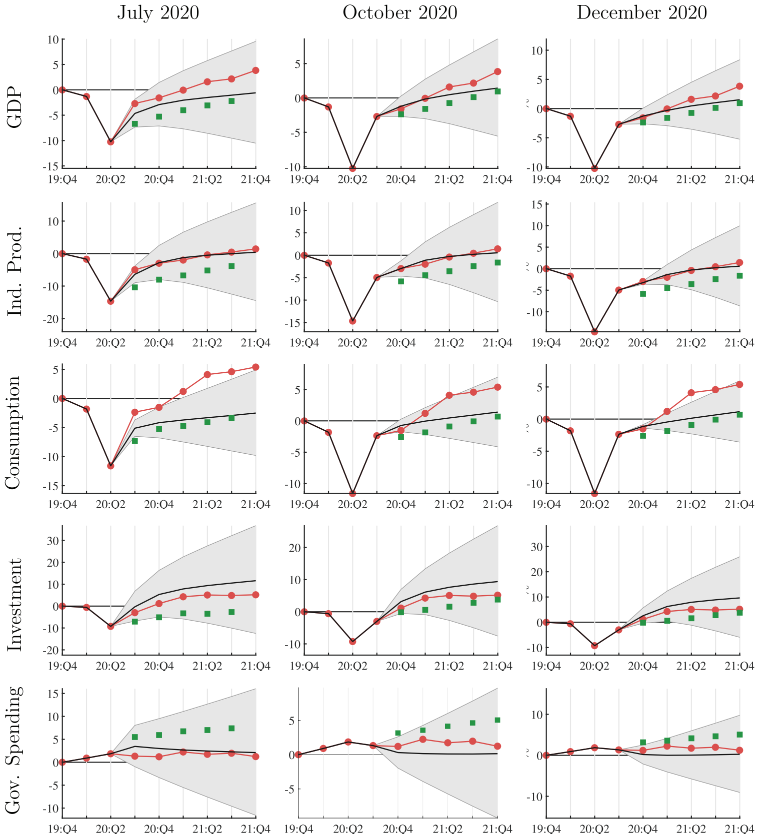
In the last column we show forecasts based on approach F3 where we robustify the ST by inflating the estimated innovation covariance matrix by a factor of $30^2$. Based on the calculations summarized in Table 1, it is not surprising that the F3 forecasts look essentially identical to the F1 forecasts. Despite the inflated innovation variance, inference on the latent state continues to be driven by the April outlier.

### *5.2 The Second Half of 2020*

We now turn to forecasts during 2020:Q3 and Q4. We proceed with the baseline approach of combining E1 and F1. MF-VAR forecasts, SPF forecasts, and actuals from the January 2022 vintage are presented in three figures: real activity variables in Figure 5, labor market variables in Figure 6, and inflation and financial variables in Figure 7. The July 2020 panels overlay the MF-VAR forecasts with SPF forecasts from the Q3 survey, whereas the October and December 2020 panels compare the MF-VAR forecasts to Q4 SPF forecasts. As discussed in Section 4.2, for the first month within a quarter, the SPF forecasters have a slight informational advantage compared to the MF-VAR, whereas for the third month within a quarter, the MF-VAR has a strong advantage.

**Real Activity and Government Spending.** In July 2020 the MF-VAR predicts that GDP and industrial production return to their respective 2019:Q4 values in the second half of 2021. The median forecast from the SPF is less optimistic and about 3 percent to 5 percent lower than the MF-VAR forecast. While the October and December industrial production forecasts from the MF-VAR look quite similar to the July forecast, the GDP forecasts made in 2020:Q4 imply a slightly stronger recovery than the July forecast. Compared to the July forecasts, the gaps between MF-VAR and

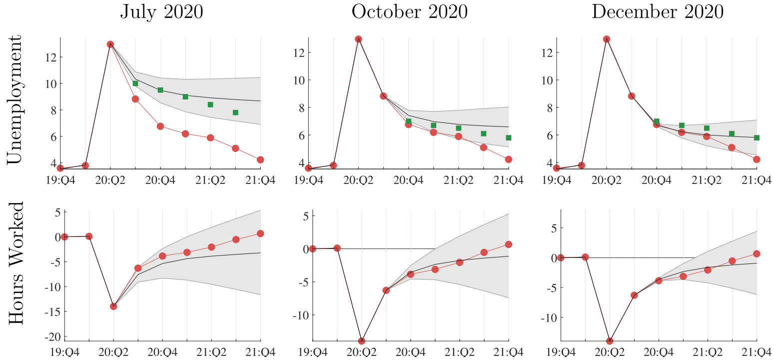
**Figure 5. Real Activity Forecasts in 2020:Q3 and Q4**




**Note:** We forecast quarterly averages. Actual values (solid red, January 2022 vintage) and forecasts: median (solid black) and 90 percent bands (light grey) constructed from the posterior predictive distribution. Green squares represent median forecasts from the SPF. We depict percentage change relative to December 2019. The MF-VAR is estimated based on the January 2020 vintage; filtering uses the vintage available at the forecast origin (baseline approach, E1 and F1).

SPF forecasts narrow in Q4 (October and December). Compared to the Q2 forecasts presented in Section 5.1, the most remarkable difference in the second half of 2020 is that the posterior median forecasts produced in Q3 and Q4 accurately predict GDP and industrial production over a one-year horizon. In fact, the MF-VAR forecasts are now more accurate than the SPF forecasts.

**Figure 6. Labor Market Forecasts in 2020:Q3 and Q4**

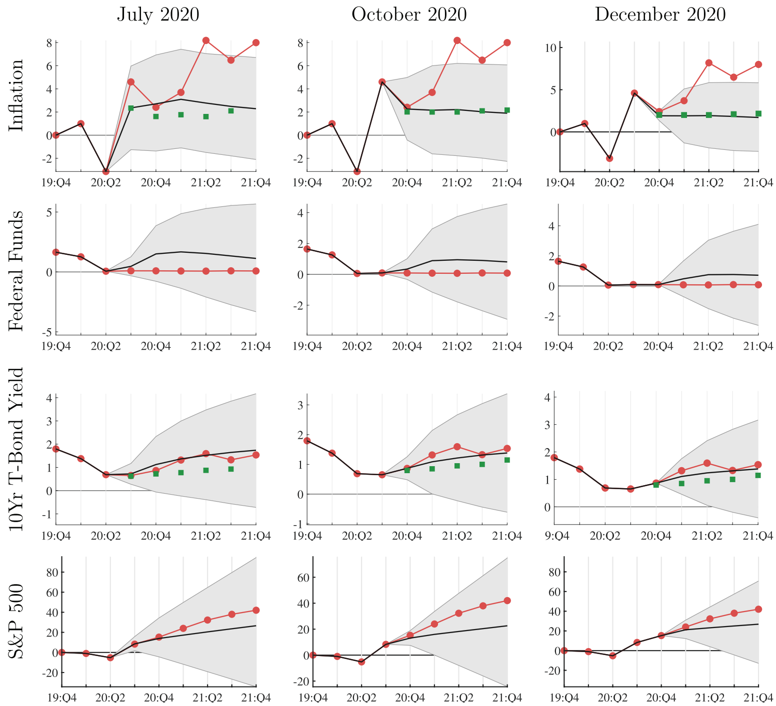



**Note:** We forecast quarterly averages. Actual values (solid red, January 2022 vintage) and forecasts: median (solid black) and 90 percent bands (light grey) constructed from the posterior predictive distribution. Green squares represent median forecasts from the SPF. For Hours Worked we depict percentage change relative to December 2019. The MF-VAR is estimated based on the January 2020 vintage; filtering uses the vintage available at the forecast origin (baseline, E1 and F1).

The MF-VAR predicts throughout the second half of 2020 that consumption returns to its December 2019 value by 2021:Q2 (October and December forecasts). The forecast error for the 2020:Q4 observation is close to zero. In 2021 actual consumption rises faster than the forecast, but by and large stays within the 90 percent credible intervals. Only the band from the December 31 forecast for 2021:Q2 does not cover the actual value. The posterior median forecasts for investment imply a quick recovery. By the end of 2021, investment is expected to be about 10 percent above the 2019:Q4 value. The forecasts from all three origins are quite accurate. Finally, the last row of Figure 5 shows government spending forecasts. The median MF-VAR consumption and investment forecasts are overall more optimistic than the SPF forecast in regard to the recovery from the pandemic downturn.

**Labor Market.** Unemployment and hours worked forecasts are presented in Figure 6. For the unemployment rate the MF-VAR and SPF forecasts are very similar. The Q3 and Q4 SPF forecasts are slightly lower than the July and October MF-VAR forecasts,

**Figure 7. Inflation and Financial Forecasts in 2020:Q3 and Q4**




**Note:** We forecast quarterly averages. Actual values (solid red, January 2022 vintage) and forecasts: median (solid black) and 90 percent bands (light grey) constructed from the posterior predictive distribution. Green squares represent median forecasts from the SPF. For S&P 500 Returns we depict percentage change relative to December 2019. The MF-VAR is estimated based on the January 2020 vintage; filtering uses the vintage available at the forecast origin (baseline, E1 and F1).

respectively, in particular over a one-year horizon. By December unemployment had fallen substantially compared to its Q2 peak and now the MF-VAR forecast that utilizes the most recent information is below the SPF forecast, at least in the short run. In absolute terms, the July forecast is too pessimistic: unemployment falls more quickly than predicted and the actual path is outside of the 90 percent band. The December MF-VAR unemployment forecast, on the other hand, is very accurate; only the 2021:Q4 actual lies slightly outside of the predictive interval. The second row of Figure 6 demonstrates that the MF-VAR is successful in predicting the recovery of hours worked.

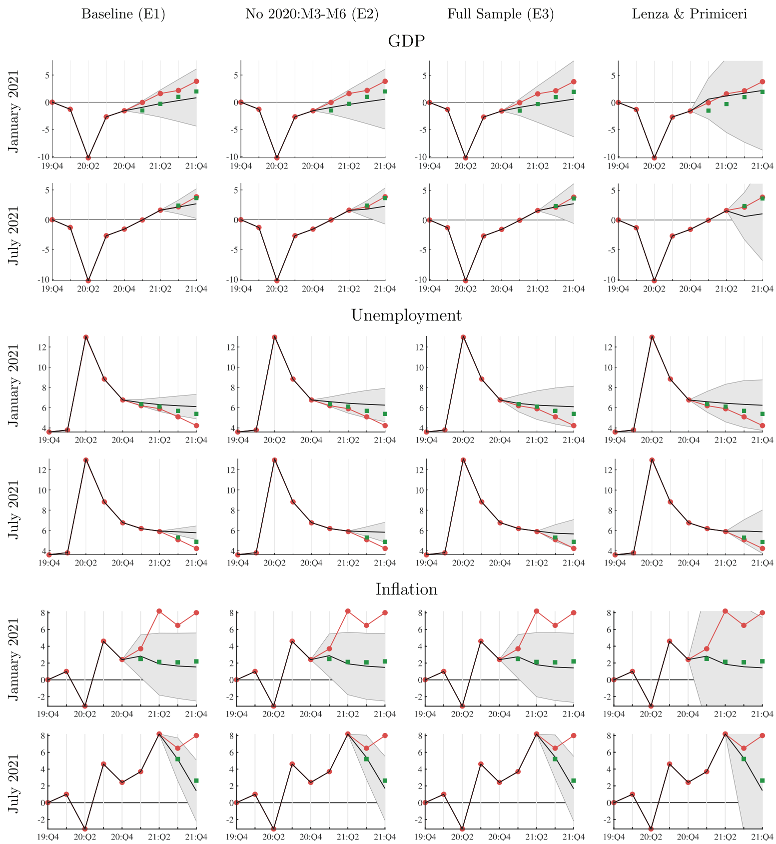
**Inflation and Financial Indicators.** Figure 7 shows forecasts of inflation and the financial variables. For October and December, the MF-VAR and SPF forecasts of inflation are very similar, despite the additional information used by the December MF-VAR. Both approaches capture the drop in inflation between 2020:Q3 and 2020:Q4, but they miss the subsequent rise in inflation, predicting that inflation stays around 2 percent throughout 2021. The MF-VAR predicts a lift-off from the effective lower bound on nominal interest rates which did not happen. While the 10-year Treasury-bond yield forecast in July correctly predicts the actual path, the median forecasts in October and December slightly underestimate the actual yield. For all three forecast origins, the MF-VAR yield forecasts dominate the SPF forecasts. Finally, the MF-VAR implied median forecasts for the S&P 500 slightly underpredict the stock market recovery.

Overall, we conclude that while the forecast performance of the MF-VAR was poor in the second quarter of 2020, the predictions are back on track in the third and fourth quarter. In fact, they are in general as good as or better than the SPF forecasts.

### *5.3 Forecasts in 2021*

Forecasts of GDP, unemployment, and CPI inflation made in January and July 2021 are depicted in Figure 8. Going forward, an important question when estimating VARs and other time-series models will be how to treat the extreme observations during the pandemic. We previously compared our baseline approach E1 of ending the estimation sample in January 2020 to the full-sample estimation E3. In addition, we now consider the following two estimation strategies. First, instead of ending the estimation sample in January 2020, we only drop four months of extreme observations (from March to June, denoted by No 2020:M3–M6) from the estimation sample, denoted by E2 in Section 3.2. We thereby allow the estimates to adapt to post–June 2020 observations. Second, we implement the LP proposal of scaling the innovation variance during 2020:Q2 in a data-driven manner and then letting the scale factor decline subsequently. By inflating the innovation covariance matrix, this approach

**Figure 8. January and July Forecasts for 2021**




**Note:** We forecast quarterly averages. Actual values (solid red, January 2022 vintage) and forecasts: median (solid black) and 90 percent bands (light grey) constructed from the posterior predictive distribution. Green squares represent median forecasts from the SPF. For GDP we depict percentage change relative to December 2019. Baseline (E1): estimation based on the January 2020 vintage. No 2020:M3–M6 (E2): we treat monthly observations from 2020:M3 to M6 and quarterly observations for 2020:Q1 and Q2 as missing. Full Sample (E3): The MF-VAR is estimated based on data available at the forecast origin. Filtering uses the vintage available at the forecast origin (F1).

also discounts pandemic observations in the model estimation stage. Throughout, we use filtering approach F1.

For the forecast origins January and July 2021 baseline estimation, the No-2020:M3–M6 estimation, and full-sample estimation yield very similar posterior median predictions, which are very close to the SPF predictions. The main difference is the width of the predictive intervals. The full estimation approach generates the widest interval among E1, E2, and E3, because the estimate of $\Sigma$ is heavily influenced by the outliers in 2020:Q2. The baseline approach yields the shortest intervals because all pandemic observations are excluded from the estimation of $\Sigma$. The approach of excluding only observations from March to June 2020 generates intervals that are slightly wider than the baseline intervals but shorter than the full-sample estimation. For instance, for the January 2021 forecast origin, the widths of the predictive intervals for 2021:Q1 are 2.3, 2.5, and 3.1 under E1, E2, and E3. The interval widths for the four-quarter-ahead forecasts are 10.5, 11.0, and 14.0, respectively. Compared to the widths of the predictive intervals, the differences in the posterior median forecasts across estimation strategies are small (less than 0.3 percentage point).

The width-based ranking of the E1, E2, and E3 forecasts for unemployment and inflation is the same as for GDP. The main difference is that for the July 2021 forecast origin the wider unemployment intervals associated with the full-sample estimates contain the actual values whereas the narrower E1 and E2 intervals do not. None of the three estimation approaches generates a forecast that is able to capture the high level of inflation in 2021.

Finally, we turn to the forecasts generated with the LP approach. The key difference is that the predictive intervals are substantially wider. For instance, the widths of the January 2021 GDP forecast intervals for 2021:Q1 and Q4 GDP are 7.5 and 22.4, respectively. Thus, they are approximately twice as wide as the other intervals. The estimated decay coefficient $\rho$ is too large for the scaling to decay sufficiently fast. Ex post, the band for the GDP forecast is unreasonably wide. The posterior median GDP point forecasts from the LP approach generated in January are slightly higher and more accurate than the other three forecasts, whereas the July forecasts are slightly lower and less accurate. The remaining panels in Figure 8 depict unemployment and inflation forecasts. The posterior median point forecasts are very similar across all four approaches, including LP. As in the case of GDP, the most striking difference between the LP interval predictions and the other three interval forecasts is that the LP intervals are considerably wider. For unemployment and inflation this arguably works in favor of LP because the unemployment and inflation realizations in the second half of 2021 are included in the predictive intervals.

A quantitative comparison of our empirical findings to those reported by LP and CCMM is difficult because the variables included in the VAR are different, the other studies are not using real-time data, and the forecast objects—in our case, variables aggregated to quarterly frequency—are different. Moreover, LP condition their forecasts on the path of unemployment. Figure 3 of LP compares June 2020 interval forecasts from the volatility-break model to a constant-volatility model estimated with data up until February 2020 (baseline estimation E1 in our classification). LP's volatility-break intervals are considerably wider than the constant-volatility intervals. Figure 4 of LP provides the same comparison for the May 2021 forecasts. Here the intervals from the two methods have similar widths, meaning that the estimated decay rate for the volatility spike is quite large. In contrast, we find that for July 2021 the intervals generated with the LP approach remain considerably wider than our baseline intervals, as we estimate a smaller decay rate for our set of variables. CCMM plot unemployment forecasts in their Figure 5, comparing their preferred stochastic volatility (SV) model with outliers and conditional Student-$t$ distributions to an SV model in which outliers were ex ante identified and replaced by imputed values in a way that is similar to what we labeled as "robust ME." Their December 2020 forecast is comparable to our January 2020 forecast. For that particular origin, dropping versus modeling the outliers delivers very similar point and interval forecasts which appear to match our unemployment forecasts.

Overall, we conclude that excluding the March to June 2020 observations is a promising way of handling the estimation problem of vector autoregressive time-series models going forward. This approach trades off ease of implementation against some elegance and accuracy and is desirable in settings in which a more sophisticated modeling approach appears to be overly costly. Our state-space approach treats outliers as missing observations and imputes values based on the estimated VAR law of motion. In regular VARs the analysis could be further simplified by also dropping periods for which right-hand-side variables are contaminated by extreme outliers, instead of imputing missing lags.

## 6. Conclusion

We resuscitated the mixed-frequency vector autoregression (MF-VAR) developed in Schorfheide and Song (2015) to generate macroeconomic forecasts for the United States during the COVID-19 pandemic from April 2020 to August 2021 in real time. While the forecasting performance of the MF-VAR was quite poor compared to the SPF from April to June 2020, the MF-VAR produced forecasts that are of similar accuracy as the SPF forecasts from July 2020 onward. The only adjustment that we made relative to our pre-pandemic MF-VAR specification was to exclude observations from the early part of the pandemic from the estimation sample. Importantly, we did not modify the model ex post to be able to generate good forecasts in the March to June period retrospectively. This finding is remarkable because it implies that going forward, in applications in which a careful modeling of outliers is impractical, VARs can simply be estimated by excluding observations from the first half of 2020. Our results also suggest that it is prudent for the assessment of the forecasting performance of time-series models to separate the first months of the pandemic from later periods. Because the period from March to June 2020 was highly unusual in many dimensions, the forecast performance in the subsequent months is likely to be more indicative of future forecast performance.

## Appendix

This appendix consists of the following sections:

- A.1 Derivations for Section 2
- A.2 Computational Details
- A.3 Data Set

### *A.1 Derivations for Section 2*

We calculate

$$\begin{aligned}
\ell_y(\hat{\theta}, y_t; Y_{(-t)}, \chi_t) &= \frac{\partial}{\partial y_t}\big[\ln p(y_t|Y_{1:t-1}, \hat{\theta}, \chi_t) + \ln p(y_{t+1}|Y_{1:t}, \hat{\theta}, \chi_t)\big] \\
&= -\frac{y_t - y_{t|t-1}}{F_{t|t-1}} + \frac{y_{t+1} - y_{t+1|t}}{F_{t+1|t}}\frac{\partial}{\partial y_t} y_{t+1|t} \\
&= -\frac{y_t - y_{t|t-1}}{F_{t|t-1}} + \frac{y_{t+1} - y_{t+1|t}}{F_{t+1|t}}\theta\lambda(P_{t-1|t-1}, \chi_t, \theta).
\end{aligned}$$

In turn,

$$
\begin{aligned}
&\ell_{y\theta}(\hat{\theta}, y; Y_{(-t)}) \\
&= \frac{1}{F_{t|t-1}} \frac{\partial}{\partial\theta} y_{t|t-1} + \frac{y_t - y_{t|t-1}}{F_{t|t-1}^2} \frac{\partial}{\partial\theta} F_{t|t-1} \\
&\quad - \frac{1}{F_{t+1|t}} \left( \frac{\partial}{\partial\theta} y_{t+1|t} \right) \theta\lambda(P_{t-1|t-1}, \chi_t, \theta) \\
&\quad - \frac{y_{t+1} - y_{t+1|t}}{F_{t+1|t}^2} \left( \frac{\partial}{\partial\theta} F_{t+1|t} \right) \theta\lambda(P_{t-1|t-1}, \chi_t, \theta) \\
&\quad + \frac{y_{t+1} - y_{t+1|t}}{F_{t+1|t}} \Big[ \lambda(P_{t-1|t-1}, \chi_t, \theta) + \theta\lambda_\theta(P_{t-1|t-1}, \chi_t, \theta) \Big].
\end{aligned}
$$

We obtain

$$
\begin{aligned}
\frac{\partial}{\partial\theta} y_{t|t-1} &= s_{t-1|t-1} \\
\frac{\partial}{\partial\theta} F_{t|t-1} &= 2\theta P_{t-1|t-1} \\
\frac{\partial}{\partial\theta} y_{t+1|t} &= \lambda(P_{t-1|t-1}, \chi_t, \theta) y_t + \theta\lambda_\theta(P_{t-1|t-1}, \chi_t, \theta) y_t \\
&\quad + 2\theta \big[ \lambda(P_{t-1|t-1}, \chi_t, \theta) - 1 \big] s_{t-1|t-1} \\
&\quad + \theta^2 \lambda_\theta(P_{t-1|t-1}, \chi_t, \theta) s_{t-1|t-1} \\
\frac{\partial}{\partial\theta} F_{t+1|t} &= 2\theta\lambda(P_{t-1|t-1}, \chi_t, \theta)\chi_{u,t} + \theta^2 \lambda_\theta \big( P_{t-1|t-1}, \chi_t, \theta \big) \chi_{u,t}.
\end{aligned}
$$

Moreover,

$$
\begin{aligned}
\lambda_\theta(P, \chi, \theta) &= \frac{2\theta P(\theta^2 P + \chi_{\epsilon,t} + \chi_{u,t}) - 2\theta P(\theta^2 P + \chi_{\epsilon,t})}{(\theta^2 P + \chi_{\epsilon,t} + \chi_{u,t})^2} \\
&= \frac{2\theta P \chi_{u,t}}{(\theta^2 P + \chi_{\epsilon,t} + \chi_{u,t})^2}.
\end{aligned}
$$

We can now take limits

$$
\lim_{\chi_{u,t} \longrightarrow \infty} F_{t|t-1} = 0
$$

$$\lim_{\chi_{u,t}\longrightarrow\infty} \lambda(P,\chi_t,\theta) = 0$$

$$\lim_{\chi_{u,t}\longrightarrow\infty} \lambda(P,\chi_t,\theta)\chi_{u,t} = \theta^2 P_{t-1|t-1} + 1$$

$$\lim_{\chi_{u,t}\longrightarrow\infty} \lambda_\theta(P,\chi_t,\theta) = 0$$

$$\lim_{\chi_{u,t}\longrightarrow\infty} \lambda_\theta(P,\chi_t,\theta)\chi_{u,t} = 2\theta$$

$$\lim_{\chi_{u,t}\longrightarrow\infty} \frac{\partial y_{t+1|t}}{\partial\theta} = 2\theta s_{t-1|t-1}$$

$$\lim_{\chi_{u,t}\longrightarrow\infty} \frac{\partial F_{t+1|t}}{\partial\theta} = 4\theta^3 + 2\theta$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} F_{t|t-1} = 0$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} \lambda(P,\chi_t,\theta) = 1$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} \lambda(P,\chi_t,\theta)\chi_{u,t} = 1$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} \lambda_\theta(P,\chi_t,\theta) = 0$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} \lambda_\theta(P,\chi_t,\theta)\chi_{u,t} = 0$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} \frac{\partial y_{t+1|t}}{\partial\theta} = y_t$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} \frac{\partial F_{t+1|t}}{\partial\theta} = 2\theta.$$

In turn,

$$\lim_{\chi_{u,t}\longrightarrow\infty} \ell_{y\theta}(\hat{\theta},y_t;Y_{(-t)},\chi_t) = 0$$

$$\lim_{\chi_{\epsilon,t}\longrightarrow\infty} \ell_{y\theta}(\hat{\theta},y_t;Y_{(-t)},\chi_t) = -\frac{\theta y_t}{\theta^2+2} - 2\theta^2\frac{y_{t+1}-\theta y_t}{(\theta^2+2)^2} + \frac{y_{t+1}-\theta y_t}{\theta^2+2}.$$

### A.2 Computation Details

We modify the posterior sampler developed in Schorfheide and Song (2015) to account for the latent scale sequence $s_t$ defined in (19) and its associated parameter vector $\vartheta$. The Bayesian computations are implemented with a Metropolis-within-Gibbs sampler that iterates over the following three conditional distributions:[11]

$$\begin{aligned} p(\Phi,\Sigma|Z_{0:T},Y_{-p+1:T},\vartheta) &\propto p(Z_{1:T}|z_0,\Phi,\Sigma,\vartheta)p(\Phi,\Sigma|\lambda) \\ p(Z_{0:T}|\Phi,\Sigma,Y_{-p+1:T},\vartheta) &\propto p(Y_{1:T}|Z_{1:T})p(Z_{1:T}|z_0,\Phi,\Sigma,\vartheta) \\ &\quad \times p(z_0|Y_{-p+1}) \\ p(\vartheta|\Phi,\Sigma,Z_{0:T},Y_{-p+1:T}) &\propto p(Z_{1:T}|z_0,\Phi,\Sigma,\vartheta)p(\vartheta), \end{aligned} \tag{A.1}$$

where the third distribution is new. The modifications are as follows:

**Step 1:** Conditional on $Z_{0:T}$ the MF-VAR reduces to a standard linear Gaussian VAR with a conjugate prior. To sample from $p(\Phi,\Sigma|Z_{0:T},Y_{-p+1:T},\vartheta)$, write the VAR in slight abuse of notation as

$$x_t' = z_{t-1}'\Phi + s_t u_t', \tag{A.2}$$

where we treat $x_t$ as observed and incorporate a constant term in the definition of $z_{t-1}$. Recall that the sequence $\{s_t\}$ can be generated from $\vartheta$. The likelihood function is given by

$$\begin{aligned} &p(X|\Phi,\Sigma,S) \\ &\propto \left(\prod_{t=1} |s_t^2\Sigma|^{-1/2}\right) \\ &\quad \times \exp\left\{-\frac{1}{2}\sum_{t=1}^{T} \mathrm{tr}\left[s_t^{-2}\Sigma^{-1}(x_t' - z_{t-1}'\Phi)'(x_t' - z_{t-1}'\Phi)\right]\right\} \end{aligned}$$

[11] Lenza and Primiceri (2022) use a posterior sampler that integrates out $(\Phi,\Sigma)$ analytically. Because of the state-space form of the MF-VAR, this approach is not feasible in our settings. Thus, we will use a Metropolis-within-Gibbs step.

$$\propto \left(\prod_{t=1} s_t^{-n}\right) |\Sigma|^{-T/2} \exp\left\{-\frac{1}{2}\mathrm{tr}\left[\Sigma^{-1}(\tilde{X} - \tilde{Z}_{-1}\Phi)'(\tilde{X} - \tilde{Z}_{-1}\Phi)\right]\right\}, \tag{A.3}$$

where $\tilde{X}$ has rows $x_t'/s_t$ and $\tilde{Z}_{-1}$ has rows $z_{t-1}/s_t$. Thus, the posterior sampler for $(\Phi, \Sigma)$ only requires the transformation of $X$ into $\tilde{X}$ and $Z_{-1}$ into $\tilde{Z}$.

**Step 2:** Sampling from $p(Z_{0:T}|\Phi, \Sigma, Y_{-p+1:T}, \vartheta)$ can be easily implemented by replacing the covariance matrix $\Sigma$ by $\tilde{\Sigma}_t = s_t^2\Sigma$ in every period $t$.

**Step 3:** We follow Lenza and Primiceri (2022) in using a Pareto distribution to form a prior for $\bar{s}_j^2$ and a Beta distribution for $\rho$. Thus,

$$p(\vartheta) = \left(\prod_{j=0}^{2} \frac{1}{\bar{s}_j^2}\mathbb{I}\{\bar{s}_j^2 \geq 1\}\right) \frac{1}{B(p,q)}\rho^{p-1}(1-\rho)^{q-1}, \tag{A.4}$$

where $p$ and $q$ are chosen such that the Beta distribution has mean 0.8 and standard deviation 0.2. We split $\vartheta$ into three components—$\bar{s}_0^2$, $\bar{s}_1^2$, and $(\bar{s}_2^2, \rho)$—and sample each component conditional on values for the other three components.

**Sampling from the Posterior of $\bar{s}_0^2$.** Note that $\bar{s}_0^2$ only affects the density for period $t_*$:

$$\begin{aligned} &p(\bar{s}_0^2|\Phi, \Sigma, Z_{0:T}, Y_{-p+1:T}, \vartheta_-) \\ &\propto \frac{1}{\sqrt{\bar{s}_0^{2n}}} \exp\left\{-\frac{1}{2\bar{s}_0^2}\mathrm{tr}\left[\Sigma^{-1}(x_{t_*}' - z_{t_*-1}'\Phi)'(x_{t_*}' - z_{t_*-1}'\Phi)\right]\right\} \\ &\quad \times \mathbb{I}\{\bar{s}_0^2 \geq 1\}\frac{1}{\bar{s}_0^2}. \end{aligned}$$

Now define

$$\beta_0 = \frac{1}{2}\mathrm{tr}\left[\Sigma^{-1}(x_{t_*}' - z_{t_*-1}'\Phi)'(x_{t_*}' - z_{t_*-1}'\Phi)\right], \quad \alpha_0 = n/2.$$

Then the distribution of $\bar{s}_0^2$ is inverse Gamma $(\alpha_0, \beta_0)$ truncated at 1.[12] Notice that the distribution of $\bar{s}_0^2$ is independent of the other $\vartheta$ elements.

**Sampling from the Posterior of $\bar{s}_1^2$.** Note that $\bar{s}_1^2$ only affects the density for period $t_* + 1$:

$$\begin{aligned} & p(\bar{s}_1^2|\Phi, \Sigma, Z_{0:T}, Y_{-p+1:T}, \vartheta_-) \\ & \propto \frac{1}{\sqrt{\bar{s}_1^{2n}}} \exp\left\{ -\frac{1}{2\bar{s}_1^2} \text{tr}\big[\Sigma^{-1}(x'_{t_*+1} - z'_{t_*}\Phi)'(x'_{t_*+1} - z'_{t_*}\Phi)\big] \right\} \\ & \quad \times \mathbb{I}\{\bar{s}_1^2 \geq 1\} \frac{1}{\bar{s}_1^2}. \end{aligned}$$

Now define

$$\beta_1 = \frac{1}{2}\text{tr}\big[\Sigma^{-1}(x'_{t_*+1} - z'_{t_*}\Phi)'(x'_{t_*+1} - z'_{t_*}\Phi)\big], \quad \alpha_1 = n/2.$$

Then the distribution of $\bar{s}_1^2$ is inverse Gamma $(\alpha_1, \beta_1)$ truncated at 1. Notice that the distribution of $\bar{s}_1^2$ is independent of the other $\vartheta$ elements.

**Sampling from the Posterior of $(\bar{s}_2^2, \rho)$.** Note that $(\bar{s}_2^2, \rho)$ affect the density for period $t_* + 2$ onwards:

$$\begin{aligned} & p(\bar{s}_2^2, \rho|\Phi, \Sigma, Z_{0:T}, Y_{-p+1:T}, \vartheta_-) \\ & \propto \left( \prod_{t=t_*+2}^{T} \frac{1}{1 + (\sqrt{\bar{s}_2^2} - 1)\rho^{t-t_*-2}} \right)^n \\ & \quad \times \exp\left\{ -\frac{1}{2} \sum_{t=t_*+2}^{T} \frac{1}{\big(1 + (\sqrt{\bar{s}_2^2} - 1)\rho^{t-t_*-2}\big)^2} \right. \\ & \quad \left. \times \text{tr}\big[\Sigma^{-1}(x'_{t_*} - z'_{t_*-1}\Phi)'(x'_{t_*} - z'_{t_*-1}\Phi)\big] \right\} \\ & \quad \times \mathbb{I}\{\bar{s}_2^2 \geq 1\} \frac{1}{\bar{s}_2^2} \frac{1}{B(p,q)} \rho^{p-1}(1-\rho)^{q-1}. \end{aligned}$$

[12]The $IG(\alpha, \beta)$ distribution has density $(\beta^\alpha/\Gamma(\alpha))(1/x)^{\alpha+1}\exp(-\beta/x)$.

**Table A.1. ALFRED Series Used in Analysis**

| Time Series | ALFRED Name |
|---|---|
| Gross Domestic Product (GDP) | GDPC1 |
| Fixed Investment (INVFIX) | FPIC1 |
| Government Expenditures (GOV) | GCEC1 |
| Unemployment Rate (UNR) | UNRATE |
| Hours Worked (HRS) | AWHI |
| Consumer Price Index (CPI) | CPIAUCSL |
| Industrial Production Index (IP) | INDPRO |
| Personal Consumption Expenditure (PCE) | PCEC96 |
| Federal Fund Rate (FF) | FEDFUNDS |
| 10-Year Treasury Bond Yield (TB) | GS10 |
| S&P 500 (SP500) | SP500 |

This density does not belong to a specific family of distributions from which we can sample directly. Thus, we use a random-walk Metropolis-Hastings step.

**Initialization of $\vartheta$ and Proposal Covariance Matrix.** (i) We initialize $\rho^0$ using the prior mean of 0.8. (ii) Based on parameter estimates from a run that stops estimation in, say, December 2019, we use the estimates $(\hat{\Phi}, \hat{\Sigma}, \hat{Z})$ to compute $(\alpha_j, \beta_j)$ for the conditional posteriors $p(\bar{s}_j|\cdot)$, $j = 0, 1$. We initialize $\bar{s}_j$ using the mean $\beta_j/(\alpha_j - 1)$. Assuming that $\bar{s}_2$ only affects observation $t = t_* + 2$, the same approach can be used to initialize $\bar{s}_2$. (iii) For the proposal covariance matrix in the random-walk Metropolis-Hastings step, we use a diagonal matrix. The element for $\rho$ is a fraction of its prior variance, e.g., $0.2^2/10$, and for $\bar{s}_2$ we use $\beta_2^2/(\alpha_2 - 1)^2(\alpha_2 - 2)$, where $\alpha_2$ and $\beta_2$ are defined in the same way as $\alpha_1$ and $\beta_1$.

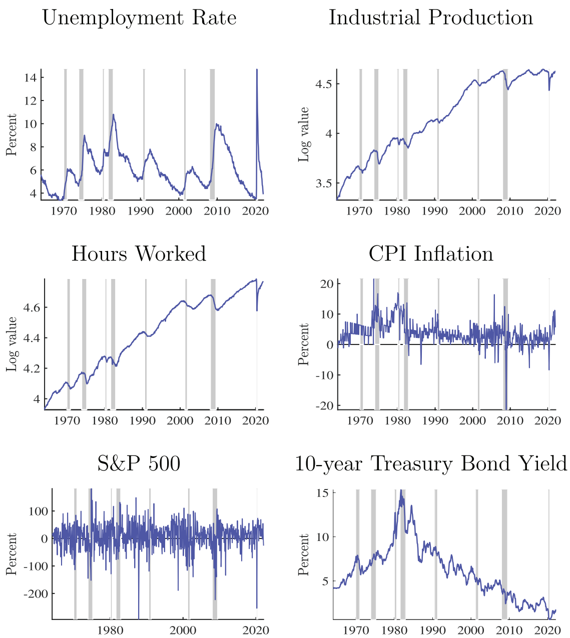
## *A.3 Data Set*

The 11 real-time macroeconomic data series are obtained from the ALFRED (Archival Federal Reserve Economic Data) database maintained by the Federal Reserve Bank of St. Louis. Table A.1 summarizes how the series used in this paper are linked to the series provided by ALFRED.

The recent vintages of PCE and INVFIX from ALFRED do not include data prior to 2002. However, the most recent data for PCE and INVFIX can be obtained from BEA or NIPA tables. Specifically, we download "Table 2.8.3. Real Personal Consumption Expenditures by Major Type of Product, Monthly, Quantity Indexes" for PCE and "Table 5.3.3. Real Private Fixed Investment by Type, Quantity Indexes" for INVFIX, which are available from January 1, 1959 and January 1, 1948 to current periods, respectively. First, we compute the growth rates from the quantity indices. Based on the computed growth rates, we can backcast historical series up to January 1, 1964 using the January 1, 2002 data points as initializations. We think this is a reasonable way to construct the missing points for PCE and INVFIX.

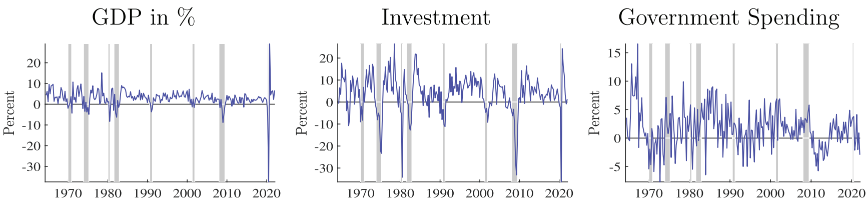
Figures A.1 and A.2 provide the time-series plot of our 11 macroeconomic variables obtained from the August 2021 vintage.

**Figure A.1. Monthly Data**




**Note:** Month-on-month percentage changes are annualized. The data are obtained from the January 2022 vintage, starting from 1964. The shaded bars indicate the NBER recession dates.

**Figure A.2. Quarterly Data, Q-o-Q Growth Rates in Annualized %**




**Note:** The data are obtained from the January 2022 vintage, starting from 1964. The shaded bars indicate the NBER recession dates.

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# Government Debt and Expectations-Driven Liquidity Traps*

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The presence of an effective lower bound on the nominal interest rate creates a risk that expectations of low inflation become entrenched. When this happens, distortionary taxation and expansionary fiscal policies may result in a large accumulation of debt that spurs inflation when the lower bound ceases to bind. The corresponding increase in expected real interest rates then further depresses consumption and output. In light of this outcome, the welfare-maximizing strategy in an expectations-driven liquidity trap is to downsize the government by concurrently cutting taxes and spending. This policy achieves the twin objective of stimulating the economy while containing the debt accumulation.

JEL Codes: E43, E52, E62, E63.

## 1. Introduction

The low rate environment observed since the Great Recession and until recently has reduced the cost of debt-financed fiscal stimuli. This opportunity has been exploited extensively by the U.S. government, with the ratio of privately held government debt over GDP ballooning to unprecedented levels. Conventional wisdom is that spending policies have large multiplicative effects in a liquidity trap because they alleviate the shortfall in inflation and reduce real rates. This insight concerns liquidity traps that are caused by large contractionary shocks on private demand. However, the long

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duration of binding lower-bound episodes experienced in advanced economies suggests a potential shift in expectations. In this context, central banks have increasingly acknowledged the risk of low inflation expectations becoming entrenched because of the asymmetric response of interest rates to inflation.[1] While monetary policy can in principle curb inflation by tightening its stance, the presence of an effective lower bound on the policy rate renders the task of anchoring inflation expectations a more delicate one.

Hence, it is crucial to understand the implications of accumulating government debt in a liquidity trap caused by negative feedback loops on expectations. This paper seeks to answer this question based on a New Keynesian model in which occasional shifts in households' confidence lead to a stationary environment characterized by deflation and depressed output even in the absence of a deterioration in economic fundamentals. I label this environment the *unintended* regime as opposed to the *intended* regime where inflation is anchored at the central bank's target and the output gap is zero, and study the macroeconomic implications of a *regime shock* that causes switches from one regime to the other. I show that those dynamics have important consequences for deficit-financed fiscal stimuli when taxes are confined to labor income. More specifically, I consider a deficit-financed and *perfectly timed* exogenous spending increase and tax cut when government debt is stabilized through an endogenous response of labor taxes to the inherited level of debt. There are three main insights stemming from this analysis.

First, the unavailability of lump-sum taxes causes a negative shift in confidence to weigh more heavily on economic activity. The inflation shortfall in the unintended regime raises the real cost of debt while subdued consumption shrinks the tax base. Hence, the government accumulates debt in the unintended regime that spurs inflation once the lower bound stops binding through the cost-push effect of endogenous labor taxes. The ensuing monetary policy tightening increases real interest rates so that the intertemporal consumption smoothing of the households crowds out consumption in the unintended regime. I label the crowding-out effect of debt *the expectation*

[1] In its 2020 strategic review, the Federal Reserve emphasized the importance of staying ahead of the inflation curve to avoid sliding inflation expectations.

*channel* and show that this channel offsets most of the upward pressure of endogenous taxes on the marginal costs of the firms in the unintended regime.

Second, standard fiscal stimuli are self-defeating in an expectations-driven liquidity trap; an expansionary fiscal policy leads to a net drop in output. Moreover, the effects are qualitatively different whether the policy consists in a spending stimulus or a tax cut. To understand this result, I study a simplified economy without debt and show that the inflation response to fiscal policy depends on the anticipated impact of price setting on firms' markup. An exogenous spending stimulus (tax cut) is deflationary (inflationary) because the long expected duration of the lower-bound episode implies that the price markup is decreasing in inflation. The deflationary effect of the spending stimulus causes the government to accumulate more debt in the liquidity trap to compensate for the increase in the real cost of its liabilities. Hence, endogenous labor taxes increase in the intended regime and monetary policy tightens in response to the cost-push effect, crowding out consumption through the expectation channel. By contrast, debt soars less with a tax cut because the rise in inflation reduces the real cost of debt and widens the tax base. Nevertheless, the crowding-out effect of the expectation channel dominates the crowding-in effect of lower real rates in the unintended regime and results in a negative net effect on output, albeit lower than the one of the spending stimulus. I show also that the recessionary effects of deficit-financed fiscal policies may be overturned if the duration of the policy intervention in the unintended regime is reduced, consistently with the findings of Wieland (2018).

Third, an analysis on optimized rules reveals that the welfare-maximizing policy consists in a reduction of the size of the state; the government should provide a significant tax cut combined with a spending cut. On the one hand, the tax cut allows to mitigate the inflation shortfall in the unintended regime. On the other hand, the spending cut reinforces this inflationary effect while slowing down the accumulation of debt. Exiting the liquidity trap with a lower debt burden is effective in stimulating consumption of forward-looking households because it reduces the cost-push effect of labor taxes and the expected real rates. Those benefits are also attested by the positive output effect of a faster debt consolidation in the tax rule.

The interactions between fiscal and monetary policy in a low rate environment have received considerable attention in the New Keynesian literature. Influential studies such as Christiano, Eichenbaum, and Rebelo (2011), Woodford (2011), and Erceg and Lindé (2014) have shown that the fiscal multiplier of government spending policies can be large in a liquidity trap driven by fundamental shocks because they create inflation and reduce the real rates.[2] Moreover, in the presence of distortionary taxes on labor income, financing the stimulus with bonds issuance turns out mostly innocuous because the enlargement of the tax base (partially) offsets the additional debt burden. Unsurprisingly, Burgert and Schmidt (2014) also find that deficit-financed stimuli constitute the optimal policy for a discretionary planner when dealing with large contractionary demand shocks. While those results build a solid case for an expansionary fiscal policy in a fundamental-driven liquidity trap, it remains unclear how they would extend to a liquidity trap driven by shifts in consumers' confidence.

Several papers have studied the characteristics of expectations-driven liquidity traps in a New Keynesian framework. The closest to this paper is Mertens and Ravn (2014), who study the effect of fiscal policy in a stationary environment characterized by deflation and depressed output. However, differently from this paper, their model is non-linear and they assume that lump-sum taxes balance the budget constraint of the government every period. Hence, Ricardian equivalence holds in their model and financing fiscal stimuli with debt or taxes does not affect other macroeconomic variables. More generally, the literature about expectations-driven liquidity traps can be divided into two strands. One strand studies the macroeconomic outcomes in this type of environment. For example, Borağan Aruoba, Cuba-Borda, and Schorfheide (2018) estimate a model subject to both fundamental- and expectations-driven liquidity traps and find that the former corresponds more to the U.S. experience while the latter can describe the Japan economy since the late 1990s. Schmitt-Grohé and Uribe (2017) show that adding job market frictions can help this kind of model in explaining jobless recoveries. Jarociński and Maćkowiak (2018) combine those insights with the

[2]In particular, see Appendix B of Christiano, Eichenbaum, and Rebelo (2011) for the case of distortionary taxation most closely related to this paper.

literature on self-fulfilling debt crises to demonstrate the efficacy of mutualized debt in avoiding bad economic outcomes. Nakata and Schmidt (2022) show that traditional ingredients of optimal fiscal and monetary policy are largely powerless in stabilizing the economy when the liquidity trap is non-fundamental. The second strand of this literature studies how to suppress the existence of this type of liquidity traps altogether. Building on the insights of Benhabib, Schmitt-Grohé, and Uribe (2002), those papers have mainly focused on the design of ad hoc rules in achieving this outcome as in Sugo and Ueda (2008), Schmidt (2016), and Tamanyu (2022).

The remainder of the paper is organized as follows. Section 2 describes the model and the existence of expectations-driven liquidity traps. Section 3 provides a simplified example of an economy without debt to clarify the plain-vanilla effects of fiscal policy. Section 4 contains the main analysis on the role of debt in the expectations-driven liquidity trap. After discussing the equilibrium responses to fiscal policy, this section inspects the importance of the expectation channel as a driver of macroeconomic dynamics in the unintended regime. Section 5 considers optimized rules to identify the best fiscal strategy and extends the results of the previous section to recurrent regime shocks. Finally, Section 6 concludes.

## 2. The Model

The model is a cashless New Keynesian economy with monopolistic competition and nominal rigidities. The private sector is composed of an infinitely lived representative household, a representative aggregate good producer, and a continuum of intermediate good producers. The public sector is represented by two institutions, a central bank and a government respectively in charge of monetary and fiscal policy decisions.

### *2.1 Households and Firms*

The representative household derives utility from consuming the private good $c_t$ and the public good $G_t$ while it dislikes hours worked

$h_t$. I assume a separable utility function leading to the following expected lifetime utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \xi_t \left[ \frac{c_t^{1-\gamma_c}}{1-\gamma_c} + \nu_g \frac{G_t^{1-\gamma_g}}{1-\gamma_g} - \nu_h \frac{h_t^{1+\gamma_h}}{1+\gamma_h} \right], \tag{1}$$

where $\mathbb{E}_t$ is the rational expectations operator conditional on information in period $t$; $\beta$ is the time discount factor. Parameters $\gamma_c$ and $\gamma_g$ are respectively the intertemporal elasticity for private and government consumption, and $\gamma_h$ is the inverse of the Frisch elasticity. I also attach utility weights $\nu_g$ and $\nu_h$ to characterize preference for government consumption and hours, relative to private consumption.

The variable $\xi_t$ is an exogenous process characterizing the time preference. Under this specification, time preference between states of two consecutive periods evolves according to $\xi_t/(\beta\xi_{t+1})$. This process characterizes the fluctuations at the origin of *fundamental-driven* liquidity traps (FDLT). Hence, I introduce the variable $d_t \equiv \xi_{t+1}/\xi_t$, which I refer to as a demand shock.

The household sells hours to intermediate firms for a wage $W_t$ net of labor taxes $\tau_t$ and may save via a one-period nominal and non-state-contingent real government bond, $b_t^h$. Firm profits yield a dividend $\Pi_{i,t}$, and constant lump-sum transfers $T$ are collected from the government to finance the steady-state employment subsidy (see intermediate firms' optimization problem below). The household budget constraint (in real terms) reads

$$c_t + \frac{b_t^h}{R_t} = (1-\tau_t) w_t h_t + \frac{b_{t-1}^h}{\pi_t} + \int_0^1 \frac{\Pi_{i,t}}{P_t} di - \frac{T}{P_t}, \tag{2}$$

where $R_t$ is the gross nominal interest rate, $P_t$ is the price of consumption goods, and $\pi_t = P_t/P_{t-1}$ is the gross inflation rate. The household chooses $\{c_t, h_t, b_t^h\}_{t=0}^{\infty}$ to maximize expected lifetime utility (1) subject to (2) and the no-Ponzi scheme conditions on the nominal asset

$$\lim_{j\to\infty} \underset{t}{\mathbb{E}} \left( \left( \prod_{k=0}^{t+j} \frac{1}{R_k} \right) B_{t+j}^h \right) \geqslant 0.$$

Intermediate firms operate under monopolistic competition and seek to maximize profits subject to quadratic price adjustment costs à la Rotemberg (1982). From the profit-maximization problem of the final producer, the demand function of the generic firm producing $i$ is given by

$$y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\theta} y_t, \tag{3}$$

where $\theta$ is the marginal rate of substitution between varieties. The program of the firm $i$ is

$$\max_{P_{i,t}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \xi_t \lambda_t \times \left[\left(\frac{P_{i,t}}{P_t}\right)^{-\theta} y_t \left(\frac{P_{i,t}}{P_t} - (1-s)w_t\right) - \frac{\psi}{2}\left(\frac{P_{i,t}}{P_{i,t-1}} - 1\right)^2 y_t\right], \tag{4}$$

where $\lambda_t$ is the multiplier of budget constraint from the household problem and $\psi$ is the price adjustment cost factor.

Parameter $s$ is a time-invariant employment subsidy, financed with lump-sum transfers, that offsets steady-state distortions stemming from monopolistic competition and distortionary taxation.[3] This subsidy is used in Section 5 on optimized rules to guarantee the efficiency of the economy at the steady state and derive the social loss function.

### *2.2 Log-Linear Approximation*

The non-linear equilibrium equations are log-linearized around the zero inflation steady state.[4] In the benchmark model, the subsidy is set to zero ($s = 0$) and the steady state is distorted. The system of linear equations characterizing the private-sector decisions reads

$$\beta\tilde{b}_t - \tilde{b}_{t-1} - b(\beta\hat{\imath}_t - \hat{\pi}_t) - \Psi^b_G \hat{G}_t + \Psi^b_c \hat{c}_t + \Psi^b_\tau \tilde{\tau}_t = 0 \quad \text{(BC)} \tag{5}$$

$$\hat{c}_t = -\gamma_c^{-1}(\hat{\imath}_t - \mathbb{E}_t\hat{\pi}_{t+1} - \hat{d}_t) + \mathbb{E}_t\hat{c}_{t+1} = 0 \quad \text{(EE)} \tag{6}$$

$$\hat{\pi}_t = \beta\mathbb{E}_t\hat{\pi}_{t+1} - (\theta-1)\psi^{-1}\hat{\mu}_t \quad \text{(PC)}, \tag{7}$$

---

[3]This implies that distortions from labor taxation do occur outside the steady state. See Leith and Wren-Lewis (2013) for a similar use of a steady-state subsidy.

[4]A description of the non-linear economy and the efficient steady state can be found in Appendix A.1 and Appendix A.3, respectively.

where the price markup of the firms is given by

$$\hat{\mu}_t = -\Psi_c^\mu \hat{c}_t - \Psi_G^\mu \hat{G}_t - \Psi_\tau^\mu \tilde{\tau}_t. \tag{8}$$

All variables are in log-deviations from their steady-state value, except for government debt ($\tilde{b}_t \equiv b_t - b$) and the tax rate ($\tilde{\tau}_t \equiv \tau_t - \tau$), which are expressed in deviations from their steady-state value.[5] The coefficients are defined as

$$\begin{array}{ll} \Psi_G^b \equiv 1 - \tau w y(1+\gamma_h) y^{-1} G & \Psi_G^\mu \equiv \gamma_h y^{-1} G \\ \Psi_c^b \equiv \tau w y(\gamma_c + (1+\gamma_h) y^{-1} c) & \Psi_c^\mu \equiv \gamma_c + \gamma_h y^{-1} c \\ \Psi_\tau^b \equiv w y (1-\tau)^{-1} & \Psi_\tau^\mu \equiv (1-\tau)^{-1}. \end{array}$$

The first equation is the budget constraint (BC) of the government. It states that the net nominal debt position must be financed with an appropriate surplus (or deficit). The government surplus depends positively on inflation and taxes (which include both the tax base and the tax rate) and negatively on interest rates and spending. The law of motion for debt is a constraint in my model because government liabilities are ultimately financed with distortionary taxes on labor income. The second equation is the Euler equation (EE) that links the real rate of return on assets to the intertemporal tradeoff of the households. The third equation is the Phillips curve (PC) at the heart of the New Keynesian model that establishes a negative relationship between inflation and the infinite discounted stream of expected price markups.[6] Notice that the price markup of the firms (8) is decreasing in the fiscal instruments. An exogenous increase in government spending and/or in the labor tax rate creates excess demand in the labor market that pushes up the real wage and thus reduces the price markup.

### *2.3 Public Policy*

In this paper, I consider the standard case of a monetary policy following a Taylor rule that responds to inflation deviations from target:

[5]Under baseline calibration, $y = 0.25$ and so $\tilde{b}_t$ can be interpreted as debt deviations in percentage of annual steady-state output.

[6]To see this, substitute forward (7) recursively to obtain $\hat{\pi}_t = -(\theta - 1)\psi^{-1}\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \hat{\mu}_{t+j}$.

$$\hat{\imath}_t = max[-log(\beta^{-1}), \phi_\pi \hat{\pi}_t]. \tag{9}$$

The max operator implies that monetary policy is constrained by an effective lower bound (ELB) on the nominal interest rate.

With regard to fiscal policy, I assume realistically that only distorting income taxes are available to the government and, hence, its solvency condition becomes binding. More specifically, tax variations have two components: an endogenous component that reacts to inherited government debt and an exogenous component that is independent of debt. The labor tax rule reads

$$\tilde{\tau}_t = \phi_\tau \tilde{b}_{t-1} + \epsilon_{\tau,t}, \tag{10}$$

where $\epsilon_{\tau,t}$ governs the tax stimulus and is contingent to the state of the economy.

### *2.4 Calibration*

Numerical experiments in this paper are performed under the following calibration. A time period represents one-quarter of a year. The preference parameters, $\nu_g$ and $\nu_h$, are chosen to be consistent with households working one-quarter of their time endowment and with a share of government spending equating one-fifth of output. The annual interest rate in the intended steady state is set to 2.5 percent and pins down the time discount factor, $\beta$. The parameters of the Phillips curve are standard to the literature. The intertemporal elasticity of private and public consumption, and the inverse of the Frisch elasticity, are equal to 1. The elasticity of substitution between intermediate goods, $\theta$, corresponds to a price markup over the marginal cost of 10 percent. Given the value of $\theta$, the parameter of the price adjustment cost, $\psi$, matches its Calvo (1983) equivalent (up to a first-order approximation around the deterministic steady state) when the average duration for setting prices equals one year.

Regarding public policy, I assume that the Taylor parameter is $\phi_\pi = 1.5$, a standard value in the literature. As a baseline calibration of the tax rule (10), I choose $\phi_\tau = 0.1$, implying that a 10 percentage point increase in the debt-to-output ratio lifts the labor tax rate by 1 percentage point. This calibration ensures medium-run fiscal solvency and makes fiscal policy passive in the sense of Leeper

**Table 1. Baseline Calibration**

| Symbol | Description | Value |
|---|---|---|
| $\beta$ | Subjective Discount Factor | 0.9938 |
| $\theta$ | Elasticity of Substitution among Goods | 11 |
| $\epsilon$ | Price Adjustment Cost | 117.805 |
| $\gamma_c$ | Intertemporal Elasticity of $c$ | 1 |
| $\gamma_h$ | Intertemporal Elasticity of $h$ | 1 |
| $\upsilon_h$ | Utility Weight on Labor | 20 |
| $\phi_\pi$ | Inflation Parameter in Taylor Rule | 1.5 |
| $\phi_\tau$ | Tax Parameter in Fiscal Rule | 0.1 |
| $\beta b$ | Steady-State Market Value of Debt (%) | 50 |

(1991). Since the pace of debt consolidation is potentially influential for the macroeconomic dynamics, I investigate the sensitivity of the results when varying this parameter in Appendix E.2. Moreover, for the numerical exercises precluding the use of lump-sum taxes, I need to choose a steady-state value of government debt. Baseline calibration assumes that the market value of debt amounts to 50 percent of annual GDP, a value that is roughly consistent with the average debt ratio observed in the United States since the Great Recession (and before the COVID-19 crisis) according to the data of the Federal Reserve Economic Database (FRED) of the Federal Reserve Bank of St. Louis. The parameter values are summarized in Table 1. Finally, the baseline fiscal interventions are calibrated as follows (unless otherwise specified). The spending expansion corresponds to a 1 percentage point increase in the spending-to-output ratio from 20 percent to 21 percent ($\hat{G}^u = 0.0488$). The tax cut corresponds to a 1 percentage point decrease in the labor tax rate ($\epsilon^u_\tau = -0.01$).

## *2.5 Expectations-Driven Liquidity Traps*

As first demonstrated by Benhabib, Schmitt-Grohé, and Uribe (2001), non-linear monetary policy rules such as (9) imply the existence of a stationary environment characterized by depressed inflation and consumption and a nominal rate that is constrained by the ELB. In what follows, I label this environment the *unintended* regime as opposed to the *intended* regime in which inflation is on target and the ELB does not bind. The unintended regime is often seen

(Arifovic, Schmitt-Grohé, and Uribe 2018; Tamanyu 2022) as resulting from self-fulfilling pessimism. For a reason that is left unspecified, rational agents begin to anticipate a negative economic outlook and reduce their demand for consumption goods. The central bank wants to alleviate the drop in inflation by cutting the nominal rate, but the ELB prevents the response to be sufficiently accomodative. This constrained policy response causes the initial pessimistic expectations to realize and the economy ends up trapped in a low inflation equilibrium. Consistently with this intuition, the unintended regime is often called an *expectations-driven liquidity trap* (EDLT). I use those two terms interchangeably. Before studying the implications of debt in this environment, I provide a simplified example in which lump-sum taxes balance the budget constraint every period to gain intuition about the effect of fiscal policy on inflation.

## 3. Fiscal Policy with Lump-Sum Taxes

As we will see, an important driver of government debt dynamics and of macroeconomic outcomes is the response of inflation to a particular fiscal policy. To illustrate this inflationary effect, I start with a simplified economy in which lump-sum taxes are available and so the government budget constraint does not bind. Let's assume that the intended regime is absorbing and denote by $p_u$ the probability of remaining in the unintended regime. In this case, Appendix B shows that inflation in the unintended regime can be written as

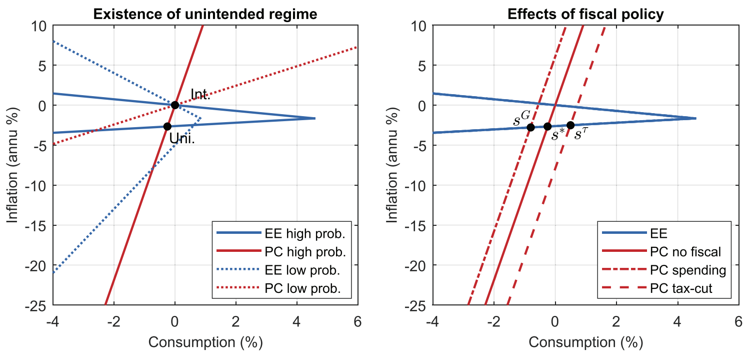
$$\hat{\pi}_t^u = \Lambda^{-1}\Big[-\hat{\imath}^* - \frac{\kappa_G}{\overline{\kappa}_c}(1-p_u)\hat{G}^u - \frac{\kappa_\tau}{\overline{\kappa}_c}(1-p_u)\tilde{\tau}^u\Big], \qquad (11)$$

where $\Lambda \equiv p_u - \frac{(1-p_u)}{\overline{\kappa}_c} + \frac{\beta p_u}{\overline{\kappa}_c}(1-p_u)$ and $\kappa_G \equiv \frac{\gamma_h(\theta-1)}{\psi}Gy^{-1}$, $\kappa_\tau \equiv \frac{(\theta-1)}{(1-\tau)\psi}$, $\overline{\kappa}_c \equiv \frac{\gamma_c(\theta-1)}{\psi} + \frac{\gamma_h(\theta-1)}{\psi}cy^{-1}$.

Parameter $\Lambda$ has two roots: $p_u^* = 0.68 < 1$ and $p_u^{*\prime} = 1.48 > 1$. Thus, for a bounded probability of remaining in the unintended regime $0 < p_u < 1$, the following sign restrictions apply:

$$\Lambda \begin{cases} < 0, & \text{if } 0 < p_u < p_u^* \\ > 0, & \text{if } p_u^* < p_u < 1. \end{cases}$$

**Figure 1. Existence Condition and Fiscal Policy in the Unintended Regime without Government Debt**




**Note:** Inflation is expressed as annualized percentages and consumption as percentage deviations from steady state. The Euler equation is in blue and the Phillips curve in red. Left panel: The solid lines correspond to a high probability ($p_u = 0.95$) of remaining in the unintended regime, while the dotted lines correspond to a low probability ($p_u = 0.5$). Right panel: The solid line corresponds to the absence of fiscal intervention, the dash-dotted line to a spending stimulus of 5 percent, and the dashed line to a tax cut of 1 percentage point.

When $p_u = p_u^*$, the equilibrium inflation rate is indeterminate. Assume first that there is no fiscal intervention, $\hat{G}^u = \tilde{\tau}^u = 0$. In this case, $\hat{\pi}_t^u = -\Lambda^{-1}\hat{\imath}^*$ and so a necessary condition for the existence of an unintended regime with binding ZLB is $p_u > p_u^*$ (otherwise $\hat{\pi}_t^u > 0$ and the Taylor rule gives a positive interest rate in the unintended regime). That is, the expected duration of the liquidity trap must be long enough. The left panel in Figure 1 shows this condition graphically. The solid lines correspond to the Euler equation (EE, blue) and Phillips curve (PC, red) when the probability of remaining in the unintended regime is $0.95 > p_u^*$. In this case, the PC crosses the EE two times. The lower intersection corresponds to the unintended regime with low inflation and consumption. The EE is upward sloping due to the positive effect of inflation on consumption when the nominal interest rate is pegged at zero. This unintended regime ceases to exist when the probability of remaining becomes too low. For example, the dotted lines correspond to $0.5 < p_u^*$ and cross only one time, at the intended regime.

Assume now that fiscal policy intervenes in the unintended regime. Consider first a perfectly timed increase in government spending ($\hat{G}^u > 0$). Labor demand increases in response to higher public consumption. All else equals, wages must rise to clear the labor market and so firms' markup deteriorates. From (11), the marginal effect of a change in government spending on inflation is given by $\partial\hat{\pi}_t^u/\partial\hat{G}^u = -\Lambda^{-1}\frac{\kappa_G}{\tilde{\kappa}_c}(1-p_u)$ and is thus negative for $p_u > p_u^*$. In words, the lower markup stemming from the spending stimulus depresses inflation in the EDLT.

Next, consider a perfectly timed tax cut ($\tilde{\tau}^u < 0$). A tax cut increases the net disposable income of households and thus boosts labor supply. All else equal, wages must now drop to clear the labor market and thus firms' markup improves. From (11), the marginal effect of a change in labor taxes on inflation is given by $\partial\hat{\pi}_t^u/\partial\tilde{\tau}^u = -\Lambda^{-1}\frac{\kappa_\tau}{\tilde{\kappa}_c}(1-p_u)$. In an EDLT ($p_u > p_u^*$), the higher markup stemming from the tax cut stimulates inflation.

Thus, in an EDLT, the inflation response depends on the impact of the fiscal intervention on the firms' markup. More specifically, inflation increases (decreases) if the exogenous fiscal policy improves (deteriorates) firms' markup. This result is analogous to the findings of Mertens and Ravn (2014) in a non-linear economy with Calvo (1983)-style sticky prices. The intuition is as follows. The Phillips curve (7) indicates that firms will adjust prices sluggishly whenever the observed markup deviates from their desired markup. In normal circumstances, this relationship implies an increase in prices when the markup deteriorates. However, when the economy is stuck in a liquidity trap of unusually long expected duration, such common price increase would have a long-lasting negative effect on the real interest rate and would thus crowd in consumption heavily. Since the markup would deteriorate further in this case (because of the upward pressure that additional demand puts on marginal costs), this outcome cannot restore equilibrium. Instead, prices must fall so that the corresponding expected rise in the real interest rate crowds out consumption to a level consistent with the firms' markup in the new equilibrium.

Those mechanisms are illustrated in the right panel of Figure 1. In the unintended regime, the Euler curve is flatter than the Phillips curve (the converse would hold in an FDLT). This slope implies that consumption is hypersensitive to changes in inflation because of the strong effect on real interest rates explained above. Before the fiscal intervention, the economy rests at the equilibrium $s^*$. The spending expansion causes a fall in the price markup that shifts the Phillips curve upwards (dash-dotted red line). To reach the new equilibrium $s^G$, consumption has to move *left* along the Euler curve (from –0.24 percent in $s^*$ to –0.81 percent in $s^G$), reflecting the crowding-out effect of higher real interest rates. By contrast, the increase in the price markup generated by the tax cut shifts the Phillips curve downwards (dashed red line) so that consumption now has to move *right* along the Euler curve to reach equilibrium $s^\tau$ (in which consumption is now positive with a gap of 0.5 percent). Thus, inflation and consumption must increase to recover the markup consistent with the new equilibrium.

## 4. Fiscal Policy when Government Debt Matters

In this section, I explore how the financing source of fiscal stimuli affects their effectiveness in an EDLT. Consistently with the previous section, uncertainty is captured by a two-state Markov process. As explained, the existence of an EDLT requires that agents attach a high probability to staying in the unintended regime. As a benchmark calibration, I assume $p_u = 0.95$. Moreover, for the ease of the exposition, the intended regime is absorbing (I relax this assumption in the next section). The probability transition matrix is thus given by

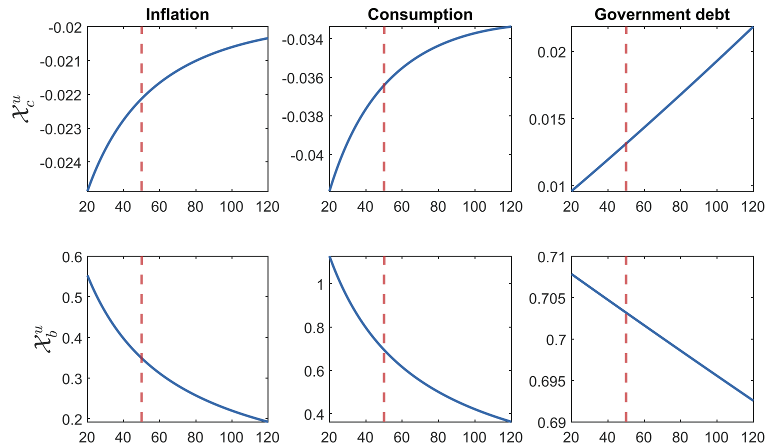
$$\begin{bmatrix} p_i & (1-p_i) \\ (1-p_u) & p_u \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0.05 & 0.95 \end{bmatrix}.$$

Given that taxes are confined to labor income, government debt becomes a state variable that matters for the decisions of the households and firms. Hence, I write the policy function for any variable $x_t = \{\hat{c}_t, \hat{\pi}_t, \hat{\imath}_t, \hat{y}_t, \tilde{b}_t\}$ as follows:

$$x_t^i = \mathcal{X}_c^i + \mathcal{X}_b^i \tilde{b}_{t-1}$$
$$x_t^u = \mathcal{X}_c^u + \mathcal{X}_b^u \tilde{b}_{t-1},$$

where $\mathcal{X}_c^{u,i} = \{\mathcal{C}_c, \mathbf{\Pi}_c, \mathcal{I}_c, \mathcal{Y}_c, \mathcal{B}_c\}^{u,i}$ is a regime-dependent constant and $\mathcal{X}_b^{u,i} = \{\mathcal{C}_b, \mathbf{\Pi}_b, \mathcal{I}_b, \mathcal{Y}_b, \mathcal{B}_b\}^{u,i}$ is a regime-dependent policy response to inherited government debt. To recover the value of

**Figure 2. Policy Functions with Respect to the Steady-State Debt Level**




**Note:** The solid blue line corresponds to the constant coefficient (top panels) and to the debt coefficient (bottom panels) in the unintended regime policy function. The horizontal axis is the steady-state level of debt and the dashed red line indicates the baseline calibration (50 percent of annual GDP).

those coefficients, I rely on a method of undetermined coefficients. Appendix C provides more details about this method.

## *4.1 Intrinsic Role of Government Debt*

Before considering the effectiveness of fiscal policy in stabilizing the economy subject to regime shocks, I provide intuition about the role of debt and the endogenous tax response without fiscal intervention. Figure 2 displays the policy functions for different levels of steady-state government debt. The vertical dashed red line corresponds to the baseline calibration (50 percent of annual output).

The figure reveals several important features of the policy functions when debt matters for private agents' decisions. First, government debt is above its steady-state level in the unintended regime even without exogenous fiscal intervention. The low inflation in the EDLT increases the real value of government debt and induces a monetary tightening upon the exit of the trap in response to the cost-push effect of taxes. Expectations of higher real interest rates crowd out consumption in the unintended regime via the intertemporal consumption smoothing motive of the households. In what follows, I will refer to this crowding-out effect of government debt on consumption as *the expectation channel.*

Figure 2 shows that the level at which debt stabilizes in the unintended regime depends positively on steady-state debt. A same drop in inflation has a proportionally larger effect on the real value of debt when steady-state debt increases. As a result, inflation and consumption have a higher intercept and are less sensitive to variations in the inherited level of debt. Nevertheless, the larger debt accumulation aggravates the recession because of the anticipated contractionary monetary policy in the intended regime.

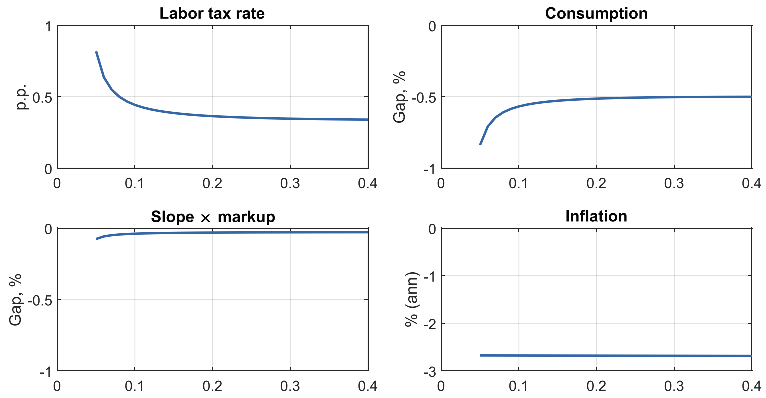
Notice also that the long-run level of inflation in the unintended regime is practically insensitive to the endogenous tax response to government debt. Although higher endogenous taxes tend to decrease the price markup of the firms in (8), the bulk of this effect is offset by the crowding out of consumption through the expectation channel.

To illustrate this argument, Figure 3 shows the long-run equilibrium values of selected variables (taxes, consumption, the product of the Phillips curve slope and the price markup, and inflation) in the unintended regime for values of the parameter $\phi_\tau$ in (10) ranging from 0.05 to 0.4. The upper left panel reveals that endogenous taxes are higher in the long run when the pace of debt consolidation is lower because of larger debt accumulation. At the same time, this larger debt amplifies the crowding out of consumption via the expectation channel (upper right panel). As a result, the period $t$ price markup effect in the Phillips curve given by $(\theta - 1)\psi^{-1}\hat{\mu}_t$ in (7) is left virtually unchanged (bottom left) and firms do not need to revise their prices (last panel).

### *4.2 Equilibrium Responses to Fiscal Policy*

As we will see in this section, financing fiscal stimuli with government debt is not innocuous in my non-Ricardian economy. Figure 4 describes the equilibrium responses to various fiscal policies. Before the regime shock occurs, the economy is assumed to have been trapped in the unintended regime for a sufficiently long time so that

**Figure 3. Unresponsiveness of Long-Run Inflation to Endogenous Taxes in the Unintended Regime**




**Note:** Long-run equilibrium responses in the unintended regime (y-axis) to various calibrations of the feedback parameter $\phi_\tau$ in the tax rule (x-axis). Variables slope × markup ($(\theta-1)\psi^{-1}\hat{\mu}_t$ in (7)) and consumption are expressed in percentage deviations from the steady state. Inflation is in annual percentages and the tax rate in absolute percentages. Despite varying levels of taxes, the inflation response remains flat across paces of consolidation.

government debt has converged to its stationary level.[7] To see what this level corresponds to, consider the debt policy function in period $t$ after convergence has occurred:

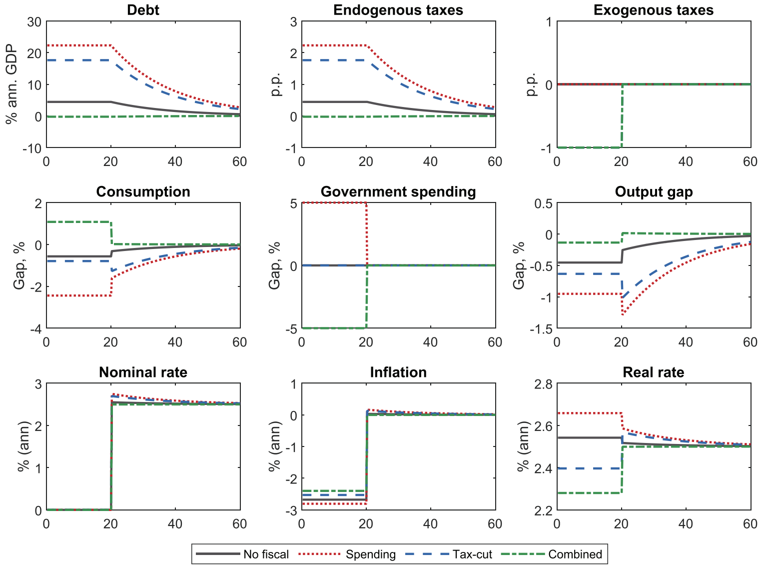
$$\tilde{b}_t = \mathcal{B}_c^u + \mathcal{B}_b^u \tilde{b}_{t-1}.$$

Recursive backward substitution of this equation yields the following general expression:

$$\tilde{b}_t = \mathcal{B}_c^u \sum_{j=1}^{N} \mathcal{B}_b^{u\,j-1} + \mathcal{B}_b^{u\,N}\tilde{b}_{t-N} = \mathcal{B}_c^u \left( \frac{1-\mathcal{B}_b^{u\,N}}{1-\mathcal{B}_b^u} \right) + \mathcal{B}_b^{u\,N}\tilde{b}_{t-N}.$$

[7]Since the intended regime is absorbing, the economy has to start in the unintended regime before the transition occurs. The time needed to phase out an arbitrary level of initial debt in this regime depends on the gap with the stationary level but is typically short. For simplicity, it can be assumed that the economy starts with a stock of debt equal to the stationary level, in which case convergence is instantaneous.

**Figure 4. Effects of a Fiscal Stimulus in an Expectations-Driven Liquidity Trap**




**Note:** The solid black line corresponds to the absence of fiscal intervention, the dotted red line to a spending increase of 1 percent of GDP, the dashed blue line to a tax cut of 1 percentage point, and the dash-dotted green line to a simultaneous spending cut and tax cut of 1 percent of GDP and 1 percentage point, respectively. Government spending, consumption, and the output gap are expressed in percentage deviations from the steady state. Inflation, the nominal interest rate, and the real interest rate are in annual percentages. Debt is in percentage of annual output and the tax rate in absolute percentages. The economy starts in the unintended regime after debt has converged to its long-run stationary level. The regime shock occurs after 20 years.

Hence, taking $N \to \infty$, the stationary level of debt for $\mathcal{B}_b^u < 1$ corresponds to $\tilde{b}_t = \mathcal{B}_c^u/(1 - \mathcal{B}_b^u)$. Notice also that when $\mathcal{B}_b^u \geq 1$, the path of government debt is explosive and so the system does not admit a stationary solution.

How do debt dynamics influence the transmission of fiscal policy? The dotted red line and the dashed blue line in Figure 4 correspond to the same fiscal stimuli as before but in an EDLT with endogenous debt accumulation. The effects turn out sensibly different from Section 3. First of all, both stimuli are now *self-defeating*;

by attempting to stimulate the economy, fiscal policy instead aggravates the recession. Second of all, the negative effect on consumption and output is more pronounced with a spending stimulus than with a tax cut. Appendix E.1 shows that those effects may be overturned by reducing the expected duration of the fiscal policy. As explained by Wieland (2018), this expected duration, rather than the type of liquidity trap, determines whether or not the policy expands output. In an FDLT, the expected duration of a perfectly timed stimulus is low enough for the policy to be expansionary because of the short expected duration of the lower-bound episode itself. In contrast, the high expected duration of the EDLT renders the same perfectly timed stimuli contractionary.

The first panel shows that expansionary fiscal policies increase debt accumulation in the unintended regime over the long run. At the onset of the intended regime, the larger stock of inherited debt translates into a higher tax rate that pushes up inflation and increases the nominal interest rate in the Taylor rule. This monetary tightening implies that real interest rates (bottom right panel) are consistently higher after the regime shock has occurred so that output plummets due to the crowding-out effect on consumption (middle right and middle left panels, respectively).

Hence, there is a trade-off between providing a stimulus in the unintended regime and reducing the debt burden inherited by the government upon the exit of the liquidity trap. Central to this trade-off are the rational expectations of the private sector. Forward-looking agents anticipate that real rates will be higher in the intended regime when the government accumulates more debt to finance its stimulus. As demonstrated in the next subsection, the expectation channel has adverse effects on consumption and inflation in the unintended regime.

In this respect, the spending stimulus (dotted red line) has the largest impact on debt accumulation in the unintended regime because of two combined effects on deficits: a direct effect from the increase in spending and an indirect effect from drop in inflation which increases the real cost of debt. Hence, with a spending stimulus, real rates stand in excess from their steady-state level in the unintended regime *and* for a prolonged period after the regime shock, strongly crowding out consumption in the unintended regime (−2.4 percent). This private consumption effect prevails over the demand effect of the stimulus and produces a negative net effect on output.

By comparison, the tax cut (dashed blue line) has a lower impact on debt accumulation (17.6 percent of GDP against 22.3 percent of GDP with the spending policy). The inflationary effect associated with lower exogenous taxes partly offsets the drop in revenues by decreasing the real cost of debt and by widening the tax base. This higher inflation also implies that real interest rates inside and outside the liquidity trap have opposite effects on consumption. Nevertheless, the middle left panel shows that the crowding-out effect of the higher expected real rates and subdued economic activity upon the exit of the trap dominates in the unintended regime and implies that the tax cut is recessionary when financed with debt issuance.

Thus, purely deficit-financed fiscal stimuli are inadequate in an EDLT because of their recessionary effects in the intended regime and the intertemporal transmission through the expectation channel. This conclusion is disappointing when compared to outcomes of similar policies in a FDLT. Appendix D shows that the same increase in government spending is successful at stimulating output when the liquidity trap is caused by a large contractionary demand shock. This favorable outcome stems from the inflationary effect of additional public consumption that lowers the real interest rate when the zero lower bound (ZLB) is binding and crowds in consumption (see, e.g., Christiano, Eichenbaum, and Rebelo 2011; Erceg and Lindé 2014). In my non-Ricardian model, the larger deficits also trigger an endogenous rise in the labor tax rate that strengthens this channel by pushing up inflation further.[8] By contrast, the tax cut remains a self-defeating policy in this environment due to the deflationary effect of the large debt accumulation that boosts real interest rate expectations upon the exit of the liquidity trap (see Eggertsson 2011 for a similar self-defeating effect without debt accumulation).

The results discussed so far suggest that a desirable policy mix in the EDLT should aim at crowding in consumption in the unintended regime while simultaneously curtailing the accumulation of government debt. The dash-dotted green line in Figure 4 shows that this

[8]The effectiveness of labor taxes in crowding in consumption at the ZLB depends on the presence of non-Ricardian households and the degree of wage stickiness as shown by de Beauffort (2023).

outcome can be achieved by cutting taxes and government spending at the same time. This combined strategy maintains government debt close to its steady-state level. In the EDLT, the lower level of taxes and government spending both improve the markup of the firms and thus call for a price increase (to persistently lower real rates and to stimulate consumption). Consequently, real interest rates in the unintended regime plummet and successfully crowd in consumption. The last section of the article demonstrates that a similar policy mix corresponds to the welfare-maximizing strategy of the government when EDLTs are recurring events.

### *4.3 Inspecting the Expectation Channel*

In an EDLT, government debt thus provides an additional channel that feeds into expectations of private agents and weakens the effectiveness of expansionary fiscal policies. The way this expectation channel plays out is, however, not obvious. For example, Nakata and Schmidt (2022) show that an increase in the inflation target that lowers the real interest rate in the intended regime can reduce inflation and consumption in the unintended regime. Their findings suggest that the expectation channel in an EDLT may work in reverse with respect to an FDLT. This section shows, through two examples, that imposing non-Ricardian fiscal policy restores the conventional view on the expectation channel. The reason is the following.

An expected rise in the real interest rate upon the exit of the trap provides an incentive for households to consume less out of their current income. When Ricardian equivalence holds, the particular path of government debt and lump-sum taxes is irrelevant for the equilibrium values of consumption and other real variables. Hence, market clearing requires either households' income or the relative price of consumption to adjust. Nakata and Schmidt (2022) show that income cannot be the variable of adjustment in an EDLT because of the hypersensitivity of consumption (more than one-for-one) to income changes. Consequently, the real interest rate has to drop and, with nominal rates pegged at zero, this means inflation must increase. Imposing distortionary taxes changes this conclusion because it enables households to smooth consumption by investing in risk-free assets. In particular, households will respond to an expected drop in their consumption (because of higher expected real rates) by increasing their current savings in nominal assets. As for FDLTs, this implies that an expected monetary tightening depresses consumption and inflation in the unintended regime.

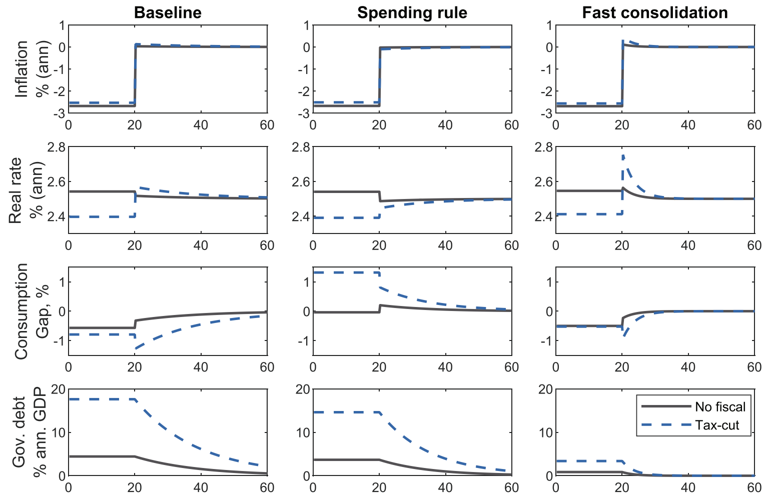
Finally, notice that the effect of the expectation channel appears rather strong in Figure 4. Despite the lower real interest rates that the tax cut induces in the unintended regime, consumption deteriorates with respect to the no-intervention case. This can be explained by the relative duration of each regime in the figure. With $p_u = 0.95$, the unintended regime is expected to last for an average of five years. In contrast, the intended regime is absorbing, and thus the full increase in the real rate (until debt has returned to steady state) is expected to occur after the regime switch. Section 5 considers alternate regimes with limited duration. When the average duration is the same for each regime, a tax cut emerges as the optimized rule, provided that debt accumulation is contained through a concurrent cut in spending.

#### *4.3.1 Policy Rules*

To demonstrate the conventional effect of the expectation channel with non-Ricardian fiscal policy, this section revisits the impulse responses to a tax cut assuming two different policy rules: (i) a feedback rule that adjusts spending to stabilize government debt and (ii) a higher feedback coefficient on labor tax adjustments.

Consider first a spending rule that stabilizes debt according to $\hat{g}_t = \phi_g \tilde{b}_{t-1}$. For the numerical exercise, I set $\phi_g = -0.5$, which implies that a 10 percent increase in the inherited debt-to-output ratio reduces spending by 5 percent (about 1 percent of GDP). The middle column of Figure 5 shows the effect of a tax cut of 1 percentage point under this rule. The tax cut increases debt accumulation in the unintended regime and implies lower government spending and output in the intended regime due to the consolidation effort. Compared to the baseline tax rule (left column), inflation in the intended regime is now below the no-intervention case so that monetary policy turns expansionary. Despite a similar real rate gap (14 basis points) in the unintended regime, the two policy rules yield opposite consumption responses. The negative relationship between current consumption and expected real rates confirms the conventional view on the expectation channel when non-Ricardian fiscal policy prevails.

**Figure 5. Alternative Policy Rules to Inspect the Expectation Channel**




**Note:** The first column corresponds to the baseline model with endogenous tax response to lagged debt, the middle column to an endogenous response of government spending as an alternative fiscal rule, and the right column to the baseline but with accelerated consolidation pace ($\phi_\tau = 0.4$ instead of $\phi_\tau = 0.1$). The solid black line shows responses without fiscal intervention and the dashed blue line with a tax cut of 1 percentage point. Consumption is expressed in percentage deviations from the steady state. Inflation and the real interest rate are in annual percentages. Debt is in percentage of annual output. The economy starts in the unintended regime after debt has converged to its long-run stationary level. The regime shock occurs after 20 years.

The second example seeks to demonstrate that the path of expected real rates in the intended regime is a significant driving force of the consumption response in the unintended regime. To this end, I assume now that the feedback parameter in the labor tax rule ($\phi_\tau$) increases from 0.1 to 0.4.[9] The effect of this modification on the equilibrium responses to the tax cut is displayed in the last column of Figure 5. The higher consolidation pace implies that the government leaves the trap with a lower debt level (last panel). As a result, the total increase in labor taxes necessary to return debt to

[9] Other intermediate values are considered in Appendix E.2, which studies the sensitivity of the main results to the calibration of the tax rule.

its steady-state level is both lower and concentrated in the first periods following the regime switch. Compared to the baseline calibration of the tax rule (first column), lower inflation persistence in the intended regime mitigates the total expected monetary tightening so that the consumption loss is now much closer to the no-intervention case. Thus, the expectation channel is sensitive to the amount of government debt accumulated upon the exit of the trap.

### *4.3.2 Convenience Yield*

In this section, I investigate how the expectation channel depends on (i) the discounting of the households for future consumption and (ii) the link between the level of debt and its servicing costs at positive interest rates. To this end, consider a modified version of the model in which government bonds enter in the utility function of the representative household (referred to below as preference over safe assets (POSA)). Under this specification, bond yields are a function of two components: the underlying consumption claims (as previously) and the total supply of government bonds (the *convenience yield*). More details are provided in Appendix F. The modified Euler equation reads

$$\hat{c}_t = -\gamma_c^{-1}\delta(\hat{\imath}_t - \mathbb{E}_t\hat{\pi}_{t+1}) + \delta\mathbb{E}_t\hat{c}_{t+1} + (1-\delta)\gamma_b(b^{-1}\tilde{b}_t - \hat{\imath}_t). \quad (12)$$

Parameter $\delta = \beta R$ is the discounting wedge and parameter $\gamma_b$ is the wealth curvature.[10] The discounting wedge represents the net weight that the household attaches to $t+1$ marginal consumption, while the wealth curvature controls the elasticity of the bond yield with respect to the bond supply.

Let us first focus on the effect of the discounting wedge on the expectation channel. To isolate this effect, I assume linear POSA ($\gamma_b = 0$) so that the supply of government bonds does not have a direct impact on interest rates. Then, by substituting (12) forward recursively and imposing a transversality condition on consumption, I obtain the following expression for the impact of expected real interest rates on current consumption:

[10]For the calibration of the POSA parameters, see Appendix F.

$$\hat{c}_t = -\gamma_c^{-1}\mathbb{E}_t \sum_{j=0}^{\infty} \delta^{j+1}\hat{r}_{t+j}, \tag{13}$$

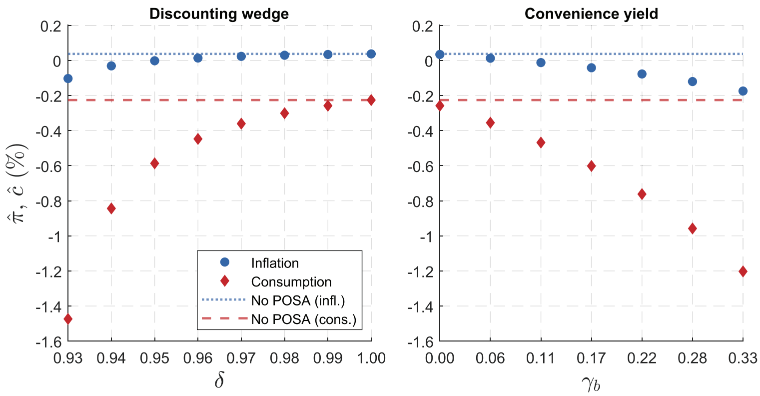
where $\hat{r}_{t+j} = \hat{\imath}_{t+j} - \hat{\pi}_{t+j+1}$. Notice that without POSA, the discounting wedge is $\delta = 1$.[11] Then, (13) implies that, for any positive integer $T$, a variation in the real interest rate that takes place in quarter $t + T$ will have the same effect on current consumption. By contrast, the presence of POSA introduces additional discounting in the Euler equation and lowers the strength of the expectation channel. When $\delta < 1$, the effect of the decline in future real interest rates on $\hat{c}_t$ becomes $\delta^{T+1}\,\mathbb{E}_t\,\hat{r}_{t+T}$ and thus converges to zero as $T \to \infty$. The left panel in Figure 6 investigates the implications of the discounting wedge for the tax-cut policy. Each marker in the figure corresponds to the inflation (blue circle) and consumption (red diamond) responses to the tax cut in the unintended regime in percentage deviations from the no-intervention scenario.

Without POSA ($\delta = 1$), the consumption gap caused by the tax cut is $-0.23$ percent when compared to the no-intervention scenario. As the discounting wedge decreases, the gap widens and reaches $-1.47$ percent when $\delta = 0.93$. What explains this stronger negative effect of the tax cut on consumption when $\delta$ decreases?

Figure 6 reveals that when $\delta < 0.95$ the inflation response to the tax cut in the unintended regime (blue circles) turns negative when compared to the no-intervention scenario. With strong enough discounting, the lower sensitivity of consumption to future real interest rates illustrated above implies that a common fall in prices is now effective in restoring equilibrium when firms' markup improves. The inflation response to the tax cut is thus analogous to the one observed in an FDLT (see Appendix D) and, likewise, implies that the policy is particularly damaging for consumption (red diamonds) because of higher real interest rates that prevail both inside and outside the liquidity trap. Increasing $\delta$ renders consumption more sensitive to future real rates and thus alleviates the drop in inflation and associated crowding-out effect. For $\delta > 0.95$, the positive inflation response to the tax cut in the EDLT is restored.

[11] To see this, notice that the steady-state Euler equation gives $\chi c^{\gamma_c}\left(\frac{b}{R}\right)^{-\gamma_b} = 1 - \delta$. Hence, without POSA ($\chi = 0$), we have $\delta = 1$.

**Figure 6. Effects of POSA in an Expectations-Driven Liquidity Trap**




**Note:** Long-run equilibrium responses of inflation (blue circles) and consumption (red diamonds) to a 1 percentage point tax-cut policy in the unintended regime expressed as percentage deviations from the benchmark of no fiscal intervention. The horizontal lines (dotted blue for inflation and dashed red for consumption) correspond to the absence of POSA (i.e., $\delta = 1$ and $\gamma_b = 0$). The left panel and the right panel analyze respectively the role of the discounting wedge and the convenience yield (through the expectation channel) for the effectiveness of fiscal policy.

Next, I fix the discounting wedge to its baseline value ($\delta = 0.99$) to focus on the effect of the wealth curvature. The right panel of Figure 6 shows that the inflationary effect (blue circles) of a deficit-financed tax cut depends quantitatively and qualitatively on $\gamma_b$. With $\gamma_b$ low enough, the tax cut remains inflationary with respect to the no-intervention policy. However, the inflation gap is decreasing in $\gamma_b$ and even turns negative for $\gamma_b > 0.06$. In this case, the debt accumulation caused by the tax cut compresses the convenience yield and crowds out consumption at the onset of the intended regime. Expectations of lower real activity and inflation push prices down in the unintended regime. With the nominal rate pegged at zero, consumption plummets in response to the rise in real interest rate. The red diamonds in the right panel show that that the recessionary effect of the tax cut is strongly increasing in the wealth curvature because of the more negative response of convenience yields to debt accumulation. This result contrasts with Rannenberg (2021), who finds that the wealth curvature does not matter much for the effectiveness of a perfectly timed spending stimulus in an FDLT because the high fiscal multiplier implies that debt accumulation is negligible. Evidently, this does not hold in an EDLT since, as I have demonstrated, a spending stimulus increases the debt burden significantly. Finally, notice that the results with POSA obtained in this section would also extend to a model with government default in which the perceived probability of default is correlated to the level of debt as in Bonam and Lukkezen (2019).

## 5. Optimized Rules

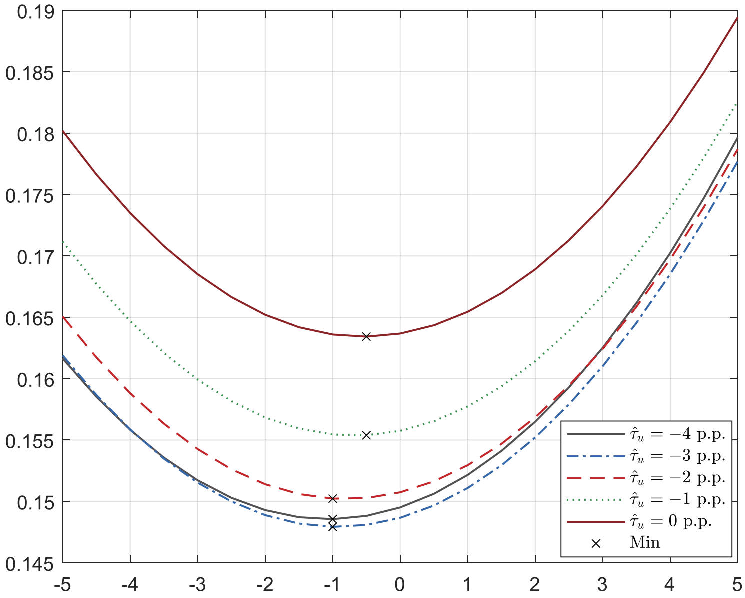
The previous section explores the implications of accumulating debt for the effect of fiscal stimuli when fiscal and monetary policy are conducted according to standard ad hoc rules. While purely deficit-financed fiscal stimuli were clearly unsuccessful at stimulating output, combined strategies that contain debt accumulation seemed more promising. In this section, I thus investigate whether such strategies would prevail when fiscal policy rules are optimized in an environment of recurring regime shifts. For this purpose, I assume that the employment subsidy takes a value consistent with an efficient steady state. This assumption allows me to derive a meaningful welfare criterion to rank policy outcomes. As demonstrated in Appendix H, a second-order approximation of the household's utility around the efficient steady state gives an unconditional expected lifetime welfare loss equal to $\frac{1}{2}U_c\mathcal{L}$ with

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \left[ \gamma_c c \hat{c}_t^2 + \gamma_g G \hat{G}_t^2 + \gamma_h y \hat{y}_t^2 + \iota y \pi_t^2 \right]. \tag{14}$$

Moreover, a permanent reduction in private consumption by the share $\mathcal{S}$ lowers the utility of the household by an amount equivalent to $\frac{U_c C \mathcal{S}}{1-\beta}$. Hence, I express the welfare loss in consumption equivalent as $\frac{U_c C \mathcal{S}}{1-\beta} = \frac{1}{2}U_c\mathcal{L}$, or

$$\mathcal{S} = \frac{1}{2}(1-\beta)C^{-1}\mathcal{L}.$$

**Figure 7. Welfare Loss for Different Fiscal Policies**




**Note:** Each curve corresponds to a different tax cut ranging from $-0.4$ pp to 0 pp. The vertical axis captures the associated welfare loss in consumption equivalent depending on a specific spending policy (gap, percents) in the horizontal axis.

To assess the effectiveness of fiscal policy in stabilizing target variables, I simulate the economy for 600 quarters and 500 samples.[12] The regime shock continues to follow a Markov chain; however, now I assume that none of the regimes is absorbing. Instead, I choose $p_u = p_i = 0.98$, a value that implies an average duration of 12.5 years for each regime. Figure 7 plots the welfare loss depending on the fiscal policy implemented in the unintended regime.

Each curve corresponds to a tax policy, while the horizontal axis represents the associated spending policy. From the position of the curves, cutting taxes in the unintended regime appears welfare improving provided that the stimulus is not too large. The optimal

[12]The first 100 quarters of each sample are discarded as a burn-in period.

tax cut turns out to be −3 percentage points (pp) since any tax cut above this value moves the curve to the north. Notice that the no-intervention policy entails the largest consumption loss. Moreover, for any tax cut larger than or equal to zero, decreasing government spending by an adequate amount can further improve welfare. This amount depends positively on the size of the tax cut. To shed light on the mechanisms underlying those results, Table 2 shows the average outcome for key variables in the unintended (U) regime versus the intended (I) regime for selected fiscal policies.

First, notice that the optimized policy alleviates the inflation shortfall in the unintended regime (−2.33 percent) when compared to the case of no intervention (−2.55 percent). This result is intuitive, for both the tax cut and the spending cut are inflationary in an EDLT. Hence, this policy supports output and consumption by lowering real rates. However, the tax cut may not be too large because the increase in debt implies higher real rates when the ELB stops binding. The decrease in government spending provides some fiscal space in this regard. Nevertheless, government debt is on average 25 percent (13.5 percent) above its steady-state value in the unintended (intended) regime. Consequently, consumption and output are subdued in the intended regime because monetary policy tightens in reaction to the cost-push effect of labor taxes.

Hence, the optimized policy strikes a balance between the benefits occurring in the unintended regime and the costs occurring in the intended regime. This trade-off largely depends on the conditional expectations of the private agents in each regime. In this regard, the second line of the table shows that inflation in the intended regime is negative when fiscal policy is muted. The pronounced deflation in the unintended regime weighs negatively on inflation expectations even outside the liquidity trap since forward-looking households attach a positive probability (though low) for the EDLT to occur again in the future.

This analysis clarifies the role of fiscal policy in an EDLT when government debt matters. In this type of liquidity trap, monetary policy is helpless in stabilizing the economy. For example, Nakata and Schmidt (2022) show in a Ricardian economy with lump-sum taxes that increasing the inflation target of a time-consistent planner or increasing the weight it attaches to inflation stabilization in its objective has opposite effects on inflation inside and outside an

**Table 2. Welfare Loss and Macroeconomic Outcomes of Fiscal Policy**

| Fiscal Policy | $\widehat{G}_u$ | $\widetilde{\tau}_u$ | $\mathcal{L}$ | $\widehat{\pi}$ | | $\widehat{c}$ | | $\widehat{y}$ | | $\widehat{b}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | U | I | U | I | U | I | U | I |
| Optimized | –1 | –3 | 0.15 | –2.33 | 0.37 | 0.35 | –0.84 | 0.08 | –0.67 | 25.08 | 13.53 |
| No Stimulus | 0 | 0 | 10.57 | –2.55 | –0.13 | –0.11 | 0.08 | –0.09 | 0.06 | 0.07 | –0.02 |
| Excessive Tax Cut | 0 | –4 | 1.19 | –2.26 | 0.53 | 0.22 | –1.22 | 0.17 | –0.97 | 35.43 | 19.08 |
| Spending Cut Only | –5 | 0 | 21.74 | –2.53 | –0.09 | 0.95 | 0.35 | –0.24 | 0.28 | –7.49 | –3.90 |

**Note:** Government spending, consumption, and output are expressed in percentage deviations from the steady state. Inflation is in annual percentages. Debt is in percentage of annual output and the tax rate in absolute percentages. Welfare loss is in percentage of permanent consumption equivalent for the optimized policy and in percent excess deviation from the optimized policy for the other policies. U and I stand for the unintended and intended regime, respectively.

EDLT and the gains in stabilizing the economy are therefore unclear. In my model, fiscal policy attempts to anchor inflation (expectations) in the two regimes. In achieving this objective, the government is however constrained by the debt accumulation and its implications for monetary policy once the ELB stops binding. To illustrate this last point, consider the excessive tax cut (−4 percent) in the third line of the table. While inflation is better stabilized in this case, it is at the cost of accumulating a large amount of debt. As a result, consumption and output drop too much in the intended regime and the welfare loss increases by 1.2 percent.

Notice that a spending cut alone may seem appealing because it increases inflation in the EDLT while consolidating debt and lowering the endogenous response of taxes. However, as witnessed by the last line of the table, it turns out to have the worst effect on welfare. The reason is twofold. First, despite lowering the real rates and stimulating consumption, the spending cut reduces output in the unintended regime because of the negative effect on public demand. Second, in the absence of other policies, the consolidation of debt (−7.5 percent in the unintended regime) implies that inflation is subdued in the intended regime.

Finally, I close the discussion with an important remark on the optimized strategy. The result of improving welfare in a liquidity trap by cutting taxes and government spending admittedly seems far fetched given the large expansionary fiscal policy that we have observed in reality. First of all, this result holds only in an EDLT with a long-lasting intervention. Hence, if the liquidity trap is fundamental, shrinking the size of the state would be counterproductive. To illustrate this point, Appendix G evaluates the optimized rules when the policymaker is uncertain about the type of liquidity trap occurring. To this end, I assume that once in a high state of demand, there is a positive probability to fall in a liquidity trap. However, now this liquidity trap may be either fundamental driven or expectations driven. The optimized strategy in this context is to adopt the status quo (except for a mild spending cut). Since fiscal policy has opposite effects depending on the type of liquidity trap, the government refrains from intervening. Second of all, the duration of the intervention matters for the results. If the policy is not going to outlast the liquidity trap, then it will never be recessionary in an FDLT. As demonstrated in this paper, this affirmation is not true for an

EDLT: a perfectly timed stimulus puts a significant strain on public finances and depresses output during the downturn.

## 6. Conclusion

With the COVID-19 crisis unfolding, deficit-financed fiscal stimuli have grown in popularity in the United States and other advanced economies. One of the main insights of the literature on fiscal and monetary policy in a fundamental-driven liquidity trap is that the large multiplier of spending policies tremendously reduces its impact on debt accumulation. However, the soaring debt-to-GDP ratios may be a sign that we are overestimating those self-financing effects. At the same time, central banks are emphasizing the risk of long-lasting liquidity traps caused by self-fulfilling expectations. The reality might be somewhere in between. Nevertheless, this paper shows that financing government spending with debt issuance can be counterproductive in an expectations-driven liquidity trap because it increases real rates both at the effective lower bound and in its aftermath. In this context, reducing the size of the state supports economic activity by reaping the benefits of a tax cut while keeping the accumulation of debt at a manageable level. This policy alleviates the need for a monetary tightening at the exit of the liquidity trap and stimulates consumption of forward-looking households during the downturn by reducing expected real rates.

## Appendix A. The Non-linear Economy

### *A.1 Equilibrium Conditions*

The representative household maximizes its expected lifetime utility (1) subject to its budget constraint (2). Attaching multiplier $\lambda_t$ to the constraint, the first-order necessary conditions (FONCs) of this problem are standard:

$$\nu_h h_t^{\gamma_h} c_t^{\gamma_c} = (1-\tau_t) w_t$$

$$R_t^{-1} = \beta d_t \mathbb{E}_t \left[ \frac{c_t^{\gamma_c}}{\pi_{t+1} c_{t+1}^{\gamma_c}} \right].$$

The problem (4) of the intermediate firm gives rise to the following FONC:

$$w_t = \frac{\theta - 1}{\theta(1-s)} - \frac{\psi}{\theta(1-s)} \times \left(\pi_t(\pi_t - 1) - \beta d_t \mathbb{E}_t \left[\frac{c_t^{\gamma_c}}{c_{t+1}^{\gamma_c}} \frac{y_{t+1}}{y_t} \pi_{t+1}(\pi_{t+1} - 1)\right]\right).$$

Moreover, the budget constraint of the government in real terms reads

$$\frac{b_t}{R_t} - \frac{b_{t-1}}{\pi_t} - G_t + \tau_t w_t y_t - s(w_t y_t - wy) = 0.$$

Together with the resource constraint, $y_t\left(1 - \frac{\psi}{2}(\pi_t - 1)^2\right) = c_t + G_t$, those equations can be log-linearized to obtain the system of equations in the text.[13]

## *A.2 The First-Best Allocation*

The first-best allocation solves the problem

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \xi_t \left[\frac{c_t^{1-\gamma_c}}{1-\gamma_c} + \nu_g \frac{G_t^{1-\gamma_g}}{1-\gamma_g} - \nu_h \frac{h_t^{1+\gamma_h}}{1+\gamma_h} + \omega_t(y_t - c_t - G_t)\right]$$

that gives the following FONCs:

$$c_t^{-\gamma_c} = \omega_t, \quad \nu_h y_t^{\gamma_h} = \omega_t, \quad \nu_g G_t^{-\gamma_g} = \omega_t.$$

Hence, at the first best, it holds that $(1-\tau_t)w_t = 1$.

## *A.3 The Steady State (Non-efficient and Efficient)*

The non-efficient steady state corresponds to the case where $s = 0$. It is characterized by the following set of equations:

$$y = c + G$$

[13]In the text, the system is reduced to three equations by substituting out output and wages using, respectively, the log-linearized resource constraint and the log-linearized intratemporal consumption-leisure trade-off.

$$R = \beta^{-1}$$
$$w = \frac{\theta - 1}{\theta}$$
$$\tau = (wy)^{-1}[G + b(1-\beta)]$$
$$\nu_h = y^{-\gamma_h} c^{-\gamma_c} w(1-\tau)$$
$$\nu_g = G^{\gamma_g} c^{-\gamma_c}.$$

In the *efficient* steady state, the subsidy is set to attain the first best, $(1-\tau)w = 1$, and is given by

$$s = 1 - \frac{\theta - 1}{\theta}(1 + G + (1-\beta)by^{-1})^{-1}.$$

Moreover, the equations for the steady-state tax rate and wage become

$$\tau = \frac{\theta s - 1}{\theta - 1} \qquad w = \frac{\theta - 1}{(1-s)\theta}.$$

The other steady-state equations remain unchanged.

## Appendix B. Analytical Derivations in the Economy with Lump-Sum Taxes

In the presence of lump-sum taxes, I can drop the budget constraint from my system of equations. Under the non-linear Taylor rule (9), I can write the system as a collection of four equations: two for the intended regime and two for the unintended regime:

$$\hat{c}_t^i = -\gamma_c^{-1}(\phi_\pi \hat{\pi}_t^i - \mathbb{E}_t^i \hat{\pi}_{t+1}) + \mathbb{E}_t^i \hat{c}_{t+1} \tag{B.1}$$
$$\hat{\pi}_t^i = \kappa_G \hat{G}_t^i + \overline{\kappa}_c \hat{c}_t^i + \kappa_\tau \tilde{\tau}_t^i + \beta \mathbb{E}_t^i \hat{\pi}_{t+1} \tag{B.2}$$
$$\hat{c}_t^u = -\gamma_c^{-1}(-i^* - \mathbb{E}_t^u \hat{\pi}_{t+1}) + \mathbb{E}_t^u \hat{c}_{t+1} \tag{B.3}$$
$$\hat{\pi}_t^u = \kappa_G \hat{G}_t^u + \overline{\kappa}_c \hat{c}_t^u + \kappa_\tau \tilde{\tau}_t^u + \beta \mathbb{E}_t^u \hat{\pi}_{t+1}, \tag{B.4}$$

where $\kappa_G \equiv \frac{\gamma_h(\theta-1)}{\psi} G y^{-1}$, $\kappa_\tau \equiv \frac{(\theta-1)}{(1-\tau)\psi}$ and $\overline{\kappa}_c \equiv \frac{\gamma_c(\theta-1)}{\psi} + \frac{\gamma_h(\theta-1)}{\psi} c y^{-1}$.

Solving the PC for consumption gives

$$\hat{c}_t^u = \overline{\kappa}_c^{-1}\Big(\hat{\pi}_t^u - \kappa_G \hat{G}_t^u - \kappa_\tau \tilde{\tau}_t^u - \beta \mathbb{E}_t^u \hat{\pi}_{t+1}\Big).$$

Combining this expression with the EE gives

$$-\hat{\imath}^* = \overline{\kappa}_c^{-1}\Big(- \hat{\pi}_t^u + \kappa_G(\hat{G}_t^u - \mathbb{E}_t^u \hat{G}_{t+1}) + \kappa_\tau(\tilde{\tau}_t^u - \mathbb{E}_t^u \tilde{\tau}_{t+1}) \\ + (\overline{\kappa}_c + 1 + \beta)\mathbb{E}_t^u \hat{\pi}_{t+1} - \beta \mathbb{E}_t^u \hat{\pi}_{t+2}\Big).$$

With probability $p_u$, the economy remains in the unintended regime, in which case next-period inflation is equal to current inflation. Moreover, with probability $(1 - p_u)$, a regime shock hits the economy and inflation is equal to its value in the intended regime, i.e., $\hat{\pi}_t^i = 0$. Notice that the same logic applies to government spending and labor taxes because of the perfectly timed assumption. Then, I can write

$$-\hat{\imath}^* = \overline{\kappa}_c^{-1}\Big(- \hat{\pi}_t^u + \kappa_G(\hat{G}_t^u - \mathbb{E}_t^u \hat{G}_{t+1}) + \kappa_\tau(\tilde{\tau}_t^u - \mathbb{E}_t^u \tilde{\tau}_{t+1}) \\ + (\overline{\kappa}_c + 1 + \beta)p_u \hat{\pi}_t^u - \beta p_u^2 \hat{\pi}_t^u\Big),$$

which, solving for inflation, gives Equation (11) in the text.

## Appendix C. Solving the Expectations-Driven Liquidity Trap

I denote the coefficients related to the constant terms by $\mathcal{C}_c^r$, $\mathcal{B}_c^r$, $\mathcal{Y}_c^r$, $\mathbf{\Pi}_c^r$, $\mathcal{I}_c^r$ and the coefficients related to lagged debt by $\mathcal{C}_b^r$, $\mathcal{B}_b^r$, $\mathcal{Y}_b^r$, $\mathbf{\Pi}_b^r$, $\mathcal{I}_b^r$. Superscript $r \in \{u, i\}$ indicates the regime. The strategy to recover those coefficients is the following. Gather all the constant terms on the left-hand side of each equation and all the terms pre-multiplying the state variable on the right-hand side of the equation. Then, find the value of the coefficients that implies each side of every equation in the system is equal to zero. This involves two steps. First, solve the system of right-hand-side equations. Second, using the coefficients recovered for lagged debt, solve the system of left-hand-side equations.

More specifically, the system of right-hand-side equations contains a set of equations for the intended regime and a set for the unintended regime. The system for the intended regime reads

$$
\begin{aligned}
0 &= 1 - \Omega\beta^{-1}\mathbf{\Pi}_b^i + \Omega\mathcal{I}_b^i - w\tau y\Big(\gamma_c\mathcal{C}_b^i + (1+\gamma_h)\mathcal{Y}_b^i + \frac{\phi_\tau}{(1-\tau)\tau}\Big) \\
&\quad - \beta\mathcal{B}_b^i \\
0 &= \mathbf{\Pi}_b^i - \kappa_y\mathcal{Y}_b^i - \kappa_c\mathcal{C}_b^i - \kappa_\tau\phi_\tau - \beta\Big(p_i\mathbf{\Pi}_b^i\mathcal{B}_b^i + (1-p_i)\mathbf{\Pi}_b^u\mathcal{B}_b^i\Big) \\
0 &= \gamma_c\mathcal{C}_b^i - \gamma_c\Big(p_i\mathcal{C}_b^i\mathcal{B}_b^i + (1-p_i)\mathcal{C}_b^u\mathcal{B}_b^i\Big) + \mathcal{I}_b^i \\
&\quad - \Big(p_i\mathbf{\Pi}_b^i\mathcal{B}_b^i + (1-p_i)\mathbf{\Pi}_b^u\mathcal{B}_b^i\Big) \\
0 &= \mathcal{I}_b^i - \phi_\pi\mathbf{\Pi}_b^i \\
0 &= y\mathcal{Y}_b^i - c\mathcal{C}_b^i.
\end{aligned}
$$

The system for the unintended regime reads

$$
\begin{aligned}
0 &= 1 - \Omega\beta^{-1}\mathbf{\Pi}_b^u + \Omega\mathcal{I}_b^u - w\tau y\Big(\gamma_c\mathcal{C}_b^u + (1+\gamma_h)\mathcal{Y}_b^u + \frac{\phi_\tau}{(1-\tau)\tau}\Big) \\
&\quad - \beta\mathcal{B}_b^u \\
0 &= \mathbf{\Pi}_b^u - \kappa_y\mathcal{Y}_b^u - \kappa_c\mathcal{C}_b^u - \kappa_\tau\phi_\tau - \beta\Big(p_u\mathbf{\Pi}_b^u\mathcal{B}_b^u + (1-p_u)\mathbf{\Pi}_b^i\mathcal{B}_b^u\Big) \\
0 &= \gamma_c\mathcal{C}_b^u - \gamma_c\Big(p_u\mathcal{C}_b^u\mathcal{B}_b^u + (1-p_u)\mathcal{C}_b^i\mathcal{B}_b^u\Big) + \mathcal{I}_b^u \\
&\quad - \Big(p_u\mathbf{\Pi}_b^u\mathcal{B}_b^u + (1-p_u)\mathbf{\Pi}_b^i\mathcal{B}_b^u\Big) \\
0 &= \mathcal{I}_b^u \\
0 &= y\mathcal{Y}_b^u - c\mathcal{C}_b^u.
\end{aligned}
$$

Together, this gives a non-linear system of 10 equations in 10 unknowns that I solve using the routine *fsolve* in MATLAB. Once the coefficients of lagged debt have been recovered, the system of constant terms can be solved. As before, it consists in two sets of equations for the intended and unintended regime. For the intended regime, the system reads

$$0 = -\Omega\beta^{-1}\mathbf{\Pi}_c^i + \Omega\mathcal{I}_c^i - w\tau y(\gamma_c\mathcal{C}_c^i + (1+\gamma_h)\mathcal{Y}_c^i) - \beta\mathcal{B}_c^i$$

$$0 = \mathbf{\Pi}_c^i - \kappa_y\mathcal{Y}_c^i - \kappa_c\mathcal{C}_c^i - \beta\Big(p_i(\mathbf{\Pi}_c^i + \mathbf{\Pi}_b^i\mathcal{B}_c^i) + (1-p_i)(\mathbf{\Pi}_c^u + \mathbf{\Pi}_b^u\mathcal{B}_c^i)\Big)$$

$$0 = \gamma_c\mathcal{C}_c^i - \gamma_c\Big(p_i(\mathcal{C}_c^i + \mathcal{C}_b^i\mathcal{B}_c^i) + (1-p_i)(\mathcal{C}_c^u + \mathcal{C}_b^u\mathcal{B}_c^i)\Big)$$
$$+ \mathcal{I}_c^i - \Big(p_i(\mathbf{\Pi}_c^i + \mathbf{\Pi}_b^i\mathcal{B}_c^i) + (1-p_i)(\mathbf{\Pi}_c^u + \mathbf{\Pi}_b^u\mathcal{B}_c^i)\Big)$$

$$0 = \mathcal{I}_c^i - \phi_\pi\mathbf{\Pi}_c^i$$

$$0 = y\mathcal{Y}_c^i - c\mathcal{C}_c^i.$$

For the unintended regime, the system reads

$$0 = -\Omega\beta^{-1}\mathbf{\Pi}_c^u + G\hat{G}^u + \Omega\mathcal{I}_c^i - w\tau y\Big(\gamma_c\mathcal{C}_c^i + (1+\gamma_h)\mathcal{Y}_c^i + \frac{\tilde{\tau}^u}{(1-\tau)\tau}\Big)$$
$$- \beta\mathcal{B}_c^i$$

$$0 = \mathbf{\Pi}_c^u - \kappa_y\mathcal{Y}_c^u - \kappa_c\mathcal{C}_c^u - \kappa_\tau\tilde{\tau}^u$$
$$- \beta\Big(p_u(\mathbf{\Pi}_c^u + \mathbf{\Pi}_b^u\mathcal{B}_c^u) + (1-p_u)(\mathbf{\Pi}_c^i + \mathbf{\Pi}_b^i\mathcal{B}_c^u)\Big)$$

$$0 = \gamma_c\mathcal{C}_c^u - \gamma_c\Big(p_u(\mathcal{C}_c^u + \mathcal{C}_b^u\mathcal{B}_c^u) + (1-p_u)(\mathcal{C}_c^i + \mathcal{C}_b^i\mathcal{B}_c^u)\Big)$$
$$+ \mathcal{I}_c^u - \Big(p_u(\mathbf{\Pi}_c^u + \mathbf{\Pi}_b^u\mathcal{B}_c^u) + (1-p_u)(\mathbf{\Pi}_c^i + \mathbf{\Pi}_b^i\mathcal{B}_c^u)\Big)$$

$$0 = \mathcal{I}_c^u + log(\beta^{-1})$$

$$0 = y\mathcal{Y}_c^u - c\mathcal{C}_c^u - G\hat{G}^u.$$

Again, this gives a non-linear system of 10 equations in 10 unknowns that I solve using the routine *fsolve* in MATLAB.

## Appendix D. Fiscal Policy in the Fundamental-Driven Liquidity Trap

I define a *fundamental-driven liquidity trap* (FDLT) as one that is triggered by a negative demand shock in Equation (6). For the ease of comparison, I assume that the demand shock follows the exogenous process

$$\hat{d}_t = \begin{cases} -0.016, & \text{if } t \leq T \\ 0, & \text{otherwise.} \end{cases} \tag{D.1}$$

Moreover, private agents are uncertain about when period $T$ will actually occur. This uncertainty is captured by a two-state Markov process.[14] Note that the existence of FDLTs requires their expected duration to be much lower than EDLTs (see, e.g., the discussion in Nakata and Schmidt 2019 and Kollmann 2021). As a benchmark calibration, I thus choose

$$\begin{bmatrix} p_h & (1-p_h) \\ (1-p_l) & p_l \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0.5 & 0.5 \end{bmatrix},$$

which implies an expected duration of the low state below two years.[15] The solution of the model is obtained with the same method of undetermined coefficients used for the EDLT (see Appendix C). Consider the same two perfectly timed fiscal stimuli studied in Section 3: a spending stimulus and a tax cut. Figure D.1 compares their respective effect in a FDLT when government debt matters for stabilization policies.

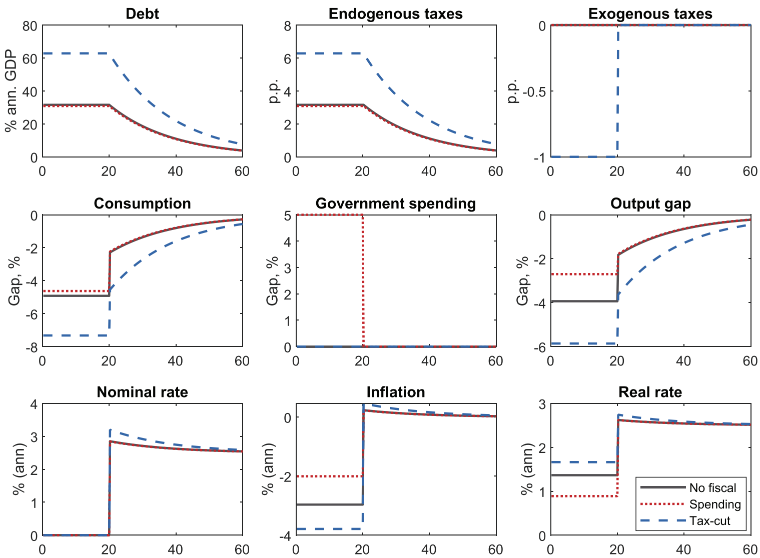
Consider first that the government increases spending to stimulate the economy (dotted red line). The top left panel shows that this strategy is effective to boost output. This result is related to the large fiscal multiplier at the ELB identified by Christiano, Eichenbaum, and Rebelo (2011), Woodford (2011), and Erceg and Lindé (2014). In parallel to the demand effect of government spending on output, larger deficits trigger an endogenous rise in the labor tax rate. As a result, the cost-push effect of taxes reduces real rates at the ELB and crowds in consumption in a virtuous loop. In particular, the bottom left panel shows that debt is reduced in response to higher spending, which indicates that the stimulus is self-financing because the positive effect on consumption widens the tax base.

Turning to the tax cut (dashed blue line), this strategy turns out to be self-defeating. Cutting taxes aggravates the inflation shortfall because of the large accumulation of debt that produces a

[14] See, e.g., Woodford (2011) for a similar characterization of an FDLT.

[15] Notice that here I refer to the high state and the low state of demand to make a distinction between the intended and unintended regime when liquidity traps are expectations driven.

**Figure D.1. Effects of a Fiscal Stimulus in a Fundamental-Driven Liquidity Trap**




**Note:** The solid black line corresponds to the absence of fiscal intervention, the dotted red line to a spending increase of 1 percent of GDP, and the dashed blue line to a tax cut of 1 percentage point. Government spending, consumption, and the output gap are expressed in percentage deviations from the steady state. Inflation, the nominal interest rate, and the real interest rate are in annual percentages. Debt is in percentage of annual output and the tax rate in absolute percentages. The economy starts in the unintended regime after debt has converged to its long-run stationary level. The demand shock occurs after 20 years.

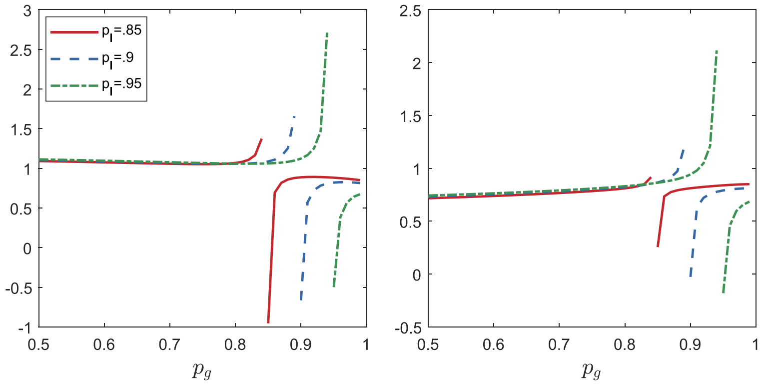
monetary tightening upon the exit of the FDLT in response to the cost-push effect of labor taxes when the policy is overturned. Consumption drops due to intertemporal consumption smoothing and the tax base shrinks. Hence, the economy is burdened by higher debt levels and lower output gap.

## Appendix E. Sensitivity Analysis

### *E.1 Expected Duration of Fiscal Policy*

Wieland (2018) shows that the multiplier of government spending depends on its duration independently of the type of liquidity trap,

**Figure E.1. Fiscal Multipliers as a Function of Policy Duration**



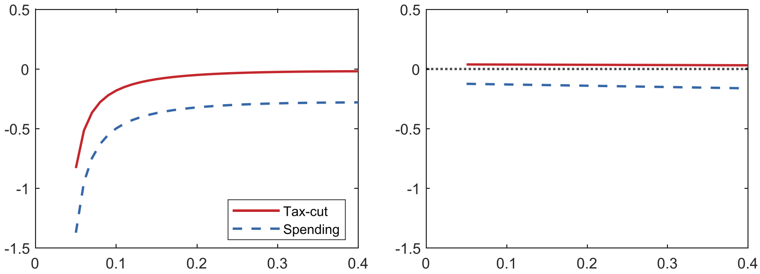

**Note:** The left panel draws the output multiplier of government spending and the right panel the one of tax cut. The solid red line, the dashed blue line, and the dashed-dotted green line correspond to the output multiplier when the probability of staying in the low confidence regime is respectively 0.85, 0.9, and 0.95. The formula for computing the multipliers is detailed in the text. The horizontal axis is the expected duration of the fiscal experiment in the low confidence regime. For high-enough duration of fiscal policy, the multiplier turns negative.

fundamentally driven or expectations driven. More specifically, the size of the multiplier is decreasing in the duration of the policy intervention.

Figure E.1 shows that this result extends to a spending stimulus when households are non-Ricardian. The figure also displays the multiplier for the tax-cut policy considered previously. Here, I assume the existence of an additional regime, denoted regime $n$, characterized by a low degree of confidence and a binding ELB but in which fiscal policy is muted. Conditional on the confidence being low, this regime is assumed to be absorbing. The policy regime considered before is now denoted regime $g$.

This setup allows me to consider fiscal policies of expected duration shorter than the expectations-driven liquidity trap itself and to analyze the resulting multipliers. The marginal multiplier for a generic period of binding ELB and operational policy is computed as $\Delta y_t/\Delta G_t$ and $\Delta y_t/(y_t|\Delta\tau_t|)$ for the spending stimulus and tax cut, respectively. The figure clearly shows that, for an expected duration

**Figure E.2. Effects of the Consolidation Pace in an Expectations-Driven Liquidity Trap**




**Note:** The solid red line and dashed blue line correspond to the output multiplier (left panel) and inflation multiplier (right panel) of the tax cut and spending stimulus, respectively. The formula for computing the multipliers is detailed in the text. The horizontal axis is the endogenous response of labor taxes to lagged debt, $\phi_\tau$.

of fiscal policy equivalent to the FDLT considered earlier ($p_g = 0.5$), the multiplier of the spending stimulus is positive in the EDLT and superior to the tax cut. Moreover, the multiplier is increasing in the duration of the policy up to a certain point because of the negative effect of cumulative inflation on the real interest rates. However, when the expected duration of the policy is equal to or higher than the expected duration of the EDLT, the multiplier drops, turning negative initially and then increasing until reaching a higher bound.

### *E.2 Effect of the Consolidation Pace*

As explained in Section 4.2, an increase in government spending affects the debt dynamics not only through its direct effect on the budget constraint but also through a reduction in the tax base. The magnitude of the debt accumulation, in turn, depends on the endogenous response of the tax rate governed by the parameter $\phi_\tau$.

To assess the effect of the consolidation pace on macroeconomic outcomes, Figure E.2 plots the output and inflation multiplier for a 1 percent of GDP increase in government spending (the dashed line) and a 1 pp tax cut (the solid line) for values of $\phi_\tau$ ranging from 0.05 to 0.4. From Section 4.1, we know that the endogenous response of taxes to debt affects inflation in the unintended regime only marginally because of two opposite effects that cancel out each other: one from the price markup variation and one from the debt accumulation. This low sensitivity of inflation is attested by the flat inflation multipliers in the right panel of Figure E.2. However, the left panel reveals that the output multiplier is less negative when $\phi_\tau$ increases due to the positive effect of bringing down the debt level faster. A government that consolidates at a slow pace finds itself with a high debt burden at the exit of the liquidity trap. Hence, inflation remains above target for a prolonged period of time after the regime shock and this provides an incentive for forward-looking households to decrease their consumption in anticipation of the contractionary monetary policy and subdued economic recovery. This expectation channel provides the incentive for an additional consolidation effort in the unintended regime.

### *E.3 Size of the Fiscal Intervention*

The numerical experiments in Section 4.2 show that output in the unintended regime deteriorates more with an increase in government spending than with a tax cut. One reason for this result is the larger debt accumulation stemming from the spending policy. A natural follow-up exercise performed in Table E.1 is thus to investigate whether this result is sensitive to the relative size of the policy experiments. The table shows the effect of different calibrations for the spending and tax-cut policies on the debt accumulation and on the output multiplier (and its components). The baseline calibration (columns +1 pp and –1 pp) assumes that government spending increases by 1 percentage point (from 20 percent of output to 21 percent) while the tax rate decreases by –1 percentage point. Clearly, the larger the fiscal expansion, the more debt accumulates in the unintended regime. For a larger tax cut of –2 pp, the debt accumulation (measured in deviations from the no-intervention case as a percentage of annual output) becomes larger than the one in the baseline increase in government spending (26.36 percent against 17.42 percent). When compared to the baseline tax cut (–1 pp), the higher debt burden leads to a larger deterioration of output (–0.09 against –0.04). Nevertheless, this deterioration remains lower than the one in the baseline spending policy (–0.12) because the tax cut is associated with a drop of the real interest rate in the unintended

**Table E.1. Size of the Fiscal Intervention and Output Multiplier**

| | Gov. Spending | | | Tax Rate | | |
|---|---|---|---|---|---|---|
| **Fiscal Policy** | **+1 pp** | **+3 pp** | **+5 pp** | **−1 pp** | **−2 pp** | **−4 pp** |
| $\Delta b_t$ | 17.42 | 49.91 | 79.69 | 13.18 | 26.36 | 52.72 |
| $\Delta y_t$ (numerator) | –0.12 | –0.35 | –0.56 | –0.04 | –0.09 | –0.18 |
| $\Delta G_t$ (denominator $G$) | 0.24 | 0.70 | 1.12 | 0 | 0 | 0 |
| $y_t \lvert\triangle\tau_t\rvert$ (denominator $\tau$) | 0 | 0 | 0 | 0.25 | 0.50 | 0.99 |
| $\Delta y_t/\Delta G_t$ or $\Delta y_t/(y_t \lvert\triangle\tau_t\rvert)$ | –0.50 | –0.50 | –0.50 | –0.18 | –0.18 | –0.18 |

**Note:** The table shows the impact of varying the size of the fiscal intervention on debt accumulation and on the numerator and denominator of output multiplier. Sizes of government spending and tax-cut policies are expressed in percentage-point deviations from respectively the steady-state spending-to-output ratio and the steady-state tax rate. All deviations in the core of the table are from the no-intervention case (stationary level in the unintended regime) in percentage of annual output.

regime that crowds in consumption and that alleviates the negative effect of debt accumulation on output (see Section 4.2). This last result can be overturned with a large-enough tax cut (–4 pp). In this case, debt accumulates so much (52.72 percent) that output in the unintended regime falls below that observed in the baseline spending policy (–0.18 against –0.12). Notice however that since this larger output deterioration is proportional to the size of the tax variation, the output multiplier remains unchanged (–0.18) and is less negative than the output multiplier of government spending (–0.5) for any size of the fiscal intervention. This confirms the superiority of the tax-cut policy in the EDLT when government debt dynamics matter for macroeconomic outcomes.

## Appendix F. Preference over Safe Assets

I consider a modified version of the model where government bonds enter in the utility function of the representative household. More specifically, the lifetime utility now becomes[16]

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \xi_t \Big[ \frac{c_t^{1-\gamma_c}}{1-\gamma_c} + \nu_g \frac{G_t^{1-\gamma_g}}{1-\gamma_g} - \nu_h \frac{h_t^{1+\gamma_h}}{1+\gamma_h} + \chi \frac{\left(\frac{b_t}{R_t}\right)^{1-\gamma_b}}{1-\gamma_b} \Big]. \quad \text{(F.1)}$$

The log-linear system now reads

$$\beta \tilde{b}_t - \tilde{b}_{t-1} - b(\beta \hat{\imath}_t - \hat{\pi}_t) - \Psi_G^b \hat{G}_t + \Psi_c^b \hat{c}_t + \Psi_\tau^b \tilde{\tau}_t = 0$$
$$\hat{c}_t = -\gamma_c^{-1} \delta (\hat{\imath}_t - \mathbb{E}_t \hat{\pi}_{t+1}) + \delta \mathbb{E}_t \hat{c}_{t+1} + (1-\delta)\gamma_b (b^{-1} \tilde{b}_t - \hat{\imath}_t)$$
$$\hat{\pi}_t = \beta \mathbb{E}_t \hat{\pi}_{t+1} - (\theta - 1)\psi^{-1} \hat{\mu}_t,$$

where $\delta = \beta R$ is the discounting wedge and $\gamma_b$ is the wealth curvature. Parameter $\chi$ governs the degree of preference over safe assets (POSA).

[16]The reason $R_t$ shows up in the utility is the following. Rannenberg (2021) considers a budget constraint of the form $\bar{b}_t = \frac{R_{t-1}\bar{b}_{t-1}}{\pi_t} + deficit_t$, where $\bar{b}_t$ is the face value of debt. To recover the (mathematically equivalent) budget constraint in this paper, one has to operate a variable change by defining $b_t = R_t \bar{b}_t$. Moreover, Rannenberg (2021) uses the following functional form for POSA: $\chi \frac{\bar{b}_t^{1-\gamma_b}}{1-\gamma_b}$. Applying the variable change, this gives $\chi \frac{(\frac{b_t}{R_t})^{1-\gamma_b}}{1-\gamma_b}$ in my model.

Under this specification, the individual discount rate exceeds the nominal return on the bond. Formally, the non-linear Euler equation reads $1 = R_t \beta \mathbb{E}_t \frac{c_{t+1}^{-\gamma_c}}{\pi_{t+1} c_t^{-\gamma_c}} + \chi \bar{b}_t^{-\gamma_b} c_t^{\gamma_c}$, where $\bar{b}_t = b_t / R_t$ is the face value of debt. The risk-free rate in the benchmark model (without POSA) is given by $R_t^* = \frac{1}{SDF_t}$, where $SDF_t \equiv \beta \mathbb{E}_t \frac{c_{t+1}^{-\gamma_c}}{\pi_{t+1} c_t^{-\gamma_c}}$ represents the stochastic discount factor of the households. Defining $\Theta_t \equiv \chi \bar{b}_t^{-\gamma_b} c_t^{\gamma_c}$, the spread can be written as $\frac{R_t}{R_t^*} = 1 - \Theta_t$. Thus, when $\chi > 0$, the risk-free rate with POSA is lower than the one in the benchmark model ($R_t < R_t^*$). This spread is interpreted as a *convenience yield* on the risk-free bond, i.e., a premium that the representative household is willing to pay for the additional safety and liquidity services attributed to this type of asset.[17] To calibrate the additional parameters, I draw on the POSA literature. As in Campbell et al. (2017), I assume that the discounting wedge is $\delta = 0.99$. Given my steady-state gross rate of $R = 1.0063$ (which corresponds to an annualized interest rate of 2.5 percent), this gives me an individual discount factor of $\beta = 0.9839$. For the same discounting wedge, Rannenberg (2019) sets the wealth curvature to $\gamma_b = 1/3$. I take this value as an upper bound and choose $\gamma_b \in [0, 1/3]$. The POSA parameter can be recovered as a residual from the steady-state Euler equation, $\chi = (1-\delta)(\frac{b}{R})^{\gamma_b} c^{-\gamma_c}$.

## Appendix G. Optimized Rules with Regime Uncertainty

Section 5 on optimized rules assumed that the economy is plagued with rare episodes of EDLTs. In reality, it might be difficult for the government to identify the true nature of a liquidity trap: fundamental driven or expectations driven. Since the perfectly timed stimuli studied in this paper have contradictory effects depending on the nature of the liquidity trap, it is interesting to evaluate the impact of regime uncertainty on the optimized policy. Intuitively, if FDLTs may arise with some probability, then cutting taxes or spending may be less desirable because it sometimes would have recessionary consequences. Hence, I simulate again the economy, but this time

[17] For a similar interpretation see, e.g., Krishnamurthy and Vissing-Jorgensen (2012).

**Table G.1. Macroeconomic Outcomes with Regime Uncertainty**

| | | | | $\widehat{\pi}$ | | | $\widehat{c}$ | | | $\widehat{b}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\widehat{G}_u$ | $\widetilde{\tau}_u$ | $\mathcal{L}$ | **U** | **L** | **H** | **U** | **L** | **H** | **U** | **L** | **H** |
| Optimized | –1 | 0 | 0.16 | –2.39 | –3.99 | –0.25 | 0.25 | –2.92 | 0.10 | –2.00 | –0.71 | –0.70 |

**Note:** Government spending and consumption are expressed in percentage deviations from the steady state. Inflation is in annual percentages. Debt is in percentage of annual output and the tax rate in absolute percentages. Welfare loss is in percentage of permanent consumption equivalent. U, L, and H stand for the unintended regime, low regime, and high regime, respectively.

assuming three regimes: an unintended regime (U) that is expectations driven, a low regime (L) that is caused by a large demand shock, and a high regime (H) with high demand and non-binding ELB. The transition probability matrix is the following:

$$\begin{bmatrix} p_{UU} & p_{UL} & p_{UH} \\ p_{LU} & p_{LL} & p_{LH} \\ p_{HU} & p_{HL} & p_{HH} \end{bmatrix} = \begin{bmatrix} 0.99 & 0 & 0.01 \\ 0 & 0.5 & 0.5 \\ 0.003 & 0.1 & 0.897 \end{bmatrix}.$$

On the one hand, this distribution implies that it is impossible to switch from one binding regime to the other. On the other hand, once in the non-binding regime, it is possible to switch to a binding regime of both kind with a higher probability of fundamental regime.

Table G.1 shows that the optimized outcome still consists in a 1 percent spending cut although now no tax cut is warranted. This policy almost corresponds to a neutral stance of fiscal policy. This result is intuitive. Since expansionary fiscal policy has opposite effects depending on the type of liquidity trap, the best strategy becomes to refrain from intervening. Notice that inflation is lower in the low regime because the spending cut is deflationary in this case. The opposite is true for the unintended regime.

## Appendix H. Derivation of the Loss Function

A second-order approximation of the representative households' utility around the efficient steady state yields

$$\begin{aligned} U(c_t, y_t, G_t) \approx{}& c^{1-\gamma_c}\hat{c}_t + \frac{1}{2}(1-\gamma_c)c^{1-\gamma_c}\hat{c}_t^{\,2} - \nu_h y^{1+\gamma_h}\hat{y}_t \\ & - \frac{1}{2}\nu_h(1+\gamma_h)y^{1+\gamma_h}\hat{y}_t^2 + \nu_g G^{1-\gamma_g}\hat{G}_t \\ & + \frac{1}{2}\nu_g(1-\gamma_g)G^{1-\gamma_g}\hat{G}_t^{\,2} + tip. \end{aligned}$$

At the efficient steady state, we have $\nu_g = G^{\gamma_g}c^{-\gamma_c}$ and $\nu_h = y^{-\gamma_h}c^{-\gamma_c}$, thus we can write

$$U(c_t, y_t, G_t) \approx c^{-\gamma_c}\left(c\hat{c}_t + \frac{1}{2}(1-\gamma_c)c\hat{c}_t{}^2 - y\hat{y}_t - \frac{1}{2}(1+\gamma_h)y\hat{y}_t^2 \right.$$
$$\left. + G\hat{G}_t + \frac{1}{2}(1-\gamma_g)G\hat{G}_t{}^2\right) + tip.$$

Next, a second-order approximation of the resource constraint $y_t\left(1 - \frac{\psi_\pi}{2}(\pi_t - 1)^2\right) = c_t + G_t$ gives

$$RC(c_t, G_t, \pi_t, \pi_{w,t}, y_t) \approx c\hat{c}_t + \frac{1}{2}c\hat{c}_t^2 + G\hat{G}_t + \frac{1}{2}G\hat{G}_t^2 + \frac{1}{2}\psi_\pi y\pi^2\hat{\pi}_t^2$$
$$= y\hat{y}_t + \frac{1}{2}y\hat{y}_t^2.$$

Solving for $c\hat{c}_t + \frac{1}{2}c\hat{c}_t{}^2$, substituting in the approximated utility and using $\pi = 1$, we arrive at the loss function in the text.

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# Sterilized Interventions May Not Be So Sterilized*

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It is widely believed that sterilized FX interventions do not affect domestic currency interest rates. The reason is the word "sterilized." Yet we show in this paper that when a collateral base for central bank operations isn't big enough, sterilized interventions may still affect interest rates, loan extension, and, hence, real economy (beyond the effects of altered exchange rate). The mechanism is simple and works through the liquidity risk premium. We demonstrate the importance of this channel through theoretical as well as empirical perspectives. Our modeling framework also provides interesting insights about a relationship between a liquidity risk and reserve requirements, among other results.

JEL Codes: E43, E58, F31.

## 1. Introduction

While theoretical contributions on a topic of foreign exchange (FX) interventions are still relatively scarce, many emerging market economies (EMEs) have been casually intervening on FX markets for quite a while, sometimes even heavily. As Bank for International Settlements (BIS) (2019) puts it, "practice has moved ahead of

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theory" in this sense. To make sure that practice does its job the right way, it is a responsibility of the economics profession to study macro-financial interlinkages related to FX interventions. The recent work of the International Monetary Fund on the Integrated Policy Framework is along these lines; it studies if and when central banks should use FX interventions in addition to other tools like a policy rate and macroprudential instruments (see Adrian et al. 2020 or Basu et al. 2020). This topic is especially important during episodes of large capital flows when central banks conduct large amounts of FX interventions. The COVID-19 crisis is an example of such an episode (International Monetary Fund 2020).

In this work of studying all the important effects of FX interventions (FXIs), we contribute to the lending side, i.e., we explore how FXIs influence domestic currency lending rates, even when the interventions are sterilized. A widely accepted view is that sterilized FXIs, in principle, have no impact on domestic currency (DC) interest rates. The reason is that when central banks sterilize their FX interventions, they essentially undo any effect that those interventions may have on a monetary base. With demand for domestic currency liquidity being unchanged, if its supply remains unchanged as well, it is natural to expect that the price (money market interest rates) will remain the same. Indeed, having no impact on DC interest rates is the way sterilized interventions are usually defined as such (e.g., Abildgren 2005 or Benes et al. 2013). Some even argued that a sterilized FXI does not have any effect on any real variable and, hence, is not an independent instrument at all (e.g., Backus and Kehoe 1989).

To be sure, the literature has identified mechanisms through which the above claim can be countered. For instance, Kumhof and van Nieuwerburgh (2002) developed a general equilibrium model that shows how sterilized FX interventions may affect a real economy. What they (and other related papers) claim is that sterilized FXIs influence uncovered interest rate parity (UIP) risk premium and that is the channel through which they affect exchange rates. A theory that we develop below, and provide some empirical support for, argues that there is another channel at work—the *FXI liquidity risk channel*—that may affect DC loan interest rates and, hence, other variables as well, including deposit (money) creation and the exchange rate.

This domestic currency liquidity risk channel of sterilized FXIs works in the following way: when banks make decisions about loan extension and, hence, deposit (money) creation, they take liquidity risk into account. The risk is that these newly created deposits may be withdrawn by those depositors that prefer cash instead. The risk is present because, in general, loans have longer maturity than deposits (i.e., maturity mismatch), so that deposits may leave a bank much faster than loans are paid off. These deposit withdrawals, in turn, necessitate central bank money (reserves). Banks may have some (precautionary) reserves above reserve requirements but, more importantly, a banking system as a whole relies on an ability to get liquidity from a central bank (e.g., central bank refinancing operations). The latter requires eligible collateral though, which may be a scarce resource in some countries. Namely, even if collateral constraint is not currently binding, when collateral base for central bank operations is not big enough, banks may *still* fear (massive) deposit withdrawals that, in principle, can make the constraint start binding in the future, until (sufficient amount of) loans are paid off. This is especially true in countries that have fragile inflation expectations and large amounts of foreign currency borrowing, where central banks may not be able to do massive liquidity injections (see Mishkin 2001). Banks internalizing this feature will set high-enough interest rates on DC loans to reflect the liquidity risk premium.

However, this fear is reduced when banks get permanent liquidity from a central bank that buys FX as opposed to getting the same amount of liquidity by borrowing from the central bank (that uses up a scarce collateral). The reduction in this fear will result in lower DC loan interest rates and/or easier terms for loans. The lower loan rates will increase demand for loans and, hence, loan extension. Newly extended loans create new purchasing power (deposits) that then puts some pressure on an exchange rate (among other prices). Hence, this novel channel, working through loan interest rates, may as well explain exchange rate effects of sterilized interventions, and this may work on top of a traditional portfolio balance channel (see, e.g., Branson and Henderson 1985). This also implies that having sufficiently large collateral base not only minimizes interest rate effects of sterilized FXIs, but also leads to low liquidity risk on average. However, achieving this is difficult unless the amount of near risk-free securities is abundant enough.[1] This means that, as a liquidity management tool, FX interventions could be considered as an independent policy instrument. Or put differently, sterilized FXIs can also be thought of as a quantitative easing (QE) tool in the presence of collateral constraints.

In addition to the conclusion that sterilized FX interventions may affect liquidity risk premium and, therefore, loan interest rates, we arrive at a number of other interesting results. Namely, our modeling framework shows that the level of reserve requirements may still matter for loan interest rates even in financial systems that operate under an interest-rate-targeting framework. Also, the public's propensity to use cash instead of bank deposits affects loan interest rate setting as well (both through a direct impact from a policy rate as well as an indirect impact on a liquidity risk premium). On the other hand, the size of government bond portfolio (or other near risk-free and liquid assets) also affects interest rates. Namely, while there are channels that result in a crowding-out effect, in our modeling framework more government bonds may put a downward pressure on loan interest rates (through a lower liquidity risk premium)—an opposite to the crowding-out channel. Finally, our framework shows that in 100 percent reserve banking, liquidity risk would either be zero (when collateral constraint for central bank operations isn't binding) or infinite (when it is binding). This shows how switching from fractional banking to full reserve banking would turn commercial banks into traditional intermediaries (as described by loanable funds theory) instead of being the major creators of (deposit) money.

Section 2 discusses the related literature, while Section 3 develops an argument for our new channel linking sterilized FXIs and domestic credit conditions. Namely, Subsection 3.1 develops a theoretical model that shows how profit-maximizing banks set interest rates and react to central bank interventions, while the following subsection shows empirically how important this channel has been for interest rate setting in Georgia and quantifies the effects. Section 4 concludes.

[1] In other words, taking risky assets as a collateral for central bank operations is a tricky task (possibly, unless a very big haircut is applied), as it is a quasi-fiscal step.

## 2. Literature Review

Our paper is related to two different domains of economic literature: one that examines macroeconomic implications of sterilized FXIs mainly through their impact on lending rates, loan extensions, and aggregate demand; and one that investigates the effects of financial frictions (i.e., constraints on the amount/value of safe assets that can be used as a collateral in interbank markets) on bank lending and output. The first part of the literature, while containing only a small number of papers, displays mixed results, some claiming that sterilized FXIs (buying FX) have expansionary effects on an economy through stimulating domestic currency credit to the private sector, while others strongly doubt the existence of such a relationship.

For example, Hofmann and Shin (2019) propose a model similar to the banking model of Bruno and Shin (2015) which implies that a purchase of U.S. dollars by a central bank sterilized through a corresponding sale of domestic bonds slows down domestic currency credit supply. The model arrives at this conclusion through two different but mutually enforcing channels. The first one is a "risk-taking channel" of the exchange rate, as the authors name it, and the second one is the widely known "crowding-out" channel. The risk-taking channel arises from the fact that borrowers have a legacy debt in a foreign currency (in this case, in U.S. dollars) and hence are subject to balance sheet effects of the exchange rate. When the central bank intervenes by purchasing USD, given that local currency depreciates, borrowing firms bearing USD-denominated debts on their balance sheets become more vulnerable as a result of higher debt service burden. This increased vulnerability of borrowers directly translates into a higher tail risk for banks with a diversified loan portfolio. And, given that banks follow a value-at-risk (VaR) rule, a higher tail risk dampens domestic credit growth. The crowding-out channel, on the other hand, works through reducing banks' lending capacity due to the absorption of the increased supply of domestic bonds coming from the sterilization leg of the FX intervention. The authors then test these two channels against a high-frequency micro data set and confirm that sterilized FX purchases have a significant and persistent dampening effect on new domestic bank credit. Qualitatively similar results are found by some other authors such as Céspedes, Chang, and Velasco (2017) and Chang (2018), though mechanisms at play for the crowding-out channel to work are completely different.

Contrary to the results above, Gadanecz, Mehrotra, and Mohanty (2014) conduct an empirical investigation of effects of sterilized FX purchases on bank lending and find the expansionary effects of such FXIs, which they believe to be stemming from the resulting shift in the composition of the banking system's balance sheets. In this work, the authors consider two competing hypotheses through the country-level panel data from emerging market economies (EMEs). One is that liquid government and central bank securities may act as a substitute for bank credit and, hence, crowd out lending to the private sector—an idea in line with Bernanke and Blinder (1988) and others discussed above. The alternative hypothesis, however, states that those government and central bank securities are considered by banks as an equivalent to central bank reserves and, hence, they reduce liquidity constraints which, in turn, leads to increased lending to the real economy (Kashyap and Stein 1997, 2000). The empirical results support the alternative hypothesis and conclude that an increase in government bonds and central bank securities, as a result of the sterilization leg of large-scale and persistent FX purchases in EMEs, leads to an expansion in credit to the private non-banking sector. Furthermore, as the authors argue, this result is economically as well as statistically significant. Similar results are presented by Vargas, González, and Rodríguez (2013) using a small open-economy dynamic stochastic general equilibrium (DSGE) model with financial sector.

As for the second strand of the literature, Gorton and Laarits (2018) emphasize the role of safe assets (i.e., high-quality collateral) for the well-functioning of the modern banking system and its resilience in times of distress. Caballero and Farhi (2018) point to the devastating effects of the shortage of safe assets for the overall economy. In a more tractable and insightful general equilibrium model with interbank money markets, central bank, and collateralizable assets, De Fiore, Hoerova, and Uhlig (2019) show that when interbank money markets suffer from large and abrupt private haircut increases, liquidity constraints for banks turn binding, and lending and, consequently, output drop significantly. In such cases, the presence of a central bank by providing collateralized loans at noticeably lower haircuts can alleviate banks' liquidity shortage and push lending activity back on track.

Linking the two strands, we employ this role of high-quality collateral in banks' liquidity management and formulate the theoretical model accompanied with empirical investigation to contribute to the first domain of the literature, claiming that sterilized interventions (FX purchases) can have a positive real effect on the economy through their impact on collateral sufficiency, lending rates, and credit extension. In particular, we recognize the importance of possible liquidity constraints that private banks may face and take into account when deciding their optimal portfolio allocations. Furthermore, under our setup sterilization does not necessarily require any deliberate issuance or purchase of government securities. Instead, as is the case for inflation-targeting central banks operating under interest-rate-targeting framework and structural liquidity deficit, sterilization happens automatically through central bank borrowing instruments (e.g., refinancing loans or, if not directly provided, some kind of standing facilities of the central bank). Building on this, in the next section we provide a theoretical model followed by an empirical investigation.

## 3. Interventions and Interest Rates

In this section we develop a theory of the *FXI liquidity risk channel* and provide some empirical support for it for the case of Georgia. Namely, first, we obtain an analytic representation of the dependence of loan interest rates on FXI, i.e., develop a theoretical model that shows how profit-maximizing banks would take a collateral constraint for central bank operations into account when setting interest rates on loans and deposits. Then, we bring the key testable implications of the model to data. In particular, we estimate a distributed lag model with Georgian data, which shows the significance of our channel, both economically as well as statistically.

### *3.1 Theoretical View*

The discussion of the theoretical side is split into two parts: describing the key assumptions of our model setup/framework and enumerating its key implications, which, in addition to our main result on

FXI, also shows other interesting takeaways—underlying the usefulness/realism of the model.

### *3.1.1 Modeling Framework*

A partial equilibrium model is introduced to describe how (infinitely many) banks (each of them represented by an index $i$), operating in a monopolistic competitive market,[2] make decisions on financial variables, such as an amount of loans ($L_t(i)$), reserve holdings ($Q_t(i)$), deposits ($D_t(i)$), holdings of government securities ($S_t(i)$), refinancing loans from a central bank ($R_t(i)$), and all the respective interest rates, to maximize their profit. While we are keeping banks' balance sheets as simple as possible, this degree of detail is still sufficient to realistically arrive at novel results regarding FXI (and not only). Our banks are distributed on a $[0, 1]$ interval. Commercial bank $i$'s balance sheet[3] is summarized below:

Commercial Bank $i$

| Assets | Liabilities |
|---|---|
| ($L_t(i)$) Loans | Deposits ($D_t(i)$) |
| ($Q_t(i)$) Reserve Balances | Refinancing Loans ($R_t(i)$) |
| ($S_t(i)$) Securities | |

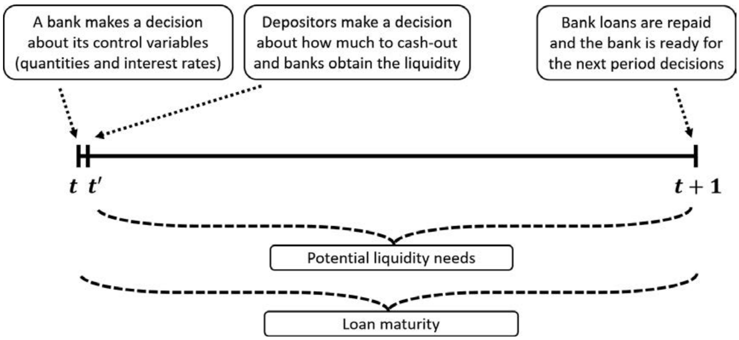
Each individual bank's decision is subject to a risk of liquidity shortfall, a situation when a bank is short of eligible collateral (government securities) to obtain liquidity from the central bank for settling transactions with other banks, satisfying reserve requirements, or satisfying cash withdrawals.

Before discussing how banks are making decisions on various markets, we explain the timing convention built into our model. Here we emphasize three possible time instants during each period: time instant $t$, when banks have to make their decisions to plan their business (the monetary amount of loans to extend and at what

[2]All the assumptions of our model are summarized in Appendix C.

[3]We abstract from capital adequacy issues, since this is a different (credit risk) topic and, while introducing more complexity, would not alter our qualitative results (on liquidity risk). We also abstract from interbank market borrowings, because we tried modeling it in our framework and the key model implications remained the same.

**Figure 1. Timing of the Model**




**Source:** Authors' construction.

interest rate, etc.); time instant $t'$, when depositors decide how much cash to withdraw and when banks will need to obtain a sufficient amount of liquidity (to satisfy withdrawals); and time instant $t+1$, when the period is finalized (loans are repaid, etc.) and the bank is ready for the next period. This process is summarized in Figure 1.

Given these time instants, we can define the maturity of loans and banks' borrowings for obtaining liquidity. Namely, loan maturity is the period between $t$ and $t+1$, while the maturity of a bank's borrowing from the central bank is the period between $t'$ and $t+1$. Because $t$ and $t'$ are assumed to be very close, those two maturities are practically the same. Hence, in the optimization problem all interest rates are assumed to be for the same maturity: a period from time instant $t$ to that of $t+1$. Banks maximize their profit (net interest margin) subject to several constraints, which we discuss now one by one.

In the case of loans, each bank is making decisions about the monetary amount of loans ($L_t(i)$) to extend and what interest rate to charge ($i_t^l(i)$); however, they face a demand constraint—the monetary amount of loans each bank can extend depends on overall loan demand ($\bar{L}_t$),[4] how different the bank's loan interest rate is relative

[4]Variables with bars over them indicate that they are not modeled here endogenously—their values are determined outside of our framework (something that could be relaxed while applying the approach to a general equilibrium model).

to a market average ($\bar{i^l_t}$), and how high an elasticity of substitution ($\varepsilon^l$) there is between different bank loans (i.e., measure of bank competition)—standard result of constant elasticity of substitution (CES) aggregation:

$$L_t(i) \leq \left(\frac{i^l_t(i)}{\bar{i^l_t}}\right)^{-\varepsilon^l} \bar{L_t}. \tag{1}$$

Each bank must maintain reserve balances that at least satisfy minimum reserve requirements ($rr$). For this, banks may have to take out refinancing loans ($R_t(i)$) from the central bank to manage liquidity. An interest rate paid on those loans equals the policy rate ($\bar{i_t}$). As in many countries (with a corridor system for interest rates), we also assume that the central bank remunerates reserve balances with the policy rate only if those reserves are required, while excess reserves are remunerated at zero. This incentivizes the banks to not hoard reserves.

Monopolistic competitive banks are the only primary dealers on government securities' market in our model. They are bidding their own preferred yields $i^s_t(i)$ when the government issues securities and the amount of securities each bank obtains through the auction is constrained with an interest-elastic demand schedule. This downward-sloping demand schedule, linking the yield bid by each bank and the share of securities obtained by this bank, also depends on the aggregate amount of securities $\bar{S}_t$ supplied by the government (or aggregate amount of borrowing demanded by it) and average yield on those securities—again, standard CES aggregation[5]:

[5]We acknowledge that government bonds are more like a homogeneous asset, and a competitive threat in such a market means everyone would bid the same interest rate on the auction (since below that would make no economic sense and above that a buyer will be left without any bond whatsoever). However, this argument presumes each bank has an ability to buy the whole bond portfolio, which may not be realistic. Instead, we assume that each bank, e.g., due to a leverage ratio cap, can at most buy a certain (relatively small) portion of the whole portfolio, even if it bids the lowest interest rate. This means that even if one bank knows that its competitor will bid a very low interest rate, this bank will still not have an incentive to follow suit and can instead bid a bit higher rate (if it's not too desperate for bonds), but still be able to get at least some portion of bonds. When the number of banks becomes large (infinity, in the limit), this assumption results in a downward-sloping demand curve for bonds.

$$S_t(i) \leq \left(\frac{i_t^s(i)}{\bar{i}_t^s}\right)^{-\varepsilon^s} \bar{S}_t. \tag{2}$$

Then, deposit demand also restricts the banks from setting deposit interest rates below the policy rate by more than a mark-down $\frac{\varepsilon^d-1}{\varepsilon^d}$, which measures a competition in the deposit market:

$$i_t^d(i) \geq \frac{\varepsilon^d - 1}{\varepsilon^d}\bar{i}_t. \tag{3}$$

Next, each bank also internalizes the presence of its balance sheet identity $(L_t(i)+Q_t(i)+S_t(i) = D_t(i)+R_t(i))$ as well as the way permanent liquidity is provided in the system.[6] The latter is reflected in the fact that a bank needs smaller refinancing loans the higher is the amount of FX reserves the central bank accumulates:

$$R_t(i) = Q_t(i) + cD_t(i) + \hat{E}_t(i) - \bar{R}_t^{fx}. \tag{4}$$

This equation incorporates the fact that the public (non-bank sector) has cash demand consisting of two parts: average demand for cash (constant $c$ fraction of deposits), $cD_t(i)$, and stochastic demand for it,[7] $\hat{E}_t(i)$. This cash demand may be satisfied by the central bank accumulating FX reserves $\bar{R}_t^{fx}$ (against which it provides liquidity to the non-bank sector, even if through banks). But whatever cash demand is left needs to be satisfied by banks. Banks, on the other hand, need to obtain liquidity to (i) satisfy this (net) cash demand as well as (ii) hold it (in the form of $Q_t(i)$) to satisfy reserve requirements. Hence, they have to obtain this needed liquidity from the

[6]The only way for the central bank to provide permanent liquidity to our model economy is through FX interventions. We could have easily included a central bank's open-market operations with government bonds, but it would not have changed the final results. Buying government bonds does not relax the collateral constraint, as the bond owner becomes the central bank instead of a commercial bank, which is a (major) bondholder here. On the other hand, whenever the central bank conducts an FX intervention, even if through commercial banks, it eventually buys (sells) FX from (to) non-banks, since our assumption is that the banks have a closed FX position. This is how most financial systems work worldwide. But even if we relax this assumption, results wouldn't change much. And when FX reserves increase on the asset side of the central bank balance sheet, so does the liquidity (which is a liability of the central bank).

[7]This shock can be interpreted as an idiosyncratic liquidity shock to a particular bank.

central bank (by refinancing loans, $R_t(i)$). The above equation simply uses this information to express demand for refinancing loans as a function of all the above (of which FXI is the most relevant here). In turn, the amount of permanent liquidity provided (or withdrawn) through FX interventions is exogenous to each bank. We assume that distribution of (non-bank) clients who get to adjust their balances at commercial banks after the central bank's FXI is also exogenous and symmetric[8] to banks. If we were to integrate this demand for refinancing loans over all the banks, we would nicely arrive at the central bank balance sheet identity, which states that demand for central bank money (coming from reserve requirements and cash demand) will be satisfied by either the central bank's net foreign assets (FX reserves here) or net domestic assets (refinancing loans here).

Last but not least, there's one key constraint each bank also faces, in addition to more standard ones listed above: if there are massive-enough deposit withdrawals so that the bank reaches its collateral constraint (with a collateral base in this case being equal to $S_t(i)$ for each bank), then it incurs an additional cost (say cost of a bank run) equal to $\Delta_t(i)$.[9] Given these constraints and decisions in our model, each monopolistic competitive commercial bank's profit reads (given there are no excess reserves[10]):

$$\Pi_t(i) = \begin{cases} (i_t^l(i)L_t(i) + \bar{\imath}_t Q_t(i) + i_t^s(i)S_t(i)) & \\ \quad - (i_t^d(i)D_t(i) + \bar{\imath}_t R_t(i)), & \text{if } R_t(i) \leq S_t(i) \\ (i_t^l(i)L_t(i) + \bar{\imath}_t Q_t(i) + i_t^s(i)S_t(i)) & \\ \quad - (i_t^d(i)D_t(i) + \bar{\imath}_t R_t(i)) - \Delta_t(i), & \text{otherwise.} \end{cases} \tag{5}$$

[8]That's why $\bar{R_t}^{fx}$ has no $i$ index. But even if we had an asymmetric distribution of clients, what's important for our (qualitative) result is for $\bar{R_t}^{fx}(i)$ to have been an increasing function of $\bar{R_t}^{fx}$, which is a very reasonable assumption.

[9]What this cost is proportional to will be discussed below.

[10]The question can be, why do we rule out the possibility of excess reserves? The answer is a combination of two points: (i) in our model, as in corridor systems, excess reserves pay no interest (aren't remunerated), while securities pay positive interest; and (ii) excess reserves and securities provide the same degree of liquidity risk insurance because securities are 100 percent eligible as collateral (i.e., no haircut) and can always be easily liquidated. In other words, while the bank is indifferent from the benefit (liquidity) side, it strictly prefers securities from the (opportunity) cost side, meaning that if the bank has some excess liquidity, it would rather buy securities with it than hold it as excess reserves.

If we assume that these banks are risk neutral,[11] then the banks try to maximize the following expected (probability-weighted) profit:

$$\Pi_t(i) = (i_t^l(i)L_t(i) + \bar{\imath}_t Q_t(i) + i_t^s(i)S_t(i)) - (i_t^d(i)D_t(i) + \bar{\imath}_t R_t(i)) \\ - \Delta_t(i)Prob(R_t(i) > S_t(i)). \quad (6)$$

Here all interest rate parts are standard interest revenues and costs. The crucial new term, as discussed above, is $\Delta_t(i)$ which, in our model, will be non-zero. This would mean that each commercial bank, to some extent (depending on the value of $\Delta_t(i)$), fears the possibility of refinancing needs ($R_t(i)$) exceeding the available collateral for central bank operations ($S_t(i)$). The interpretation of $\Delta_t(i)$ can be from both market as well as regulatory perspective. In terms of the former, the bank may fear a bank run (liquidity crisis) and, hence, bankruptcy excluding this particular bank from future profits (given re-entry into a banking sector would, as in the real world, be costly—e.g., attracting a customer base once again is difficult). In terms of the regulatory perspective, the bank may fear a liquidity crisis, because the supervisory authority may impose large regulatory burden in that case (also reducing profits). Even if the central bank widens the collateral base and accepts other assets (like loans), the terms would still be more costly (even Bagehot's dictum instructs us to require a good collateral and a penalty rate). In any case, running out of liquidity (obtaining which requires collateral) is costly and the higher $\Delta_t(i)$, the higher is this cost in our model. Given that in the real world bank runs are something that everybody in the banking system fears and tries to protect themselves from, it only makes sense to assume non-zero (or, more precisely, positive) $\Delta_t(i)$.

Hence, a bank's profit-maximization problem[12] reads as follows:

$$\max_{\substack{i_t^l(i),L_t(i),Q_t(i),i_t^s(i),\\ S_t(i),i_t^d(i),D_t(i),R_t(i)}} \left[i_t^l(i)L_t(i) + \bar{\imath}_t Q_t(i) + i_t^s(i)S_t(i)\right] - \left[i_t^d(i)D_t(i) \\ + \bar{\imath}_t R_t(i)\right] - \Delta_t(i)Prob[R_t(i) > S_t(i)]$$

[11] Our final results seem to only get magnified with the assumption of risk aversion, as risk-averse banks would fear the collateral constraint even more.

[12] Here profit means the next-period profit, since banks decide on interest rates and profits realize afterwards. Hence, given the stochastic component $\hat{E}_t(i)$, there is some uncertainty surrounding profits that the banks are trying to maximize. This is the reason why we have $Prob(\cdot)$ in the model.

subject to

$$(i) \quad L_t(i) \leq \left(\frac{i_t^l(i)}{\bar{\imath}_t^l}\right)^{-\varepsilon^l} \bar{L}_t$$

$$(ii) \quad Q_t(i) = rr \cdot D_t(i)$$

$$(iii) \quad S_t(i) \leq \left(\frac{i_t^s(i)}{\bar{\imath}_t^s}\right)^{-\varepsilon^s} \bar{S}_t$$

$$(iv) \quad i_t^d(i) \geq \frac{\varepsilon^d - 1}{\varepsilon^d} \bar{\imath}_t$$

$$(v) \quad L_t(i) + Q_t(i) + S_t(i) = D_t(i) + R_t(i)$$

$$(vi) \quad R_t(i) = Q_t(i) + cD_t(i) + \hat{E}_t(i) - \bar{R}_t^{fx}.$$

Before completing the model description, let's have a look at the growth rates (e.g., credit growth) incorporated into the model. We assume that the system follows a balanced-growth path (BGP), implying that in the steady state, growth rates of all quantities (like, loans, deposits, reserves, etc.) are the same. In general, this shared factor that drives growth rates can be interpreted as, for instance, a labor-augmenting technology which drives the output growth in the long term and, hence, credit given that in the very long-run credit-to-GDP is stable. Linking steady-state growth rates to a single exogenous technology is an already standard feature of many DSGE models (e.g., see Christiano, Motto, and Rostagno 2010). With this shared factor, which we denote as $z_t > 0$ (growth rate of which, $\frac{z_t - z_{t-1}}{z_{t-1}} = g$, is constant along the balanced-growth path), we can now stationarize our model by dividing all quantity variables (like loans, deposits, reserves, etc.) with that shared factor $z_t$, and denote those stationarized variables with the same letters as non-stationary ones but with a lowercase. That is, we have

$$l_t(i) \equiv \frac{L_t(i)}{z_t} \qquad q_t(i) \equiv \frac{Q_t(i)}{z_t} \qquad s_t(i) \equiv \frac{S_t(i)}{z_t} \qquad d_t(i) \equiv \frac{D_t(i)}{z_t}$$

$$r_t(i) \equiv \frac{R_t(i)}{z_t} \qquad \delta_t(i) \equiv \frac{\Delta_t(i)}{z_t} \qquad \bar{r}_t^{fx} \equiv \frac{\bar{R}_t^{fx}}{z_t} \qquad \hat{e}_t(i) \equiv \frac{\hat{E}_t(i)}{z_t}.$$

Because $z_t$ is an exogenous process (and takes strictly positive values), we can safely write that $Prob\big(R_t(i) > S_t(i)\big) = Prob\Big(\frac{R_t(i)}{z_t} > \frac{S_t(i)}{z_t}\Big) = Prob\big(r_t(i) > s_t(i)\big)$.

First-order conditions of this optimization problem described above, after some manipulations (see a detailed derivation in Appendix A), yield the following equation for the loan interest rate setting (in a symmetric equilibrium)[13]:

$$\boldsymbol{i_t^l} = \frac{\varepsilon^l}{\varepsilon^l - 1}\left[\frac{1}{1+c}\boldsymbol{i_t^d} + \frac{c}{1+c}\boldsymbol{\bar{i}_t} + \delta_t \frac{rr+c}{1-rr}\boldsymbol{f}\left(\bar{r}_t^{fx} + s_t - \frac{rr+c}{1-rr}\cdot l_t\right)\right], \tag{7}$$

while almost exactly the same procedure results in the following equation for the equilibrium yield on securities:

$$\boldsymbol{i_t^s} = \frac{\varepsilon^s}{\varepsilon^s - 1}\left[\frac{1}{1+c}\boldsymbol{i_t^d} + \frac{c}{1+c}\boldsymbol{\bar{i}_t} - \delta_t \boldsymbol{f}\left(\bar{r}_t^{fx} + s_t - \frac{rr+c}{1-rr}\cdot l_t\right)\right]. \tag{8}$$

All other variables can be extracted from the constraints above (e.g., loans and securities demand schedules give the quantities of $l_t$ and $s_t$), while $f$ (a probability density function of $\hat{e}_t(i)$[14]) represents liquidity risk premium. The intuition is that the bank takes a distance between the maximum possible supply of liquidity $(\bar{r}_t^{fx} + s_t)$[15] and an average demand for liquidity $(\frac{rr+c}{1-rr}l_t)$[16] into account. The bigger this distance, the less concerned the bank is (about liquidity risk), which means charging less premium. This risk premium,

[13] The assumption here is that $0 \leq rr < 1$. The case when $rr = 1$ is discussed below. Also, in a symmetric equilibrium index $i$ does not matter, since all banks face the same problem and make the same decisions. Hence, in equilibrium conditions we can get rid of it, making the equation easier to read.

[14] As $\hat{e}_t(i) \equiv \frac{\hat{E}_t(i)}{z_t}$ is stationarized, the actual size of the liquidity shock in our model $\hat{E}_t(i)$ is gradually increasing as the financial system and, hence, the amount of deposits increase over time. In other words, while the size of the liquidity shock doesn't depend on the short-term dynamics of deposits, it depends on the long-term dynamics of it. One can argue that this seems plausible. But even if it doesn't, relaxing this assumption doesn't change the qualitative results, while it complicates the derivations.

[15] Maximum possible supply of liquidity is what central banks supply through FXI plus the collateral base (i.e., sum of all security holdings here).

[16] Average demand for liquidity is the amount of deposits each dollar of loan generates $(\frac{1}{1-rr})$ times how much liquidity each dollar of deposits necessitates on average (to satisfy reserve requirements and average cash withdrawals). The same is true for loans as well as for securities.

usually absent in DSGE models that feature banking systems, is the central part in our analysis. The implications of that premium are provided in the next subsection. Namely, we describe how optimal choices made by banks (dictated by equilibrium conditions) are affected after a change of exogenous variables or model parameters.

**Equilibrium.** In a symmetric equilibrium, loans and securities markets clear, so that $\int_0^1 L_t(i)di = \bar{L}_t$ and $\int_0^1 S_t(i)di = \bar{S}_t$. As for the deposit market, we are not showing it explicitly here. Instead, it is assumed to clear implicitly, since that would be the result of applying Walras's law.

**Possibility for General Equilibrium Extension.** Up to this point, we have discussed only the bank's optimization problem (i.e., taking demand schedules as given—something that should come out of households' or other agents' optimization problems). However, the model we consider here can (most probably) easily be made part of a general equilibrium framework. We do not argue that *any* general equilibrium model can easily incorporate our channel, but that *some* can do so. For instance, an otherwise-standard DSGE model where the collateral constraint for central bank operations is either the only financial friction or is linearly independent from other financial frictions can easily be built. In that model all equilibrium conditions will be derived independently of the derivations shown here. For example, we could have firms in our model that have standard pay-in-advance constraints and are dependent on loans. In standard DSGE models an interest rate on that loan would be based on a policy rate. But, if our channel is incorporated, then that loan rate would now also depend on FX interventions per the equation we derived above. Hence, looking at the banks' problem should be sufficient for our purposes, to see how interest rates would depend on the collateral base and central bank liquidity injections or withdrawals (e.g., through FX interventions).

### *3.1.2 Implications of the Model*

Even though the modeling framework is quite simple, it results in many interesting implications—some of them new results, while others are already well established (underlying the model's realism). The most important result here, for the purposes of this paper, is the dependence of a liquidity risk premium on central bank FX interventions. That's what we discuss first.

**FX Interventions and Loan Interest Rates.** Whenever the central bank buys FX reserves, it swaps borrowed reserves into non-borrowed reserves. Hence, even if the total amount of reserve money is unchanged (i.e., intervention is sterilized), the refinancing needs decline. The latter in turn increases the amount of free (unused) collateral and, hence, lowers the probability of reaching the collateral constraint in the event of a bank run or big liquidity needs in the future. This, in turn, reduces the liquidity risk premium and, therefore, loan interest rates. This can be shown by differentiating $i_t^l$ with respect to $\bar{r}_t^{fx}$, which would depend on the probability density function $f(\cdot)$. Here, we remain agnostic about the functional form of $f(\cdot)$. We just do not consider cases when refinancing needs are already above the collateral base, in which case the liquidity risk premium would be infinite (banks will just have to de-leverage right away or default). In addition, for positive values of its argument $x$, $f(x)$ is assumed to be a decreasing function (i.e., $f'(\cdot) < 0$[17]), so that it is less likely for a depositor to cash out large sums than smaller sums. Then we have

$$\frac{\partial i_t^l}{\partial \bar{r}_t^{fx}} = \frac{\varepsilon^l}{\varepsilon^l - 1}\delta_t \frac{rr + c}{1 - rr} f'(\cdot) < 0. \qquad (9)$$

Hence, a higher level of FX reserves (i.e., intervention on the buying side), results in a reduction of loan interest rates. Lower loan rates induce more borrowing (through loan demand schedule), which, on its own, creates new purchasing power or deposits (through balance sheet identity). This new money, at least under sticky prices or monetary non-neutrality in general, will then temporarily stimulate the real economy, including through exchange rate depreciation (which we discuss in the next part). Clearly, the channel works in the opposite direction when the central bank sells FX reserves. What's crucial for the quantitative importance of this non-linear channel is the distance between the amount of borrowing needed from the central bank and the available collateral ($f(\cdot)$ is

[17] Otherwise, we could still have the dependence of loan rates on FX interventions but with a different direction.

non-linear). The smaller this distance, the more elastic the liquidity risk premium could be to changes in FX reserves. That's why the process is non-linear: if the need for borrowing from the central bank declines from a large value, liquidity risk also declines significantly, but if this need declines by the same amount from a small value, liquidity risk may not change much (and remain close to zero). This means that buying FX and selling FX, under certain conditions, may result in asymmetric effects on interest rates.

Therefore, because of the fear of not being able to obtain liquidity in the future, this channel is mostly visible when a central bank has a net creditor position (structural liquidity deficit). If there were structural liquidity surplus in the financial system, then this liquidity risk premium channel would probably be negligible. The examples of this could be floor systems where central banks flood the system with liquidity (because assets they can buy are abundant enough), or central banks try hard to stem off exchange rate appreciation and have accumulated too much of FX reserves. But for other countries that are less developed (so that risk-free assets aren't abundant enough) and have current account deficits (so that FX reserves aren't over-accumulated), this liquidity risk premium channel is probably going to show up, as the system would be in a structural liquidity deficit.

**FX Interventions and Yields on Securities.** Another important aspect (or flip side) of our channel is that FX interventions also affect securities yields but with a different direction than loan rates. Analytically, this can be seen by differentiating $i_t^s$ with respect to $\bar{r}_t^{fx}$, which results in

$$\frac{\partial i_t^s}{\partial \bar{r}_t^{fx}} = -\frac{\varepsilon^s}{\varepsilon^s - 1}\delta_t f'(\cdot) > 0. \tag{10}$$

Intuitively, contrary to the result above with $i_t^l$, yield on securities $i_t^s$ increases as central banks accumulate FX reserves. The reason is that when FX reserves increase, so do non-borrowed reserves. This reduces the need for central bank borrowing and, hence, the probability of reaching the collateral constraint in the future. This means that a security that can be used as collateral becomes less valuable—meaning its price declines, which by definition means higher yields. Clearly, the opposite happens when central banks sell FX reserves—now the amount of non-borrowed reserves decrease, which requires more collateral and an increase in its price. This explains how securities included in collateral base may incorporate a collateral service premium into their prices. This premium, when the collateral base is quite small, can get so big that the yields on those securities may even drift below the policy rate or result in a much more flat (risk-free) yield curve. This is important, because an inverted yield curve is usually thought to be a sign of an imminent recession, while we show that in developing economies described above this may also be a sign of collateral scarcity.

**Reserve Requirements and Interest Rates.** In addition to the main results above, other interesting insights (some of them trivial and some of them usually overlooked) can also be extracted from the above optimization problem. First, according to our loan interest-rate-setting and securities yield equations, liquidity risk premium, in addition to FX reserves, depends on the reserve requirements. For loan interest rates, given $f(\cdot)$ is a probability density function and takes on positive values:

$$\frac{\partial i_t^l}{\partial rr} = \frac{\varepsilon^l}{\varepsilon^l - 1}\delta_t \frac{1+c}{(1-rr)^2}\left(f(\cdot) - \frac{rr+c}{1-rr}f'(\cdot)l_t\right) > 0. \tag{11}$$

This may be a surprise result to standard analysis of interest-rate-targeting frameworks. Whenever short-term interest rate is an operational target of a central bank, the level of a reserve requirement, the argument goes, should not matter, because if it is high or low the required reserves will always be provided by the central bank so that short-term interest rates do not change. This argument, however, misses the point we described above: the distance between central bank refinancing needs and collateral base. Indeed, whenever reserve requirements increase, for instance, banks would need to borrow more, on average, from the central bank (given non-borrowed reserves aren't changed). This would reduce the amount of free collateral and, hence, increase the probability of reaching the collateral constraint in the future. The result would be a higher liquidity risk premium and loan interest rate. Therefore, when the collateral base isn't big enough, reserve requirements still matter, even in interest-rate-targeting frameworks. Yields on securities respond to reserve requirements similarly but with a different sign—when reserve requirements increase, yields on securities decline (as collateral service becomes more valuable).

**FX Interventions and Exchange Rates.** As discussed from the very beginning of this section, our model is a partial equilibrium one. The aim was to show how FX interventions affect domestic currency interest rates. But we can go one step further and discuss how the latter, in turn, can affect the exchange rate. For this we would need to introduce some other economic agent into our model, which determines the exchange rate. Following Cesa-Bianchi et al. (2019), just for the sake of exposition, we can assume that there are households that can hold both domestic currency as well as foreign currency deposits (the latter are issued by foreign banks). These households would then arbitrage and result in a certain form of a uncovered interest rate parity (UIP) condition. Cesa-Bianchi et al. (2019) assume that these two domestic and foreign currency deposits are imperfect substitutes—leading to a deviation from a textbook UIP. With this assumption we can arrive at what they call a monetary UIP condition[18] of the following form:

$$i_t - i_t^* = (E_t x_{t+1} - x_t) + m_t, \tag{12}$$

where $i_t$ and $i_t^*$ are domestic and foreign interest rates, while $x_t$ and $m_t$ are the exchange rate[19] and monetary spread, respectively, at time $t$. What's important is that in Cesa-Bianchi et al. (2019) the monetary spread is a function of deposits. Hence, in our case it means that $m_t = m(d_t)$ with $\frac{\partial m}{\partial d_t} > 0$. This implies that whenever more domestic currency deposits are created, the monetary spread increases and depreciates the exchange rate. The reasoning is that more domestic currency money means less relative convenience of it (relative to a foreign currency). Hence, domestic currency deposit holders should be compensated by higher interest rates or otherwise exchange rate would depreciate.

Now, the question is, how do we link FX interventions in our model and the exchange rate? This channel starts from the loan rate. For instance, when the central bank buys FX, it reduces the liquidity

[18]The main part of the equation is fairly standard: interest rate differential compensating for expected depreciation.

[19]Here increase means depreciation.

risk premium (as described above)—lowering the loan rate. Lower loan rate means more loan extension, which, in turn, means more deposit creation through the balance sheet identity. More deposits then increase the monetary spread $m_t$—putting depreciationary pressure on the exchange rate.[20]

**Collateral Base and Financial-Sector Efficiency.** As also mentioned above, making sure that the collateral base for central bank operations is sufficiently large not only minimizes interest rate effects of sterilized FX interventions, but it also leads to low liquidity risk on average. This may, in principle, be related to increased efficiency in the financial sector. However, this (widening the collateral base) is a difficult task unless the amount of near risk-free (e.g., government) securities is abundant enough or excessively high haircuts are applied on risky assets. Put differently, taking risky assets as a collateral for central bank operations, even if it reduces liquidity risk, is difficult for central banks, as it is a quasi-fiscal step.

**Loan Rates and Deposit Rates.** As would have been expected, the weighted average of the deposit rate and the policy rate is the major component of the loan rate. The weights depend on the public's demand for cash relative to deposits (i.e., deposit cash-out ratio $c$). The higher this ratio, the more the commercial banks need to borrow from the central bank (to satisfy deposit withdrawals) and, hence, the more their costs depend on the policy rate. On the other hand, in cashless societies, banks would no longer need central bank borrowing[21] after loan extension and, hence, the sole determinant of the loan rate (possibly in addition to liquidity risk premium) becomes the deposit rate.[22]

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[20]It may seem like the effect on the exchange rate is solely inherited from the Cesa-Bianchi et al. (2019) model, but this is not the case. While they show how more domestic currency deposits (private money) may depreciate the exchange rate, they are completely silent on how more FX reserves may result in more domestic currency deposits. The latter is what we show in this paper.

[21]Banks may still need to borrow from the central bank to satisfy reserve requirements, but this is a neutral operation in terms of banks' profit, as long as required reserves are fully remunerated.

[22]Deposit rate could still depend on the policy rate (due to competition from government bonds, money market mutual funds, or alike). Hence, while a higher cash ratio implies the direct impact of the policy rate on the loan rate, in cashless societies, all central banks can hope for is to affect loan interest rates mainly through deposit rates.

**Cash-to-Deposit Ratio and Liquidity Risk Premium.** A bit more unexpectedly though, deposit withdrawal rate also affects the liquidity risk premium. A higher cash ratio would mean higher need for central bank liquidity and, hence, may exacerbate the problem of collateral constraint. Therefore, the higher $c$, the higher is the liquidity risk premium (clearly, holding other factors constant). This can easily be seen by differentiating $i_t^l$ with respect to $c$ (not shown here).

**Government Debt: Crowding In vs. Crowding Out.** If, in the model equilibrium conditions, we explicitly impose a symmetry between banks and then aggregate, we would get a result where the liquidity risk premium depends on an aggregate amount of securities ($\bar{s}_t$). Increasing the amount of this kind of (near) risk-free securities, like government bonds, would reduce the liquidity risk premium, per the mechanism described above. But what's striking is that this means that a bigger government bond portfolio may support lower loan interest rates and, hence, more private borrowing (crowding in). This is in contrast to the classic crowding-out argument. To be sure, we do not rule out the possibility of crowding out. Instead, what we argue is that the bigger size of the government bond portfolio may lower the liquidity risk premium, even if crowding out may still happen as a result of a deliberate central bank reaction to fiscal expansion (i.e., central banks increasing policy rates in response to higher government deficits) or higher sovereign default risk premium.

**Liquidity Risk Premium and Monetary Transmission.** Here we assumed that $\bar{s}_t$ is exogenous. But if this problem were to be incorporated into a general equilibrium model, one could easily see that monetary policy transmission would also be working through the liquidity risk premium channel, on top of more traditional channels. For instance, an increase in the policy rate would reduce prices of securities and, hence, the size of their portfolio (marked to market). Lower size of portfolio $\bar{s}_t$ would then mean less distance until the collateral constraint and, therefore, a higher liquidity risk premium—reducing loan extension and aggregate demand.

**Money Market: Demand vs. Supply.** In our model we haven't emphasized banks' borrowings from each other on the money market, in addition to central bank borrowing. Can our model say more about the equilibrium money market rate that balances money demand and supply? In fact, collateralized borrowing on the money market is essentially the same in our model as accessing the central bank facility, because both have the same maturity and both are free of risk (because of collateral). Indeed, one can assume that each bank's borrowing $r_t$ includes the liquidity from the other banks on the money market. This means that collateralized borrowing on the money market has the same interest rate as the central bank facility—that is, the policy rate.

But, in the case of uncollateralized borrowing from other banks, that's what our model does not incorporate. If it did, what could be the resulting equilibrium interest rate on that market that makes sure the demand and supply are equal? Comparing our loans $l_t$ and that kind of borrowing on the money market makes it clear that interest rate on uncollateralized money market borrowing will be directly dependent on liquidity risk premium we discussed above, like $i_t^l$ does. For instance, when a central bank sells FX and reduces non-borrowed reserves, this makes the collateral constraint more probable to become binding in the future and makes the existing liquidity more valuable, resulting in an increase of interest rates on loans whether it's to non-financial clients or financial clients. Of course, this is in line with the situation when liquidity fears shoot uncollateralized interest rates on the money market up while corresponding collateralized ones remain stable and close to the central bank's policy rate.[23]

Hence, one of the reasons why we didn't explicitly incorporate this additional layer was that the implications would be similar. Also, we can assume a symmetry in the model, where banks have similar optimization problems and if there's a flight to liquidity all banks experience this and it's the central bank that has to satisfy this demand. Therefore, one way or another we end up with the problem of how much the central bank can satisfy this demand, which depends on the collateral base.

[23] Think of the liquidity fears during the global financial crisis—yields on securities no longer deemed a good collateral shot up significantly, even as policy rates and risk-free yields dropped down.

**Fractional vs. Full Reserve Banking.** Last but not least, the bank optimization problem above was for fractional reserve banking. If we had assumed that $rr = 1$, the model would have shown that in this case the stochastic component in our model vanishes and liquidity risk premium becomes zero when collateral constraint isn't binding and infinity when it is binding. In other words, the bank would no longer include any liquidity risk premium in its loan rate if it already has enough liquidity (including securities) to cover 100 percent of a newly created deposit, or if it doesn't it will just not extend the credit (which, in principle, is equivalent to imposing an infinitely high loan rate). As expected, switching from fractional banking to full reserve banking would seem to turn commercial banks into traditional intermediaries (as described by the loanable funds theory) instead of being the major creators of (deposit) money. For a related discussion, see Jakab and Kumhof (2019).

To sum up, the model, while simple, seems rich enough. Incorporating this liquidity risk channel into general equilibrium (e.g., DSGE) models shouldn't be difficult, as discussed above. What's more challenging is the solution of the resulting model, since the liquidity risk premium in our model is non-linear. Yet there is some work, including our own, that tries to deal with the issue of solving non-linear dynamic models (see Fernández-Villaverde, Rubio-Ramírez, and Schorfheide 2016 or Mkhatrishvili et al. 2019).

### *3.2 Empirical View*

The empirical literature, as discussed above, is somewhat limited on the effects of FX interventions on lending rates. According to our theoretical discussions, FX interventions on the purchase side, for example, could relax a collateral constraint and reduce liquidity risks along with lending rates. A few empirical papers do suggest that sterilized interventions could affect credit markets through heightening a risk-taking behavior on the side of a financial system. This could drive credit expansion, something related to lower interest rates (e.g., see Gadanecz, Mehrotra, and Mohanty 2014) as in our model. However, as shown in our analytic exercise, the channel through which FX interventions affect interest rates is different from those discussed in other papers. We show that this channel depends on the size of a central bank's collateral base. The question is, do we see this in the data?

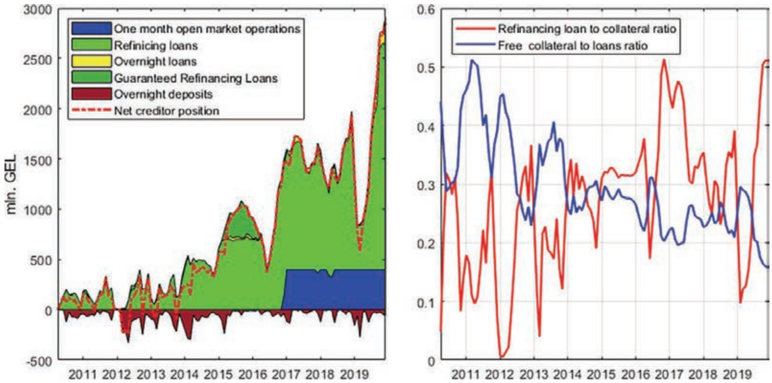
With this question in mind, we estimate a possible link between lending rates and freely available collateral (i.e., distance until the collateral constraint) in the banking system of the country of Georgia. The estimated transmission from the collateral constraint to lending rates, in turn, would be suggestive of the presence of FXI's effects on lending conditions, given that when the central bank conducts FX purchase (sell) operations it usually relaxes (tightens) the collateral constraint. To identify the above channel, our empirical strategy is somewhat similar to the literature on estimating determinants of lending rates (e.g., Almarzoqi and Ben Naceur 2015), but we further extend those empirical models by introducing freely available collateral (total amount of collateral minus borrowings from the central bank) in banks' balance sheets as an additional determinant of lending rates. To the best of our knowledge, this channel is not quantified in other empirical studies yet. Hence, we try to assess whether the amount of freely available collateral makes financial institutions more or less anxious about future liquidity risks, consequently changing rates on their loans. In other words, in case of an FX purchase by the central bank, for instance, we test "leveraging-up" effects of FX interventions.

To estimate the empirical relationship between the collateral base and loan interest rates, as mentioned, we include other standard control variables as well which could also contribute to the variation in loan interest rates of local currency loans in Georgia. In that sense, the equation estimated here is quite close to empirical models on interest rate determinants (see also Ho and Saunders 1981 or Saunders and Schumacher 2000). The estimated equation has the following form:

$$\lambda(a)i_t = \lambda(p)col_t + \lambda(q)x_t + \epsilon_t, \tag{13}$$

where $i_t$ is the interest rate on domestic currency loans (that includes all types of loans), while $col_t$ is a measure of the distance until the collateral constraint (available securities in the collateral base minus borrowings from the central bank). $\lambda(a)$, $\lambda(p)$, and $\lambda(q)$ are

**Figure 2. Monetary Policy Operations and Net Creditor Position of the NBG (left panel); Refinancing-Loans-to-Collateral and Free-Collateral-to-Loans Ratios (right panel)**




**Source:** National Bank of Georgia.

lag polynomials, while $x_t$ represents a set of control variables.[24] $\epsilon_t$ is a residual. We estimate two specifications of Equation (13): in the first specification we test whether the log of the ratio of freely available collateral (difference between collateral base and borrowings from the central bank) to loans in the local currency affects lending rates. Hence, we estimate constant elasticity of interest rate with respect to free collateral in the first specification. In the second one, we included the inverse of that ratio to estimate non-linear effects of the free-collateral-to-loan ratio on interest rates. All variables in our empirical exercise are expressed in percentage points, except the free-collateral-to-loan ratio (with the effect interpreted as a change in terms of basis points).

As mentioned above, our channel would most probably be more visible in a structural liquidity deficit scenario. This is indeed so in our case. Georgia moved to an inflation-targeting framework in 2009. Since then, as Figure 2 also shows, the net creditor position of and liquidity provision by the National Bank of Georgia (NBG) has

[24]Variable descriptions are provided below in the main text as well as in Appendix B.

been widening over time. Alongside this, freely available collateral has declined as measured either by the ratio of refinancing loans to collateral (which increased) or by the free-collateral-to-loans ratio (which decreased). The amount of collateral used in the calculation of the free collateral ratio includes all financial instruments eligible for monetary operations except loan assets. Given the fact that loan assets pledged as collateral must not be more than a certain fraction of debt securities (and have very high haircuts), their exclusion only effects the level of the collateral base but not its variation. In terms of the evolution of dependent as well as independent variables, their time-series graphs are provided in Appendix B. Worth noting is that a declining trend of loan interest rates (see Figure B.2 in Appendix B) could be related to the improved liquidity provision framework, among other factors.

As regards the control variables, to account for the *cost of funding and liquidity* we included (domestic currency) deposit and monetary policy rates in the equation. In addition, loan loss provisions (from the consolidated financial reports of commercial banks) are applied to control for *credit risk*.[25] Also, the ratio of non-interest income over assets in the banking system is used as a proxy for diversification of banks' activities. Theoretically, this may contribute to lower lending rates. To control for *macroeconomic risks* in our model, GDP growth, sovereign spread (the difference between yields on Georgia's government bonds issued in FX and U.S. government bonds with the same maturity), and CPI inflation were considered. Share of non-interest expenses is applied to account for the contribution of *overheads* in interest rates. To account for the effect of *market structure* on interest rate margins, proxies of competition are used such as Herfindahl-Hirschman (HH) and Lerner indices.[26] The ratio of equity to assets as well as the index of risk appetite from the survey on lending conditions are used to measure banks' *risk aversion* and its effects.[27] The average maturity of local currency loans,

[25]The ratio of non-performing loans to total loans was also tried, but the shortcoming of the indicator is its backward-lookingness in representing the credit risk.

[26]Based on our own calculations using financial reports of the commercial banks.

[27]However, it is questionable whether this index measures changes in banks' risk preference or reflects a variation in perceived risks. But even if we fail to

also included in the estimation, has an increasing trend in our case (see Figure B.1 in Appendix B), which, all else equal, could have an upward pressure on interest rates due to higher term premium. Despite the formal test of a unit root on lending rate suggesting the variable is trend stationary, we still include a time dummy to account for an accelerated decline of a spread between lending rates and the monetary policy rate after 2014. It seems reasonable to assume that all those controls would be sufficient to capture the net effect of collateral on interest rates.[28]

We estimate Equation (13) with a distributed lag model. Most of the variables are stationary processes, at least around a deterministic trend. We fail to show that the lending rate and free collateral are co-integrated—those variables are stationary processes around a deterministic trend. Hence, we include the trend in the estimated equation, while the variables which failed to be stationary around a deterministic trend are included in the equation in the form of first-order differences. Lag orders are selected based on Schwarz information criteria.[29] Heteroskedasticity and autocorrelation consistent (HAC) standard errors are applied for testing significance of the estimated coefficients.

Both of the estimated specifications suggest largely the same fit of the models to the data, but Specification 1 (constant elasticity of lending rates to free collateral ratio) implies a higher test statistic (for example, F statistics) to reject no relationship between the variables. However, significance levels are only marginally different from each other. An approximately same empirical fit of both of the specifications seems intuitive as long as we do not observe large shocks to the free collateral ratio when the non-linearities would be expected to kick in.

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account for the change in risk appetite (that moves interest rates and the amount of riskless assets in the same direction), the results would only underestimate the linkage we hope to prove, making our claim even more convincing.

[28] As a control, in the estimation we also tried accounting for the active dedollarization policy in Georgia that started in 2017; however, it didn't significantly change the results.

[29] The Akaike information criterion (AIC) suggested longer lag structure, but we ended up with the problem of autocorrelation in this case (probably, due to model misspecification).

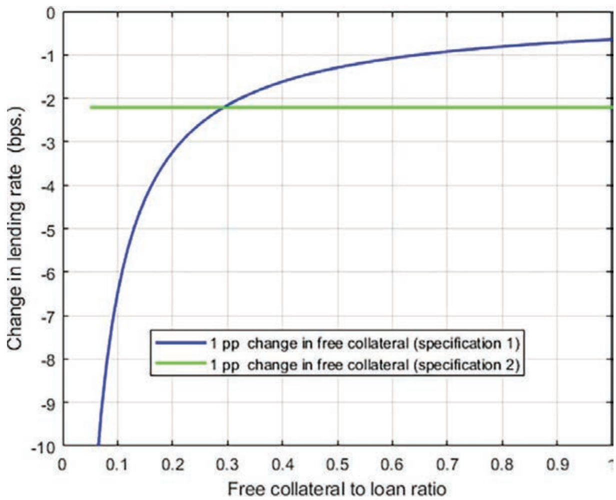
**Table 1. Results of the Estimated Distributed Lag Models**

| | **Specification 1** | **Specification 2** |
|---|---|---|
| Lending Rate(–1) | 0.288*** | 0.305*** |
| Lending Rate(–2) | 0.130* | 0.145* |
| Lending Rate(–3) | −0.110 | −0.114 |
| Lending Rate(–4) | 0.230*** | 0.245*** |
| Lending Rate(–12) | −0.158*** | −0.147*** |
| **Free-Collateral-to-Loan Ratio(–1)** | −1.367*** | |
| **Inverse Free Collateral Ratio(–1)** | | 0.366*** |
| Policy Rate | 0.154* | 0.201*** |
| Deposit Rate | 0.103 | |
| Reserve Requirement | 0.146 | 0.171* |
| d(maturity) | 2.549 | 2.914 |
| d(maturity(–1)) | −4.317* | −4.149* |
| Loan Loss Provision Ratio | −0.136 | −0.157 |
| Diversification | −2.718* | −2.834* |
| Non-interest Expense Ratio | 0.960 | 0.840 |
| d(HH Index) | 0.205** | 0.207** |
| GDP Growth | −0.130*** | −0.121*** |
| Sovereign Risk Premium | 0.393*** | 0.390*** |
| Time Dummy | −1.427*** | −1.396*** |
| Trend | −0.024** | −0.024** |
| Constant | 10.438*** | 10.324*** |
| F statistic | 150.5 | 128.5 |

**Note:** *≡ $0.05 \leq$ P-value $< 0.1$; **≡ $0.01 \leq$ P-value $< 0.05$; ***≡ P-value $< 0.01$. Definitions: Lending rate is a weighted average interest rate on Georgian lari (GEL) loans. Free-collateral-to-loan ratio is the total amount of collateral adjusted with refinancing loans divided by the total amount of lending in GEL by commercial banks; policy rate is the monetary policy (refinancing) rate, while deposit rate is an interest rate on deposits in GEL; reserve requirement is the minimum reserve ratio set by the NBG for GEL funding; maturity measures average maturity of loans in GEL; loan loss provision is the ratio of loan loss provisions to gross loans; diversification is the ratio of non-interest income to total assets, while non-interest expense ratio is a measure of non-interest expenses to total assets; HH index is the Herfindahl-Hirschman index calculated based on loan portfolios; GDP growth is year-on-year percentage change in GDP; sovereign risk premium is in bps.

The estimation results are shown in Table 1. As it shows, 1 percentage point (pp) change in free collateral ratio decreases the lending rate by 1.4 basis points (bps) on impact and by 2.2 bps in the long run, in the case of Specification 1. In Specification 2, the marginal effect of a 1 pp change in free collateral depends on the size of this ratio at the moment of the change (see Figure 3). For example,

**Figure 3. Change in Lending Rates Due to 1 pp Change in Free Collateral (as a function of the level of free collateral)**




**Source:** Authors' estimates.

if the ratio is 0.22 (as it was in Georgia at the end of 2019), then the lending rate decreases by 1.6 bps on impact and by 2.9 bps in the long run. These estimates are non-negligible and in line with our theory. As mentioned, since the impact of FX interventions on lending rates depends on the amount of free collateral in the second specification, we plot this relationship, between the effect (of FXIs) on lending rate, on the one hand, and the amount of free collateral, on the other, in Figure 3.

To put these numbers in perspective, we can consider the overall (partial-equilibrium) impact of this channel on lending rates in Georgia in 2015. Namely, FX interventions done by the NBG in 2015 contributed to higher lending rates—in a partial equilibrium sense the size of this effect, based on our empirical exercise, was close to 90 basis points, which is a significant effect,[30] in principle similar to

[30]The ratio of net FX sales to free collateral was about 40 percent at that time.

a sizable tightening in the monetary policy rate. Of course, in a general equilibrium sense it's difficult to directly infer what would have happened if our channel was absent, but this number just underlines the economic significance of our channel in Georgia, in addition to statistical significance.

Apart from the main result, in some cases the estimated coefficients of the banking-system-related variables are intuitive, but others seem against our prior beliefs: loan loss provisioning ratio, for example, is estimated to have a negative contribution to interest rates, while overheads have a positive but insignificant effect. On the other hand, the index of industry concentration has a positive impact on interest rates, as expected. The proxies of macroeconomic risks play an important role in the determination of interest rates as well. For instance, an increase in GDP growth by 1 pp reduces lending rates by 13 bps on impact, while a 1 pp shock to sovereign risk premium pushes lending rates up by 0.38 pp on impact and 0.62 pp in the long run.

As mentioned above, endogeneity problems may arise in the estimated equation if risk aversion is not properly treated—higher risk aversion pushes both lending rates as well as investments in risk-free assets up (Gadanecz, Mehrotra, and Mohanty 2014). We have applied several alternative proxies of risk aversion to fix the problem. First, we included equity-to-assets ratio (capital adequacy) and deviation of capital adequacy ratio from regulatory requirements. However, both of them were highly insignificant and made statistical properties of the estimated equation worse, while the estimates of the rest of the coefficients were not affected at all. Also, we applied a risk appetite indicator from the survey of lending conditions conducted by the NBG, but the results are not much different than in the former case. In addition, the sample size shrank further. Therefore, those proxies of risk aversion are not included in the final stage of the estimation. If those proxy variables are appropriate measures of unobserved risk aversion, then we can conclude that it doesn't have a significant simultaneous effect on lending rates and the amount of risk-free asset holdings. However, even if the above-mentioned indicators fail to adequately measure unobserved risk aversion, we can show that it could be a source of underestimation (not overestimation) of the linkage we try to prove, which is a negative impact of free collateral on lending rates.

Liquidity shocks, other than those related to collateral constraint, could be a source of a biased estimation too. For example, a run to liquidity could dry up freely available collateral and also increase lending rates at the same time. To control for liquidity shocks which are not directly driven by collateral constraint, we have included the cash-to-M3 ratio in the empirical model. However, the inclusion of the variable did not significantly change the effect of the collateral constraint. The sign of the effect was still in line with our theoretical predictions and remained significant (see Table B.1 in Appendix B). Also, instead of the free-collateral-to-loans ratio, we have applied the ratio of refinancing loans to collateral, to exclude a possible effect of an outstanding amount of loans on the magnitude of the channel in question (as loans are in the denominator in the regressor). Here as well, we still came up with the result that tightening of the collateral constraint implies higher lending rates and the effect is significant.

As an additional robustness check, we have estimated the same regression models (by applying the free-collateral-to-loans ratio as a proxy of the collateral constraint) by using interbank and government securities (T-bills and notes) interest rates as the regressand. The results are qualitatively the same. Namely, if the collateral constraint eases (free collateral increases), then interbank market rates decline. On the other hand, according to our theoretical discussion, the free-collateral-to-loans ratio is expected to have a positive effect on T-bills and notes yields. That is, when the collateral base is less binding, yields should go up. However, at first we failed to show this effect contemporaneously. The reason could be that maybe contemporaneous effects show movements along the supply curve of securities as a result of demand shocks—showing how quantities and prices (which are inversely related to yields) move together. To isolate the demand effects on yields, we have applied lagged values of the free-collateral-to-loans ratio (i.e., if the collateral has been binding, then it would be an indicator of high demand on securities in the next periods). With this we found that the third lag of the free-collateral-to-loans ratio has a positive impact on security yields.

We also tried to include the central bank's net FX purchases in our empirical models. The estimated coefficient of that additional variable was negative and significant, implying a negative effect of

FX purchases on lending rates, as expected by our theory. At the same time, the magnitude of the effect of the free collateral ratio to lending rates has decreased after the inclusion of that new variable (FXIs), which further encourages us to argue that FX interventions' effect on lending rates indeed works through tightening/relaxing the central bank collateral constraint.

As a final remark, the effects quantified in the empirical exercise seem robust across changes in model specifications as well as the definition of collateral constraint. However, more research is needed to explicitly identify episodes of shocks related to collateral constraint, given that our estimation strategy depends on the assumption that control variables are an exhaustive set of determinants of lending rates. Panel estimation seems to be a particularly fruitful area.

## 4. Conclusion

The literature has identified mechanisms through which sterilized FX interventions may affect exchange rates and a real economy. Yet, what it usually claims is that sterilized interventions work through currency or country risk premiums. The theory that we developed above, and provided some empirical support for, demonstrates an additional mechanism at work—a liquidity risk channel. This is tightly related to the available collateral that can be used for central bank operations: even when the collateral constraint isn't currently binding, if the collateral isn't sufficiently abundant banks may still fear (massive) deposit withdrawals that, in principle, can make the constraint start binding in the future. This fear, however, is reduced when banks get permanent liquidity from the central bank that buys FX as opposed to getting the same amount of liquidity by borrowing from the central bank (that uses up scarce collateral). Reduction in this fear will then result in loan interest rate reduction and, hence, more loan extension. This novel channel, working through loan interest rates, may also explain exchange rate effects of sterilized interventions. In addition, the theory above arrives at a number of other interesting results, e.g., related to reserve requirements. For future research it would be very interesting to see how important this channel would be if estimated based on a cross-country panel data.

Finally, despite a theoretical rigor and significant empirical evidence, there is one important caveat. It is very difficult to estimate a true size of the amount of unused collateral. Namely, sometimes FX of banks itself is part of a collateral base (but not always). In those cases our channel may shut down. Also, whenever commercial banks know that their central bank will find ways to expand a collateral base if needed, the banks may not have much liquidity risk fear even if the current collateral base is small. However, it is politically difficult for a central bank to take risky assets as collateral (since in that case it will essentially be conducting a quasi-fiscal operation). That's why we still think that our approach of calculating liquidity risk premium based only on near risk-less securities should be a good-enough approximation, at least in normal times.

## Appendix A. Deriving Loan Interest Rate Equation

First, let's reiterate the optimization problem with stationarized variables:

$$\max_{i_t^l(i),l_t(i),q_t(i),i_t^s(i),s_t(i),i_t^d(i),d_t(i),r_t(i)} \quad \begin{aligned} &\left(i_t^l(i)l_t(i) + \bar{\imath}_t q_t(i) + i_t^s(i)s_t(i)\right) \\ &- \left(i_t^d(i)d_t(i) + \bar{\imath}_t r_t(i)\right) \\ &- \delta_t(i)Prob(r_t(i) > s_t(i)) \end{aligned}$$

subject to

$$(i) \quad l_t(i) \leq \left(\frac{i_t^l(i)}{\bar{\imath}_t^l}\right)^{-\varepsilon^l} \bar{l}_t$$

$$(ii) \quad q_t(i) = rr \cdot d_t(i)$$

$$(iii) \quad s_t(i) \leq \left(\frac{i_t^s(i)}{\bar{\imath}_t^s}\right)^{-\varepsilon^s} \bar{s}_t$$

$$(iv) \quad i_t^d(i) \geq \frac{\varepsilon^d - 1}{\varepsilon^d}\bar{\imath}_t$$

$$(v) \quad l_t(i) + q_t(i) + s_t(i) = d_t(i) + r_t(i)$$

$$(vi) \quad r_t(i) = q_t(i) + c \cdot d_t(i) + \hat{e}_t - \bar{r}_t^{fx}$$

with all the variables as defined in the main text. We next form the Lagrangian function[31] in the following way[32]:

$$\begin{aligned}\mathcal{L} = &\left(i_t^l(i)l_t(i) + \bar{i}_t q_t(i) + i_t^s(i)s_t(i)\right) - \left(i_t^d(i)d_t(i) + \bar{i}_t r_t(i)\right)\\ &- \delta_t(i)\left(1 - \Phi\left(\bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}\cdot l_t(i)\right)\right)\\ &- \lambda_1\left(l_t(i) - \left(\frac{i_t^l(i)}{\bar{i}_t^{\,l}}\right)^{-\varepsilon^l}\bar{l}_t\right) - \lambda_2(q_t(i) - rr\cdot d_t(i))\\ &- \lambda_3\left(s_t(i) - \left(\frac{i_t^s(i)}{\bar{i}_t^s}\right)^{-\varepsilon^s}\bar{s}_t\right) + \lambda_4\left(i_t^d(i) - \frac{\varepsilon^d - 1}{\varepsilon^d}\bar{i}_t\right)\\ &- \lambda_5(l_t(i) + q_t(i) + s_t(i) - d_t(i) - r_t(i))\\ &- \lambda_6\left(r_t(i) - q_t(i) - c\cdot d_t(i) - \hat{e}_t + \bar{r}_t^{fx}\right)\end{aligned} \tag{A.1}$$

$$\left[i_t^l(i)\right]: \quad l_t(i) - \lambda_1\varepsilon^l\left(\frac{i_t^l(i)}{\bar{i}_t^{\,l}}\right)^{-\varepsilon^l}\bar{l}_t\frac{1}{i_t^l(i)} = 0 \tag{A.2}$$

$$\begin{aligned}[l_t(i)]: \quad & i_t^l(i) - \delta_t(i)\frac{rr+c}{1-rr}f\left(\bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}\cdot l_t(i)\right)\\ & - \lambda_1 - \lambda_5 = 0\end{aligned} \tag{A.3}$$

$$[q_t(i)]: \quad \bar{i}_t - \lambda_2 - \lambda_5 + \lambda_6 = 0 \tag{A.4}$$

$$[i_t^s(i)]: \quad s_t(i) - \lambda_3\varepsilon^s\left(\frac{i_t^s(i)}{\bar{i}_t^{\,s}}\right)^{-\varepsilon^s}\bar{s}_t\frac{1}{i_t^s(i)} = 0 \tag{A.5}$$

$$\begin{aligned}[s_t(i)]: \quad & i_t^s(i) + \delta_t(i)f\left(\bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}\cdot l_t(i)\right)\\ & - \lambda_3 - \lambda_5 = 0\end{aligned} \tag{A.6}$$

$$\left[i_t^d(i)\right]: \quad -d_t(i) + \lambda_4 = 0 \tag{A.7}$$

[31] To make notation easier, each Lagrange multiplier $\lambda$ means a multiplier at time $t$.

[32] By combining the constraints (ii), (v), and (vi) and using the definition of cumulative distribution function (CDF), we can write $Prob(r_t(i) > s_t(i)) = Prob\left(\hat{e}_t > \bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}l_t(i)\right) = 1 - \Phi\left(\bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}l_t(i))\right)$.

$$[d_t(i)]: \quad -i_t^d(i) + \lambda_2 rr + \lambda_5 + \lambda_6 \cdot c = 0 \tag{A.8}$$

$$[r_t(i)]: \quad -\bar{i_t} + \lambda_5 - \lambda_6 = 0 \tag{A.9}$$

$$\lambda_1 \left( l_t(i) - \left( \frac{i_t^l(i)}{\bar{i}_t^l} \right)^{-\varepsilon^l} \bar{l_t} \right) = 0 \tag{A.10}$$

$$\lambda_3 \left( s_t(i) - \left( \frac{i_t^s(i)}{\bar{i}_t^s} \right)^{-\varepsilon^s} \bar{s_t} \right) = 0 \tag{A.11}$$

$$\lambda_4 \left( i_t^d(i) - \frac{\varepsilon^d - 1}{\varepsilon^d} \bar{i_t} \right) = 0. \tag{A.12}$$

And, $\lambda_1 \geq 0$, $\lambda_3 \geq 0$, $\lambda_4 \geq 0$.

Note that constraints (i), (iii), and (iv) should be binding; otherwise, $\lambda_1 = 0$, $\lambda_3 = 0$, and $\lambda_4 = 0$ to satisfy first-order conditions. With that, (A.2), (A.5), and (A.7) imply $l_t(i) = 0$, $s_t(i) = 0$, and $d_t(i) = 0$, which we exclude as possibilities in our model and set $\lambda_1 > 0$, $\lambda_3 > 0$, and $\lambda_4 > 0$. Therefore, constraints (i), (iii), and (iv) become automatically binding.

From Equation (A.2):

$$\lambda_1 = \frac{1}{\varepsilon^l} i_t^l(i). \tag{A.13}$$

Equation (A.13) together with (A.3) implies

$$i_t^l(i) = \frac{\varepsilon^l}{\varepsilon^l - 1} \left( \lambda_5 + \frac{rr + c}{1 - rr} \delta_t(i) f \left( \bar{r_t}^{fx} + s_t(i) - \frac{rr + c}{1 - rr} \cdot l_t(i) \right) \right). \tag{A.14}$$

By combining (A.4) and (A.8) we get

$$\lambda_5 = \frac{1}{1 + c} {i_t}^d(i) + \frac{c}{1 + c} \bar{i_t} - \frac{c + rr}{1 + c} \lambda_2 \tag{A.15}$$

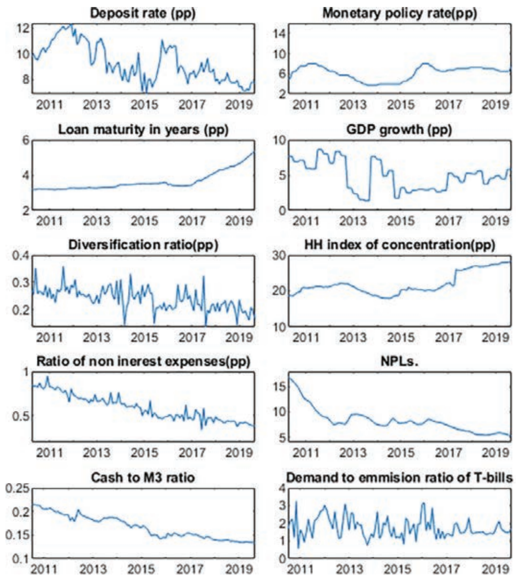
and

$$\lambda_6 = \frac{1}{1 + c} ({i_t}^d(i) - \bar{i_t}) + \frac{1 - rr}{1 + c} \lambda_2. \tag{A.16}$$

Putting (A.15) and (A.16) in Equation (A.9) implies that $\lambda_2 = 0$. Then by combining Equations (A.14) and (A.15), we get the optimality condition for the lending rate given by the equation shown in the main text. The same steps can be applied to derive the equilibrium yield on bonds.

## Appendix B. Data and Robustness Checks

### Figure B.1. Control Variables




### Figure B.2. Lending, T-bill, and Interbank Rates

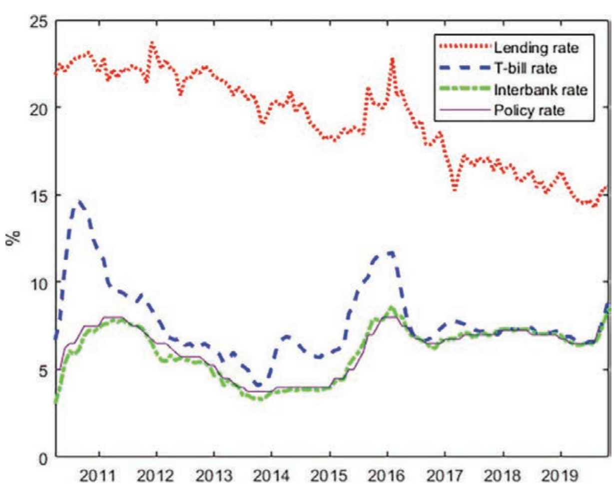
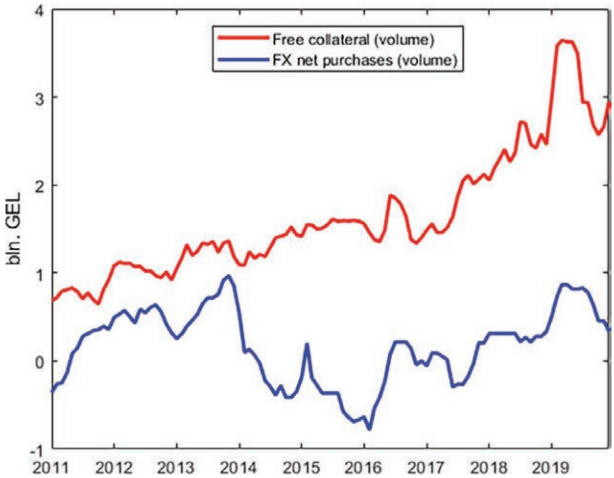


**Figure B.3. Amount of Free Collateral and FX Net Purchases[33]**




[33]The volume of net FX purchases over a 12-month rolling window, as interventions would have a cumulative effect on the amount of free collateral.

## Table B.1. Alternative Specifications and Extensions

| | Specification 1A | Specification 1B | Specification 3 | Specification 4 |
|---|---|---|---|---|
| Lending Rate(–1) | 0.402*** | 0.456*** | | |
| Lending Rate(–2) | 0.158** | | | |
| Lending Rate(–3) | −0.098 | | | |
| Lending Rate(–4) | 0.257*** | | | |
| Lending Rate(–12) | −0.258*** | −0.197*** | | |
| Interbank Rate(–1) | | | 0.525*** | |
| T-bills Rate(–1) | | | | 1.080*** |
| T-bills Rate(–2) | | | | −0.313*** |
| Refinancing-Loans-to-Collateral Ratio(–1) | | 0.155** | | |
| Free-Collateral-to-Loan Ratio(–1) | −1.274*** | | −0.36** | |
| Free-Collateral-to-Loan Ratio(–3) | | | | 0.441** |
| Policy Rate(–1) | 0.033 | 0.069 | 0.522*** | 0.540*** |
| Policy Rate(–2) | | | 0.308* | 0.249 |
| Policy Rate(–3) | | | −0.354*** | −0.489* |
| Policy Rate(–4) | | | | 0.211 |
| Deposit Rate | 0.154** | 0.203*** | | −0.310 |
| Reserve Requirement | | | 0.017 | |
| d(maturity) | 2.809 | 0.803 | | |
| d(maturity(–1)) | −4.901* | −4.151* | | |
| Loan Loss Provision Ratio | −0.344*** | −0.155* | | |
| Diversification | −4.171*** | −2.559* | | |
| Non-interest Expense Ratio | 1.873 | | | |
| d(HH Index) | 0.143 | 0.206*** | | |
| GDP Growth | −0.111*** | −0.118*** | −0.007 | −0.063** |
| GDP Growth(–1) | | | | 0.041 |
| Sovereign Risk Premium | 0.356*** | 0.432*** | 0.014 | 0.140** |
| Cash-to-M3 Ratio | 0.266** | −0.043 | −1.418 | |
| Cash-to-M3 Ratio(–1) | | 0.119 | | |
| T-bills Demand | | | | −0.142 |
| Inflation | | | | 0.042 |
| Inflation(–1) | | | | −0.044 |
| Time Dummy | | −1.971*** | 0.034 | |
| Trend | −0.022 | −0.026** | −0.001 | |
| Constant | 5.072 | 13.494*** | −0.361 | 1.305*** |

**Note:** *≡ 0.05 ≤ P-value < 0.1; **≡ 0.01 ≤ P-value < 0.05; ***≡ P-value < 0.01. Definitions: Specification 1A is Specification 1 extended with cash-to-M3 ratio as an additional control variable; Specification 1B applies refinancing loans to collateral as a measure of the collateral constraint. Specification 3 is the model where dependent variable is interbank rate, and Specification 4 estimates an effect of collateral constraint on T-bills rates. In addition to control variables defined in the main text, here are some additional variables to mention: Cash to M3 is the ratio of the cash outside of banks to M3 money aggregate; also, T-bills demand is the ratio of demand on T-bills and notes to the issuance volume (sum of the issuance volume and demand in a given month is used in the calculation of the ratio).

## Appendix C. Key Model Assumptions

Here we summarize all key modeling assumptions.

General Assumptions of the Model:

- Monopolistic competitive market structure of banking sector with (infinitely) many banks.
- Banks are making decisions on the allocation of resources at the beginning of the period to maximize profits at the end of that period.
- Three possible time instances: $t$, $t'$, and $t+1$. In time instant $t$, banks are making decisions on how to plan their business while in $t'$ depositors are deciding how much cash to withdraw from banks and, therefore, banks have to decide how much refinance loans they need from the central bank. We assume that time instances $t$ and $t'$ are practically the same.
- No term premium, as we discuss only one time period.
- Banks are risk neutral.
- Model variables follow a balanced-growth path (trend).
- Liquidity shock is assumed to be (trend) stationary.

Loan Market and Central Bank Framework:

- CES-type demand schedule for loans, where aggregate demand on loans is exogenously given.
- Interest rate accrued on refinancing loans equals the policy rate ($\bar{i_t}$).
- Reserve balances, which are required, are remunerated with the policy rate ($\bar{i_t}$) by the central bank.
- Excess reserves are remunerated at zero.
- Reserve requirements are assumed to be in the interval $0 \leq rr < 1$.

FXI and Bond/Deposit Markets:

- Each FX intervention is equally distributed across banks over the interval [0,1].
- Monopolistic competitive banks are the only primary dealers on the government securities market.

- CES-type demand schedule for bonds, where aggregate demand for bonds is exogenously given. For further discussion, see footnote 5 in Section 3.1.1.
- Banks have closed FX position.
- Deposit demand restricts banks from setting interest rates below the policy rate by more than a markdown $\frac{\varepsilon^d - 1}{\varepsilon^d}$.

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# Still "Too Much, Too Late": Provisioning for Expected Loan Losses*

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The new accounting standards of IFRS 9 and U.S. GAAP adopt the expected loss (EL) approach for loan loss recognition. We investigate the effect of the EL approach on bank loan supply and stability. When a bank is unable to anticipate a downturn in the business cycle, it ends up recognizing the bulk of expected losses *after* the arrival of a contraction. This aggravates lending procyclicality and can potentially worsen bank stability. We develop a dynamic model of a bank to quantitatively assess these effects and show that they are economically significant.

JEL Codes: G21, G28, M41, M48.

## 1. Introduction

To ensure an accurate assessment of their overall financial positions, banks periodically account for anticipated future loan losses through loan loss provisions. In doing so, they must comply with accounting standards for loan loss recognition. The recent financial crisis spurred

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criticism of the then-existing standards, which were based on the incurred loss (IL) approach. This approach limited loss recognition only to those losses that were factually identified (i.e., incurred) before the balance sheet date. As these standards led to delayed provisioning and insufficient loan loss reserves, they were blamed for contributing to the credit crunch (Financial Stability Forum 2009). The policy response was to adopt a more "forward-looking" provisioning approach based on *expected* rather than incurred credit losses.[1] Under the expected loss (EL) approach, banks' provisions constitute unbiased estimates of future losses over a specified horizon. The new accounting standards of IFRS 9 and the new U.S. GAAP replace the IL approach with the EL approach.

The objective of this paper is to quantify the long-term effect of the EL approach on the cyclicality of bank lending and stability. As a rationale for the adoption of the EL approach, the Financial Stability Forum (2009) states that "earlier recognition of loan losses could have dampened cyclical moves in the current crisis and is consistent both with financial statement users' needs for transparency regarding changes in credit trends and with prudential objectives of safety and soundness." However, there is a shared concern among academics, policymakers, and market participants that the EL approach may actually have a strong procyclical effect (Barclays 2017, European Systemic Risk Board 2017, Abad and Suarez 2018). If banks fail to anticipate a downturn in the business cycle, they recognize the bulk of expected losses *after*, and not before, the arrival of a contraction. This leads to a spike in provisions right at the start of a contraction, which erodes banks' profit margins and, unless they can swiftly raise fresh equity, reduces their lending capacity. Such a

[1]The G-20 summit in London on April 2, 2009 resulted in signing the Declaration on Strengthening the Financial System, which included the following reforms among others: strengthen accounting recognition of loan loss provisions by incorporating a broader range of credit information and improve accounting standards for provisioning. The International Accounting Standards Board (IASB) and the U.S. Financial Accounting Standards Board (FASB) set in motion a joint project to improve accounting standards and, in particular, to develop methods of accounting for credit losses that would give more timely recognition of those losses, thereby helping to reduce lending procyclicality. This effort resulted in the International Financial Reporting Standard (IFRS) 9 and the credit loss standard (ASC 326) under the U.S. GAAP (generally accepted accounting principles), both of which adopt the expected credit loss approach.

sudden front-loading of losses at the dawn of a contraction could not only force banks to cut new loans but also jeopardize their stability.

From a macroprudential point of view, bank procyclicality is widely viewed as undesirable by both academics and policymakers (Hanson, Kashyap, and Stein 2011).[2] The effort to reduce the procyclical effect of risk-based capital regulation led to the revision of the Basel Accords in the form of the new Basel III regulation, which includes policy instruments designed to reduce lending procyclicality.[3] The EL approach can potentially undermine the post-crisis regulatory effort to reduce bank procyclicality and is likely to be inefficient from a macroprudential point of view.

To quantify the effect of the EL approach, we adopt a structural, rather than reduced-form, approach.[4] We develop a dynamic model of a bank. Our model features endogenous loan origination, distribution, leverage, and default. The bank faces corporate taxes, the cost of issuing external equity, and regulation. The regulatory environment comprises a minimum capital requirement and provisioning standards. The capital structure of the bank consists of fully insured short-term deposits and equity. The asset side is composed of risky long-term loans with stochastic and time-varying default probabilities.

First, we calibrate our model under the benchmark provisioning requirement, which is based on the IL approach of the International Accounting Standards (IAS) 39. Next, we solve our model under two variations of the EL approach, namely the expected credit loss (ECL) of IFRS 9 and the current expected credit loss (CECL) of the

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[2]The literature on *optimal* time-varying capital requirements provides much support in favor of a countercyclical capital regulation (i.e., procyclical capital requirements), which helps to smooth the cyclicality of credit supply (see Kashyap and Stein 2004, Dewatripont and Tirole 2012, Repullo 2013, Gersbach and Rochet 2017, and Malherbe 2020, among others). Empirical evidence further suggests that a countercyclical capital regulation indeed helps to reduce credit crunch (Jiménez et al. 2017).

[3]Basel III instruments such as the countercyclical capital buffer, the conservation capital buffer, and contingent capital are all meant to reduce lending procyclicality.

[4]An empirical investigation using a reduced-form approach would require data that include a full credit cycle under the EL approach. However, such data are not available, since the accounting standards that adopt the EL approach either have only recently been put in effect (i.e., IFRS 9) or are still planned to be implemented (U.S. GAAP).

new U.S. GAAP.[5] We compare the solutions of the model under the two versions of the EL approach to the benchmark case.

Our quantitative results indicate that the adoption of either version of the EL approach results in a profound aggravation of lending procyclicality in the long run. Our model predicts that, on average, in a contraction, a bank originates about 6–7 percent fewer new loans under the EL than the IL approach. At the same time, unconditional on the aggregate state, the bank's lending is only about 2–3 percent lower under the EL approach. This highlights the strong procyclicality of the EL approach, as it disproportionately reduces lending in a contraction.

We further examine the procyclicality of the EL approach when a bank is subject to the countercyclical capital buffer (CCyB), which is a new Basel III policy that explicitly aims at reducing procyclicality. We find that the CCyB is unable to fully offset the procyclical effect of the EL approach—that is, the simultaneous adoption of the EL approach and CCyB also results in more procyclical lending than under the benchmark. The magnitudes, however, are attenuated. Furthermore, even when we allow the bank's profits to respond with a one-period delay to the arrival of a contraction, which effectively allows the bank to anticipate the deterioration of its balance sheet, the procyclical effect of the EL approach still persists.

Next, we show that when it comes to the effect of the EL approach on banks' stability there are two effects in play. On the one hand, under the EL approach, a bank holds larger loan loss reserves since on top of the incurred losses it must also recognize expected losses. Larger reserves provide better loss-absorption capacity, thus improving stability. On the other hand, the procyclicality of the EL approach effectively increases the volatility of the bank's profits. This, in turn, increases the bank failure rate. The overall effect of the EL approach on stability will depend on the relative strength of these two effects. Our quantitative model suggests that IFRS 9 is more likely to increase bank failure rate than U.S. GAAP. While their

[5] The primary difference between these models is that they adopt different horizons over which expected losses must be recognized. IFRS 9 is based on a mixed-horizon approach such that, depending on the loan's risk category, the bank recognizes either one-year or lifetime discounted expected losses. The new U.S. GAAP, on the other hand, requires banks to recognize lifetime discounted expected losses on all loans.

procyclical effect on lending is similar, IFRS 9 produces smaller loan loss reserves than U.S. GAAP, due to its mixed-horizon approach.

Our analysis indicates that earlier recognition of losses does not per se help to smooth lending cyclicality. It matters how early in advance future losses are recognized. If future losses were to be recognized before the arrival of a contraction, this would result in a precautionary capital buffer, which would then help to smooth lending in a downturn. For example, the Spanish dynamic loan loss provisioning approach, which prescribed higher provisions in expansions relative to contractions, allowed the banks to effectively build up a capital buffer during good times and consequently smooth lending when the contraction arrived (Jiménez et al. 2017).[6] In contrast, under the EL approach, banks will recognize the bulk of expected losses *after* the arrival of a contraction, provided they cannot anticipate the change in the aggregate state well in advance. Thus, forcing banks to recognize their future losses based on the EL approach is equivalent to imposing a more *countercyclical* capital requirement. It is well understood that a countercyclical capital requirement results in more procyclical lending (Kashyap and Stein 2004; Repullo, Saurina, and Trucharte 2010).

Our paper contributes to several strands of the literature. First, our paper relates to a large literature on the cyclical implications of bank regulation. Kashyap and Stein (2004) provide a formal analysis of the procyclical effect of capital regulation on bank lending and advocate for more procyclical capital requirements than those of Basel II. Similarly, in a dynamic model of banking, Repullo and Suarez (2013) show that procyclical adjustment to the Basel II capital requirements are welfare-improving. In general, the theoretical literature provides a vast support in favor of procyclical capital requirements (Dewatripont and Tirole 2012; Repullo 2013; Gersbach and Rochet 2017; Malherbe 2020). Empirical evidence further indicate that more procyclical capital requirements indeed help to smooth bank lending better (Behn, Haselmann, and Wachtel 2016; Jiménez et al. 2017). While this literature examines the cyclical effect of capital regulation, we focus on the cyclical effect of loan loss provisioning requirements. We show that adopting the EL approach for

[6]This approach is very similar to a countercyclical capital buffer policies such as CCyB.

loan loss recognition is similar to imposing a more countercyclical capital requirement.

Second, our paper contributes to the literature on bank loan loss provisioning. While the empirical literature on loan loss provisioning is relatively large (Ahmed, Takeda, and Thomas 1999; Laeven and Majnoni 2003; Beatty and Liao 2011; Bushman and Williams 2015; Huizinga and Laeven 2018), the theoretical literature is rather scarce. To the best of our knowledge, our paper is the first one to formally examine the effect of the provisioning requirement for future losses on bank loan supply and stability.

Third, our paper contributes to the literature that studies the cyclical impact of the expected credit loss approach of the new accounting standards. Early concerns about the potential procyclicality of the expected loss approach can be found in Laux (2012), Barclays (2017), and European Systemic Risk Board (2017). A few papers provide a quantitative assessment of the cyclical implications of the EL approach on capital and provisions. Krüger, Rösch, and Scheule (2018) show that had the banks followed the EL approach, they would have had lower levels of capital, especially during the 2007–08 crisis, and the bank capital would have been more procyclical. Under the assumption that the bank can anticipate the turn in the business cycle, Cohen and Edwards (2017) and Chae et al. (2019) show that the EL approach achieves better smoothing of provisions compared to the IL approach. Abad and Suarez (2018) quantify the procyclical effect of the EL approach on bank capital in a dynamic model of a bank with exogenous lending and heterogeneous loans. In our paper, we evaluate the effect of the EL approach on loan supply and bank stability under the bank's optimal behavior, as our settings allow for endogenous lending, financing, and default. Thus, our analysis is less prone to the Lucas critique, since we allow the bank to optimally respond to the adoption of the EL approach.

Finally, our paper broadly relates to the growing literature on the interaction between accounting practice, on the one hand, and financial stability and prudential regulation, on the other (see Goldstein and Sapra 2014 and Acharya and Ryan 2016 for a survey). Laux and Leuz (2010) provide critical analysis of the role of fair-value accounting in the recent financial crisis. Mahieux, Sapra, and Zhang (2023) examine the effect of mandatory earlier loss recognition on bank risk-taking. We contribute to this literature by pointing out that provisioning rules and capital regulation are two sides of the same coin and, thus, should not be designed independently.

The rest of the paper proceeds as follows. Section 2 provides institutional details on provisioning, the expected loss models of IFRS 9, and the new U.S. GAAP. Section 3 introduces a simple three-date model of a bank to highlight the economic mechanism through which the EL approach affects bank lending and stability. Section 4 presents a quantitative dynamic model of a bank, while the calibration of the model is found in Section 5. Section 6 contains the quantitative analysis and results of the long-term effect of adopting provisioning requirements based on the EL approach. Finally, Section 7 concludes.

## 2. Institutional Details

A loan loss provision is a non-cash expense set aside as an allowance for impaired loans. It is an accounting entry that increases loan loss reserves (a contra asset account on the balance sheet) and reduces net income. Empirically, such provisions constitute a large fraction of bank expenses (Huizinga and Laeven 2018). As a result, they substantially reduce a bank's profit in financial statements, thereby affecting regulatory capital. In the future, when the losses realize, they are charged off against the loss reserves. The rules for loan loss provisioning for internationally active banks and U.S.-based banks are formulated by the International Accounting Standards Board (IASB) and the U.S. Financial Accounting Standards Board (FASB), respectively.

The International Accounting Standards (IAS) 39, which was effective until the end of 2017, employed the so-called incurred loss model (ILM) for loan loss recognition. The ILM did not allow banks to recognize credit losses based on the events expected to happen in the future. Under the ILM, it was assumed that all loans would be repaid until the evidence to the contrary is established. Only at that point, the impaired loan (or portfolio of loans) could be written down to a lower value. Therefore, only those losses that were factually documented could be recognized.

In the aftermath of the financial crisis of 2007–08, IAS 39 was criticized for potentially contributing to the credit crunch, as it did not allow for timely loss recognition (Financial Stability Forum 2009). The policy response was to adopt a more "forward-looking" provisioning approach based on *expected* rather than incurred credit losses. To reduce the procyclical effect of provisioning and improve transparency, the IASB and the FASB created new accounting standards. Each of these standards introduces its own version of the expected loss model (ELM). IFRS 9 replaced IAS 39 in January 2018, while the implementation of the new U.S. GAAP was planned for the end of 2020 but has been delayed due to the COVID-19 pandemic.[7]

Under the ELM, banks' provisions must constitute *unbiased* estimates of future losses over a specified horizon. The defining feature of the ELM is that it employs the so-called point-in-time (PiT) loan default probabilities when estimating expected credit losses. That is, expected losses are estimated not just based on historical data but also with the incorporation of all presently available relevant information.[8] Thus, under the ELM, banks must employ statistical inference to provide an unbiased estimate of expected loan losses taking into account all currently available information.

The model of IFRS 9 adopts a mixed-horizon approach: either one-year or lifetime discounted expected losses are recognized depending on the risk category of loans. The bank must recognize one-year discounted expected losses on stage 1 (good-quality) loans and lifetime discounted expected losses on stage 2 (sub-quality) loans.[9] The current expected credit loss (CECL) model of the new U.S. GAAP adopts a lifetime horizon for the entire portfolio of loans irrespective of their credit risk. Moreover, whereas under IFRS 9 expected losses are discounted at the loan's contractual interest

[7]The adoption of IFRS 9 is still in the transitional period especially due to the COVID-19 pandemic (see Borio and Restoy 2020 for details).

[8]For example, according to the IFRS 9, "an entity shall adjust historical data, such as credit loss experience, on the basis of current observable data to reflect the effects of the current conditions and its forecasts of future conditions that did not affect the period on which the historical data is based and to remove the effects of the conditions in the historical period that are not relevant to the future contractual cash flows" (paragraph B 5.5.52 in IASB 2014).

[9]IFRS 9 also specifies stage 3 loans, which are non-performing loans (NPLs). The accounting treatment of such loans under IFRS 9 is similar to that of incurred losses under IAS 39.

rate, banks can use their own discount rates under the new U.S. GAAP.

## 3. A Simple Model

### 3.1 Setup

There are three dates labeled as $t = 0, 1, 2$. At $t = 0$, the bank starts with an initial equity endowment of $E_0 > 0$. At $t = \{0, 1\}$ the bank's risk-neutral manager maximizes the present value of expected future dividends by investing in a risky portfolio of loans $L_t$, which matures over one period at $t + 1$. The loan portfolio $L_t$ has a stochastic net repayment rate $r^L_{t+1} \sim \mathcal{N}(\mu_t, \sigma_t)$. The loan portfolio is funded with the bank's equity capital $E_t$ and one-period deposits $B_t$. Deposits are assumed to be fully insured, with the deposit insurance priced at a flat rate normalized to zero.[10] To keep the model simple, both the deposit repayment rate and the discount rate are set to zero.

The bank operates in a regulatory environment characterized by the capital regulation and provisioning requirement for expected future loan losses. In the model, the minimum capital requirement serves to minimize the probability of bank failure, thus minimizing the implicit cost of the deposit insurance. When investing in loan portfolio at $t$, at least a fraction of $\kappa_t \in [0, 1]$ of the portfolio must be financed with equity—that is, the minimum capital requirement takes the standard form of

$$E_t \geq \kappa_t L_t. \tag{1}$$

The provisioning requirement for future loan losses is specified in terms of a requirement on loan loss reserves. Specifically, the provisioning requirement stipulates that when the bank originates new loans, $L_t$, the expected losses on the entire portfolio must be recognized. Let the expected losses on portfolio $L_t$ be $\theta_t L_t$, where

[10]When the bank fails, it defaults on deposits and their interest. In that case, the deposit insurance agency fully repays the depositors the principal and the interest. Therefore, although from the point of view of the insurance agency deposits are risky, from the point of view of depositors these are risk-free claims.

$0 \leq \theta_t < 1$ is the expected loss rate; then the bank's loss reserves $R_t$ are given by[11]

$$R_t = \theta_t L_t. \tag{2}$$

Consequently, once the investment and provisioning have been made, the bank's balance sheet identity is given by

$$L_t - R_t = B_t + E_t. \tag{3}$$

The bank's profits are subject to corporate taxes. To account for loss limitations, the bank's profits are taxed at the marginal tax rate $\tau > 0$ when the profits are positive, while the tax rate is zero when the profits are negative.[12] Therefore, the corporate tax rate is a function of the bank's profits $\pi_t$ is given by

$$\tau\left(\pi_t\right) = \tau \mathbb{I}_{\pi_t > 0}, \tag{4}$$

where $\mathbb{I}_{\pi_t > 0}$ denotes an indicator functions which is equal to one when $\pi_t > 0$ and zero otherwise.

Raising equity externally is assumed to be prohibitively expensive. Thus, the bank can increase its equity capital only internally—via profit retention. The bank is subject to limited liability constraint—if the value of its equity drops below zero, the bank optimally defaults generating a zero payoff to the shareholders.

Finally, we introduce the last two ingredients into our model, which are important for the analysis of the expected provisioning requirement. First, we assume that at $t = 2$ the economy is characterized by the aggregate state $s_2$, which is either good, $s_2 = g$, or bad, $s_2 = b$. The aggregate state affects the expected loan repayment rates at $t = 2$: under the good aggregate state the expected

[11]It is important to stress that in our model the loan loss reserves $R_t$ are composed of only provisions for expected credit losses and not of realized ones. In practice, banks also keep loan loss reserves against realized losses. However, since our analysis is on the requirement for recognition of expected loss, we assume that the bank does not hold reserves against realized losses—that is, the realized losses are written off immediately as they are realized without being accumulated in the form of non-performing loans.

[12]We follow Hennessy and Whited (2007), who adopt this parsimonious approach to model a corporate tax schedule that accounts for loss limitations. Loss limitations are introduced as a kink in the tax schedule producing convexity.

loan repayment is higher than under the bad one. Furthermore, we assume that at $t = 1$ the bank receives a signal $z_1$ over the aggregate state at $t = 2$, which is either good, $g$, or bad, $b$. The signal is informative in that $P(s_2 = a|z_1 = a) > P(s_2 = a)$ for $a \in \{g, b\}$. As discussed in the previous section, under the expected provisioning requirement the bank incorporates all presently available information to estimate and recognize expected losses. Thus, the expected provisioning rate at $t = 1$ depends on the signal and, thus, is denoted as $\theta_{1|z}$. Since the expected provisioning rate effectively corresponds to an expected loss rate, it follows that $\theta_{1|g} < \theta_{1|b}$.

### *3.2 Solution*

The model is solved backwards starting at $t = 2$. The $t = 2$ profits are given by

$$\pi_2 = (1 - \tau(\pi_2)) \left[ r^L_{2|s} L_{1|z} + R_1 \right], \tag{5}$$

where the first term is the net repayment on loan portfolio, $L_{1|z}$, and the second term captures the fraction of losses on the portfolio that has already been recognized via provisioning at $t = 1$. Since the world ends at $t = 2$, the manager uses all available funds to pay out the dividend. Thus, the $t = 2$ dividend $X_2 = \pi_2 + E_1$. If $X_2 < 0$, which happens under a relatively low realization of $r^L_{2|s}$, then the bank fails at $t = 2$, in which case the value of the bank is zero due to the limited liability constraint.

At $t = 1$, the bank's manager maximizes the sum of the $t = 1$ dividend and the next period dividend, provided the bank does not fail $t = 1$, which happens under a low realization of $r^L_1$.[13] That is, the problem is given by

$$\begin{aligned} V_1 = &\max_{\{L_1\}} \left\{ X_1 + \mathbb{E}\left[X_2 | z_1, X_2 > 0\right] \right\}, \\ &\text{subject to} \quad X_1 \geq 0, \end{aligned} \tag{6}$$

[13]The bank fails at $t = 1$ if $X_1 < 0$, even if the bank does not lend—that is, $L_{1|z} = 0$.

where, from a basic accounting identity, the $t = 1$ dividend is given by

$$X_1 = E_0 + \pi_1 - E_1, \tag{7}$$

and the $t = 1$ after-tax profits are given by

$$\pi_1 = (1 - \tau(\pi_1)) \left[ r_1^L L_0 + R_0 - R_1 \right], \tag{8}$$

where the first term inside the square bracket is the net repayment on the initial loan portfolio $L_0$, and the last two terms capture provisioning for expected losses.

If the bank does not fail at $t = 1$—that is, if the realization of $r_1^L$ is sufficiently high—then conditional on the realization of the signal $z_1$ the bank chooses its optimal loan portfolio $L_{1|z}$. Since the bank is protected by the limited liability constraint, the expected $t = 2$ dividend is always positive, $\mathbb{E}[\max\{0, X_2\}] > 0$, and increasing in $L_{1|z}$. Therefore, it is straightforward to show that the manager invests as much as possible in $L_{1|z}$ until $X_1 \geq 0$ is binding. For the same reason, the minimum capital constraint is also binding at $t = 0, 1$. The optimal $L_{1|z}$ is then derived by setting $X_1 = 0$, in which case one obtains

$$L_{1|z} = \frac{\kappa_0 + (1 - \tau(\pi_1)) \left( \theta_0 + r_1^L \right)}{\kappa_1 + \theta_{1|z} (1 - \tau(\pi_1))} L_0. \tag{9}$$

Similarly, one derives the optimal initial portfolio $L_0$. Since the minimum capital constraint is binding and since recognizing expected losses at $t = 0$, $\theta_0 L_0$ brings the available equity down to $E_0 - \theta_0 L_0$, the optimal $L_0$ is given by

$$L_0 = \frac{E_0}{\theta_0 + \kappa_0}. \tag{10}$$

## *3.3 Analysis and Discussion*

### *3.3.1 Provisioning Requirement vs. Capital Requirement*

Despite its simplicity, our stylized model can be used to understand the implications of adopting expected provisioning requirement for future losses on bank lending and stability. To provide better intuition for the effect of the EL approach on bank lending and stability, it is instructive to decompose the effect of the provisioning requirement for future losses into two channels: the capital requirement channel and the tax channel, which is accomplished in a proposition below.

PROPOSITION 1. *Let* $(L_0^e, L_{1|z}^e)$ *and* $P_t$ *denote the optimal lending schedule and bank default probability at* $t = 1, 2$, *respectively, of a bank that is subject to the minimum capital requirement* $E_t \geq \kappa_t L_t$ *and the provisioning requirement* $R_t = \theta_t L_t$. *Then* $(L_0^e, L_{1|z}^e)$ *and* $P_t$ *are also the optimal lending schedule and bank default probability at* $t = 1, 2$, *respectively, of a bank that is subject to the minimum capital requirement* $E_t \geq (\kappa_t + \theta_t)L_t$ *and the provisioning requirement* $R_t = 0$, *and receives a tax subsidy* $\tau(\pi_t)\,(\theta_t L_t - \theta_{t-1}L_{t-1})$ *at* $t$.

*Proof.* The proof is straightforward. By solving for $(L_0^e, L_{1|z}^e)$ when the bank is subject to the minimum capital requirement $E_t \geq (\kappa_t + \theta_t)L_t$ and the provisioning requirement $R_t = 0$, and receives a tax subsidy $\tau(\pi_t)\,(\theta_t L_t - \theta_{t-1}L_{t-1})$ at $t$, it is straightforward to show that $(L_0^e, L_{1|z}^e)$ are given by Equations (9) and (10). □

It follows from Proposition 1 that when the future loan losses are not tax deductible, then the provisioning rate $\theta_t$ has the exact same effect on bank lending as does the required minimum equity rate $\kappa_t$. This is intuitive since accounting-wise the net income before provisions is the source for both equity capital (through retention) and loan loss reserves (LLRs) (through provisioning). Having to recognize future losses limits the bank's ability to increase equity through retention and vice versa. Therefore, the cost of provisioning is the same as those of increasing equity capital. At the same time, both LLRs and equity capital serve as a buffer to absorb the loan losses once they are realized. Our model, therefore, highlights that the minimum capital requirement and the provisioning requirement for future losses are in effect substitutes. This insight informs the policy debate around macro- and micro-prudential regulation that capital requirements (set by bank regulators) and accounting standards on provisioning (set by market regulators) cannot be isolated from each other. Moreover, the tax treatment of provisions will also influence the optimal lending policies. This has important policy implications, especially given that both the accounting standards for loan loss recognition and the capital regulation under Basel III are undergoing drastic modifications.

Therefore when future losses are not tax deductible, we can understand the effect of $\theta_t$ on lending through $\kappa_t$. In particular, increasing $\theta_t$ will lower lending, since it forces the bank to rely more on equity financing, which raises the cost of capital. Moreover, imposing a countercyclical (procyclical) provisioning requirement—that is, $\theta_{1|g} < \theta_{1|b}$, ($\theta_{1|g} > \theta_{1|b}$)—will aggravate (mitigate) lending procyclicality. This follows immediately from a well-established result in the literature: imposing a more countercyclical (procyclical) capital requirement results in a more (less) procyclical lending (Kashyap and Stein 2004; Repullo, Saurina, and Trucharte 2010).

The second channel of the effects of provisioning requirement for future losses is due to the tax deductibility of these provisions. Note that this channel is present even if the bank is not subject to the minimum capital requirement and cannot be directly offset by adjusting the minimum capital requirement.[14] According to Proposition 1, when provisions are tax deductible they generate the tax subsidy. Due to the convexity of the tax schedule $\tau(\pi_t)$, the tax subsidy has a higher value in good times, when the profits tend to be higher. Therefore, this subsidy allows the bank to lend more aggressively when times are good vis-à-vis when times are bad, thereby amplifying lending procyclicality.[15]

#### *3.3.2 Incurred Loss Approach vs. Expected Loss Approach*

Recall that under the IL approach, banks are not allowed to recognize losses that are based on events expected to happen in the future. Therefore, we accommodate the IL approach in our model by setting $\theta_t = 0$.[16] In contrast, under the EL approach the banks must

[14]The capital regulation under Basel III is conditional on banks' portfolio risk and cannot be conditioned directly on banks' profits.

[15]Naturally, reducing the convexity of the tax schedule—that is, improving the banks' ability to shift losses intertemporally—could reduce the procyclical effect of tax deductibility.

[16]We assume incurred losses are provisioned for and charged off as soon as they are incurred.

recognize expected losses on loans already at their inception. Importantly, expected losses must be estimated using all presently available information—that is, conditional on the current state. Without going too much into details on how exactly $\theta_t$ is set under the EL approach at this moment, we set $\theta_{1|a} = \theta_0 > 0$ and $\theta_{1|b} = \theta_0 + \epsilon$, where $\epsilon > 0$, so that $\theta_{1|a} < \theta_{1|b}$, which reflects the fact that expected losses are higher conditional on the bad signal about the aggregate state.

Mathematically, replacing the IL with EL approach is equivalent to simultaneously raising $\theta_0$ and $\epsilon$. Proposition 1 then helps us understand the implications of replacing the IL approach with the EL approach on bank lending and stability. In line with Proposition 1, adopting the EL approach is equivalent to tightening the capital requirement (increasing $\theta_0$) and making it more countercyclical (increasing $\epsilon$). Thus, even absent the tax deductibility of expected provisions, adopting the EL approach will depress lending, worsen lending procyclicality, and improve stability.

The following proposition formalizes our results with regard to the implications of adopting the EL approach for loan loss recognition on bank lending and stability:

PROPOSITION 2. *Let* $(L_0^i, L_{1|z}^i)$ *and* $(L_0^e, L_{1|z}^e)$ *denote optimal lending under the IL and EL approaches, respectively. Let* $P_t$ *denote the probability of bank failure at* $t = 1, 2$. *Finally, define provisioning rates for expected losses as* $\theta_{1|g} := \theta_0 > 0$ *and* $\theta_{1|b} := \theta_0 + \epsilon$, *where* $\epsilon > 0$. *Then replacing the IL approach with the EL approach*

- *lowers lending,* $dL_0^e/d\theta_0 < 0$ *and* $dL_{1|z}^e/d\theta_0 < 0$,
- *amplifies lending procyclicality,* $d\left(L_{1|g}^e - L_{1|b}^e\right)/d\epsilon > 0$,
- *improves stability,* $dP_1/d\theta_0 < 0$ *and* $dP_2/d\theta_{1|z} < 0$.

*Proof.* See proof in Appendix A. □

That the model predicts a more procyclical lending under the EL approach is problematic. One of the two objectives of adopting the more forward-looking EL approach is to reduce lending procyclicality.[17] Intuitively, this cannot be achieved under the EL approach for as long as the expected credit losses are computed based on the point-in-time (PiT) default probabilities. By construction the PiT probabilities are countercyclical—defaults are relatively more common in a recession—and thus, so are the expected credit losses.[18] While some of the countercyclicality of the EL approach can be undone via adjustments to the capital requirements, it cannot be fully eliminated due to the tax-deductibility channel discussed above. Moreover, such adjustments would make bank regulatory policy dependent on accounting rules, thus further raising its complexity.

In the next section, we extend our simple model to *quantitatively* evaluate the effect of replacing the IL approach with EL one. With a richer dynamic model, we can calibrate the model's parameters using their observed counterparts in real-world data and generate simulations to quantitatively compare the two provisioning approaches.

## 4. Quantitative Dynamic Model

The is a partial equilibrium model and the bank takes all prices as given. Time is discrete and the horizon is infinite. The timing notation in the model is such that the predetermined (i.e., state) variables at time $t$ have subscript $t-1$, while exogenous shocks realized at $t$ as well as the choice variables at time $t$ are all indexed by $t$.

The bank's risk-neutral manager, acting on the behalf of shareholders, invests in a risky and illiquid portfolio of long-term loans $L_t$ funding this investment with one-period deposits $B_t$ and equity $E_t$.

[17]The second objective is to improve transparency via more timely loan loss recognition. In our analysis, we do not analyze the effects of potential changes in transparency. While this is an extremely interesting question, our dynamic model cannot accommodate such complexity. Thus, our focus is solely on the interaction of regulatory requirements—in the form of capital constraint—and accounting standards—in the form of provisioning requirements.

[18]Incidentally, the procyclical effect of PiT default probabilities was appreciated when the internal ratings-based framework was introduced in Basel II, which makes use of the so-called through-the-cycle (TTC) default probabilities that reflect expected default rates under normal business conditions.

Deposits are assumed to be fully insured with the deposit insurance priced at a flat rate normalized to zero.[19] The bank provisions for loan losses and, thus, holds LLRs $R_t$. The following balance sheet identity holds:

$$L_t - R_t = B_t + E_t. \tag{11}$$

### *4.1 Aggregate State*

The economic environment characterized by the aggregate state $s_t$. The aggregates state follows a discrete-time Markov chain. The state space of $s_t$ consists of two values $g$ and $b$ corresponding to expansionary and contractionary aggregate state, respectively. The transition probability from state $s_t$ to $s_{t+1}$ is denoted by $q_{s_t,s_{t+1}}$.

### *4.2 Loan Portfolio*

The bank's loan portfolio consists of two types (categories) of loans: stage 1 (good credit quality) and stage 2 (impaired credit quality) loans.[20] Let $\xi_t^i \sim F(\xi_t^i; s_t)$ denote a random fraction of stage $i$ loans that defaults at the beginning of period $t$. Conditional on aggregate state, default rate $\xi_t^i$ is iid. The cumulative distribution function (CDF) is ranked in terms of first-order stochastic dominance with respect to aggregate so that $F(\xi_t^i; s_t = g) \leq F(\xi_t^i; s_t = b)$ holds.[21]

All non-defaulted loans repay the same interest $r^L_{s_{t-1}}$ at time $t$ and a fraction $\delta \in (0, 1)$ of them matures, repaying the principal.[22] Defaulted loans are resolved and written off in the same period they

[19] When the bank fails, it defaults on deposits and their interest. In that case, the deposit insurance agency fully repays the depositors the principal and interest. Therefore, although from the point of view of the insurance agency deposits are risky, from the point of view of depositors these are risk-free claims.

[20] Heterogeneity of loans based on quality is crucial for capturing regulatory aspects of different versions of the EL approach.

[21] In the calibration section, we show that under assumption that individual loans are exposed to a single common factor, and thus have imperfectly correlated defaults, $F(\xi_t^i; s_t)$ takes the form of the Vasicek distribution (Vasicek 2002).

[22] Every period, a loan matures with probability $\delta$. Therefore, the average maturity of the loan portfolio is then given by $1/\delta > 1$. Thus, the bank is engaged in maturity transformation.

default.[23] Defaulted loans yield a recovery rate of $1 - \lambda^i_{s_t} \in [0, 1]$. Thus, $\lambda^i_{s_t}$ is a loss given default rate.

The fraction of type 1 loans is given exogenously and is denoted by $\omega_{s_t}$. Therefore, the default rate for the portfolio of all loans is given by $\xi_t = \omega_{s_t}\xi^1_t + (1 - \omega_{s_t})\xi^2_t$.

Every period the bank originates new loans, $N_t \geq 0$, thus, the total portfolio of loans evolves according to the following law of motion

$$L_t = (1 - \xi_t)(1 - \delta) L_{t-1} + N_t. \tag{12}$$

Loan origination is a costly process.[24] Following De Nicolò, Gamba, and Lucchetta (2014) and Mankart, Michaelides, and Pagratis (2020), we assume a quadratic lending cost function

$$C(N_t) = \frac{\phi}{2} N_t^2, \tag{13}$$

where $\phi > 0$. We restrict $N_t$ to non-negative values—that is, the bank is not allowed to sell its loans.

### *4.3 Provisioning Requirement for Future Losses*

As in the simple stylized model, the provisioning requirement for future loan losses is specified in terms of a requirement on LLRs. The provisioning rate $\theta_{s_t} \in [0, 1]$ depends now on the aggregate state. Under the assumption that the bank does not accumulate defaulted loans in the form of NPLs and writes the losses off in the same period they materialize, its loan loss reserves are given by

$$R_t = \theta_{s_t} L_t. \tag{14}$$

[23] Assuming that a loan that defaulted during period $t$ is resolved and is written off during the same period $t$ is a simplifying assumption, as it greatly reduces the state space of the model. The consequence of this assumption is that the bank does not accumulate NPLs—all defaulted loans are resolved and written down immediately. For our purposes, this assumption is not restrictive because, as we discuss it in the later section, the incurred and expected loss approaches treat NPLs in the same way.

[24] For example, the screening cost of processing new loan applications.

The law of motion of the bank's loan loss reserves can then be written as

$$R_t = R_{t-1} - \xi_t \lambda_{s_t} L_{t-1} + LLP_t, \tag{15}$$

where $LLP_t$ denotes the bank's *total* loan loss provision: provisions for incurred losses, $\xi_t \lambda_{s_t} L_{t-1}$, and expected losses, $R_t - R_{t-1}$.

### *4.4 Profits*

The bank's profits are given by loan repayments less interest expense, operating expense, loan losses, and provisioning—that is,

$$\pi_t := r^L_{s_{t-1}}(1 - \xi_t)L_{t-1} - r_{t-1}B_{t-1} - C(N_t) - LLP_t - \iota. \tag{16}$$

The first term above is the repayment on non-defaulted loans; the second term is the interest expense on deposits, which repay risk-free rate $r_t$; the third term is the loan adjustment costs associated with new loans; the fourth term is the total loan loss provisions; the last term, a constant $\iota$, is the fixed cost of running the bank.

As in the simple stylized model, the bank's profits are subject to a convex corporate tax schedule

$$\tau(\pi_t) = \tau \mathbb{I}_{\pi_t > 0}, \tag{17}$$

where $\mathbb{I}_{\pi_t > 0}$ denotes an indicator function which is equal to one when $\pi_t > 0$ and zero otherwise. The bank's net income—that is, the after-tax profits—is given by $(1 - \tau(\pi_t))\,\pi_t$.[25]

### *4.5 Equity*

The bank's after-tax profits are either paid out as dividends or retained to increase the stock of equity. Let $X_t$ be a dividend payout at time $t$; then the bank's book equity evolves according to the following accounting identity:

$$E_t = E_{t-1} - X_t + (1 - \tau(\pi_t))\,\pi_t. \tag{18}$$

[25] If, however, provisions for future losses are not tax deductible, then the net income is given by $(1 - \tau(\pi_t + (R_{t+1} - R_t)))\,(\pi_t + (R_{t+1} - R_t)) - (R_{t+1} - R_t)$. We proceed under the assumption that the provisions are tax deductible and state it explicitly when it is not the case.

Negative values of $X_t$ mean that the bank is raising external equity. We assume that raising external equity is costly. This cost reflects the direct transactional costs (e.g., underwriter fees (Altınkılıç and Hansen 2000)) and indirect costs of raising external equity (i.e., debt overhang (Myers 1977 and Admati et al. 2018) or signaling issues (Myers and Majluf 1984)). These costs do not apply if banks retain earnings (in line with pecking-order theories).

Following Hennessy and Whited (2007), the cost of raising external equity is modeled in a reduced form. In particular, for every dollar raised in terms of equity, the bank will have to pay $1 + \eta_{s_t}$, where $\eta_{s_t} > 0$ is a flotation cost for equity. Therefore, the cost of external equity is given by

$$\eta(X_t) := \eta_{s_t} X_t \mathbb{I}_{X_t<0}, \tag{19}$$

where indicator function $\mathbb{I}_{X_t<0}$ is equal to 1 when $X_t < 0$, and 0 otherwise. Thus, $\eta(X_t)$ is strictly negative when the bank raises equity and zero otherwise.

## *4.6 Capital Requirement*

As in the simple stylized model, the bank is subject to the minimum capital requirement. Every period $t$, the bank's choice over the portfolio of loans and equity must satisfy the following minimum capital constraint

$$E_t \geq \kappa_{s_t} L_t, \tag{20}$$

where $\kappa_{s_t} \in [0, 1]$.[26]

## *4.7 Optimization Problem*

The bank's manager maximizes the present value of all future dividends.[27] The effective control variables are the next-period stock of

[26]The current regulatory regime (i.e., Basel III) is the one with risk-based capital requirements. Therefore, $\kappa_{s_t}$ is an increasing function of loan default probability. We present the formula for $\kappa_{s_t}$ in the calibration section. When constraint (20) is not binding, we say that the bank holds a voluntary capital buffer.

[27]It is straightforward to show that in our model maximizing the present value of future dividends is equivalent to maximizing the present value of the future free cash flows to equity.

equity, $E_t$, and loans, $L_t$. The choice over these controls, in turn, determines the bank's dividend payout, $X_t$, and lending, $N_t$.

Formally, given the current state of the bank, $\Xi_t = [E_{t-1}, L_{t-1}, \xi_t, s_t, s_{t-1}]$, the bank's manager maximizes the present value of all future dividends net the cost of recapitalization subject to a set of the constraints—that is, it solves

$$\begin{aligned}
V(\Xi_t) = \quad & \max_{\{E_t, L_t\}} \left\{ 0, X_t + \eta(X_t) + \beta_t \mathbb{E}\left[ V\left(\Xi_{t+1}\right) | s_t \right] \right\}, \\
\text{subject to} \quad & a) \quad E_t \geq \kappa_{s_t} L_t, \\
& b) \quad L_t - R_t = B_t + E_t \\
& c) \quad E_t = E_{t-1} - X_t + \left(1 - \tau(\pi_t)\right) \pi_t, \\
& d) \quad L_t = (1 - \xi_t)(1 - \delta) L_{t-1} + N_t, \\
& e) \quad \pi_t = r^L_{s_{t-1}} (1 - \xi_t) L_{t-1} - r_{t-1} B_{t-1} - C(N_t) \\
& \qquad - LLP_t - \iota, \\
& e) \quad R_t = (R_{t-1} - \xi_t \lambda_{s_t} L_{t-1}) + LLP_t, \\
& f) \quad R_t = \theta_{s_t} L_t, \\
& g) \quad N_t \geq 0.
\end{aligned} \tag{21}$$

The solution to the above problem is the policy functions $E^*_t : \Xi_t \rightarrow \mathcal{R}_+$ and $L^*_t : \Xi_t \rightarrow \mathcal{R}_+$, which satisfy the above system. Default takes place at time $t$ when the bank finds itself insolvent. This happens when the sum of the bank's current cash flows, $X_t + \eta(X_t)$, and continuation value, $\beta \mathbb{E}\left[V\left(\Xi_{t+1}\right) | s_t\right]$, is negative—that is, when the limited liability constraint is binding.

## 5. Calibration

### *5.1 Loan Default Rate Distribution*

Following Martinez-Miera and Repullo (2010), we assume that the probability distribution of the aggregate default rate $\xi^i_t$ is implied by the single common risk factor model of Vasicek (2002). This specification allows for imperfectly correlated individual loan defaults: the performance of an individual bank loan depends on the common and idiosyncratic factors, while the aggregate default rate $\xi^i_t$

depends only on the common factor. Moreover, this specification is adopted by the Basel Accords to provide a value-at-risk foundation to the minimum capital requirements. Appendix B provides more detailed information on this specification.

The CDF of $\xi_t^i$ conditional on aggregate state is then given by

$$F(\xi_t^i; s_t) = \Phi\left(\frac{\sqrt{1-\rho_{s_t}^i}\Phi^{-1}\left(\xi_t^i\right) - \Phi^{-1}\left(p_{s_t}^i\right)}{\sqrt{\rho_{s_t}^i}}\right), \tag{22}$$

where $\Phi(.)$ is the standard normal CDF. We derive the distribution of $\xi_t^i$ in Appendix B. Note, $F(\xi_t^i; s_t)$ has two parameters: $p_{s_t}^i$ and $\rho_{s_t}^i \in (0,1)$. The stage $i$ loan default probability $p_{s_t}^i$ is identical across all loans and is equal to the mean of $\xi_t^i$—that is, to $\mathbb{E}[\xi_{t+1}^i|s_t]$. The loan default correlation $\rho_{s_t}^i \in (0,1)$ captures the dependence of individual loan on the common risk factor and, thus, determines the degree of correlation between individual loan defaults. To calibrate the correlation coefficient $\rho_{s_t}^i$, we use the formula adopted by the Basel framework (see Equation (B.5) in Appendix B).

### *5.2 Capital Requirement*

The empirical counterpart of capital in our model is Tier 1 capital, which primarily consists of common equity. Under the risk-based approach of Basel capital regulation, $\kappa_{s_t}$ is an increasing function of loan default probability. We calibrate the capital requirement for a bank that follows the internal ratings-based (IRB) approach. Most of the largest banks adopt the IRB approach. Moreover, Basel Accords specify an explicit formula for the capital requirement under the IRB approach, which is a function of loan characteristics such as default probability, maturity, and loan loss default rate. This allows us to calibrate the minimum capital requirement so that it is consistent with the characteristics of the bank's loan portfolio. Under the IRB approach, the capital requirement for corporate and bank exposures is meant to ensure sufficient capital to cover loan losses with a confidence level of 99.9 percent. The exact formula for $\kappa_{s_t}^i$ is reported in Equation (B.6) in Appendix B.

One of the defining elements of Basel III is the countercyclical capital buffer (CCyB). The CCyB is a regulatory instrument designed to smooth lending procyclicality, which requires banks to build up an extra capital buffer during good times to increase their loss-absorption capacity for bad times. Specifically, under the CCyB a bank is required to hold the extra 2.5 percent of its risk-weighted assets (RWA) in equity during an expansion. Practically, the release and the accumulation of the CCyB should normally be implemented stage-wise over some period of time. However, to keep our model tractable, we assume that the CCyB is fully released once the aggregate state deteriorates and it must be fully accumulated right upon the improvement of the aggregate state. As such, for the calibration purposes, we assume a smaller size of the CCyB, namely 1.5 percent of its RWA. Thus, in our model, the CCyB is implemented by raising the minimum capital requirement in expansion from $\kappa_g$ to $1.188\kappa_g$.[28] We further provide robustness results when the required CCyB is at 2.5 percent of RWA.

## *5.3 Provisioning Requirement*

As discussed in Section 2, the IL approach does not allow recognition of losses that are expected to happen in the future. However, aside from accounting provisions, banks that follow the IRB approach must recognize one-year prudential expected losses on the entire portfolio of loans. These prudential expected losses, however, are computed in a different way than those under the EL approach. In particular, the prudential expected losses are computed using the so-called through-the-cycle (TTC) default probabilities and a conservative (downturn) estimate of loss given default. In our model, the TTC default probabilities correspond to the *unconditional* on the aggregate state default probabilities, $\bar{p}^i$, and the downturn estimate of loss given default is given by $\lambda_b^i$. Thus, under the ILM the bank recognizes a loss $\theta^{IRB,i}$ on a marginal loan $i$, where

$$\theta^{IRB,i} = \mathbb{E}[\lambda_b^i \xi_{t+1}] = \lambda_b^i \bar{p}^i. \tag{23}$$

[28] As per the Basel III's formula for RWA, in our model these are given by $RWA_t = \kappa_{s_{t-1}} 12.5 L_t$ at time $t$ (see paragraph (53) of the section Internal Ratings-Based Approach for Credit Risk in Basel Committee on Banking Supervision 2017). Therefore, the capital requirement conditional on an expansion increases from $\kappa_g$ to $\kappa_g + 0.015 \times 12.5\kappa_g = 1.188\kappa_g$ due to the CCyB.

Thus, the provisioning rate for the entire portfolio of loans is given by

$$\theta_{s_t}^{IRB} = \omega_{s_t}\theta^{IRB,1} + (1-\omega_{s_t})\,\theta^{IRB,2}. \tag{24}$$

Note, however, that the prudential provisions are not accounting losses and, thus, are not tax deductible.[29]

The discounted expected losses under the EL approach instead employ the point-in-time (PiT) default probabilities—that is, the expected losses are conditional on the current aggregate state. The one-year discounted expected loss rate under the EL approach is given by

$$\theta_{s_t}^{1Y,i} = \frac{1}{1+d_{s_t}}\mathbb{E}[\lambda_{s_{t+1}}^{i}\xi_{t+1}|s_t] = \frac{1}{1+d_{s_t}}p_{s_t}\mathbb{E}[\lambda_{s_{t+1}}^{i}|s_t], \tag{25}$$

while the lifetime discounted expected loss rate is given by

$$\theta_{s_t}^{LT,i} = \frac{1}{1+d_{s_t}}\mathbb{E}[\lambda_{s_{t+1}}^{i}\xi_{t+1} + (1-\xi_{t+1})(1-\delta)\theta_{s_{t+1}}^{LT,i}|s_t]. \tag{26}$$

The discount rate $d_{s_t}$ is equal to the contractual interest rate $r_{s_t}^{L}$ under IFRS 9, while under the U.S. GAAP it is implied by the bank's discount factor $\beta_t$. Note that in Equations (25) and (26), the expectations are conditional on the aggregate state, which reflects the PiT estimation of the EL approach. The closed-form solution to Equation (26) is provided in Appendix B.

Since under IFRS 9 the bank recognizes one-year and lifetime expected losses on stage 1 and stage 2 loans, respectively, the provisioning rate for the entire portfolio of loans is given by

$$\theta_{s_t}^{IFRS9} = \omega_{s_t}\theta_{s_t}^{1Y,1} + (1-\omega_{s_t})\,\theta_{s_t}^{LT,2}. \tag{27}$$

The provisioning rate for the entire portfolio of loans under the U.S. GAAP is given by

$$\theta_{s_t}^{GAAP} = \omega_{s_t}\theta_{s_t}^{LT,1} + (1-\omega_{s_t})\,\theta_{s_t}^{LT,2}, \tag{28}$$

[29] See Abad and Suarez (2018) for an in-depth discussion on prudential provisions.

since in this case the lifetime expected losses are recognized on all types of loans.

It is important to note that when we compare the IL and EL approaches, we include the IRB provisions in both scenarios. That is, regardless of the accounting approach the bank must still meet the IRB requirement. We do, however, assume that if accounting provisions for future loan losses are in excess of the prudential provisioning (under IRB), then the regulator does not object to count the accounting provisions for regulatory requirement of prudential provisions.[30]

### *5.4 Parameter Values*

The parameters of the model are listed in Table 1, along with their values and sources of calibration. Below, we present a detailed summary of how we calibrate the model.

The model features aggregate and idiosyncratic uncertainty. We set the transition probabilities for the aggregate state, $q_{s_t,s_{t+1}}$, to obtain contractions that last for 2 years, on average, and expansions that last for 6.8 years, on average, which is consistent with the National Bureau of Economic Research's dating of business cycle.[31] To that end, we set $q_{g,g} = 0.852$ and $q_{b,b} = 0.5$.[32]

Idiosyncratic uncertainty depends upon the aggregate state and is captured by the loan default process. The absence of detailed micro-level data on banks' loan portfolios creates a problem for calibrating the bank loan default process. To circumvent this problem, we follow the approach in Abad and Suarez (2018) and use the Global Corporate Default reports produced by Standard & Poor's (S&P) over the period 1981–2015 to calibrate the bank loan default process. To that end, we set the default probability of stage 1 (2) loans to 0.54 percent (6.05 percent) and 1.9 percent (11.5 percent) in expansion and contraction, respectively. These probabilities

[30]This assumption ensures there is no double provisioning problem. For example, the total provision rate under IFRS 9 is given by $\max\{\theta_{s_t}^{IFRS9}, \theta_{s_t}^{IRB}\}$, which may also require some adjustments to after tax profits since, unlike the EL provisions, the IRB provisions are not tax deductible.

[31]http://www.nber.org/cycles.html.

[32]The unconditional probability of good and bad aggregate state are given by $q_g = (1 - q_{b,b})/(2 - q_{g,g} - q_{b,b}) = 0.77$ and $q_b = 1 - q_g = 0.23$, respectively.

**Table 1. Model Parameters**

| Parameter | Description | Contraction | Expansion | Source |
|---|---|---|---|---|
| *A. Parameters Set Outside the Model* | | | | |
| Loan Default Process | | | | |
| $\lambda^1_{s_t}$ | Loss Given Default Rate Stage 1 Loans | 40% | 30% | |
| $\lambda^2_{s_t}$ | Loss Given Default Rate Stage 2 Loans | 40% | 30% | Standard & Poor's |
| $p^1_{s_t}$ | Default Probability of Stage 1 Loans | 1.90% | 0.54% | Abad and Suarez (2018) |
| $p^2_{s_t}$ | Default Probability of Stage 2 Loans | 11.50% | 6.05% | |
| $\rho^1_{s_t}$ | Loan Default Correlation Stage 1 Loans | 0.166 | 0.212 | |
| $\rho^2_{s_t}$ | Loan Default Correlation Stage 2 Loans | 0.120 | 0.126 | Equation (B.5) |
| Loan Portfolio and Repayment | | | | |
| $1/\delta$ | Average Maturity of Loans (in Years) | 5 | 5 | Call Reports |
| $\omega_{s_t}$ | Fraction of Stage 1 Loans | 0.81 | 0.85 | Abad and Suarez (2018) |
| $r^L_{s_t}$ | Loan Repayment Rate | 5.00% | 4.29% | FRED: U.S. Net Interest Margins |
| Other Parameters | | | | |
| $\beta$ | Bank Discount Factor | 0.95 | 0.95 | De Nicolò, Gamba, and Lucchetta (2014) |
| $\tau$ | Corporate Tax Rate | 0.20 | 0.20 | |
| $\eta_{s_t}$ | Flotation Cost of Equity | $\infty$ | 0.06 | De Nicolò, Gamba, and Lucchetta (2014), Dinger and Vallascas (2016) |
| $r$ | Cost of Debt (Risk-Free Rate) | 1.00% | 1.00% | |
| $q_{s_t,s_{t+1}}$ | Transition Probability of the Aggregate State | 0.5 | 0.852 | NBER Business Cycle Dating |
| *B. Parameters Calibrated Inside the Model* | | | | |
| $\iota$ | Fixed Cost of Running the Bank | 0.0045 | 0.0045 | Calibrated to match the annual bank failure rate |
| $\phi$ | Loan Adjustment Cost Parameter | 0.60 | 0.60 | Calibrated to match the loan growth rate volatility |

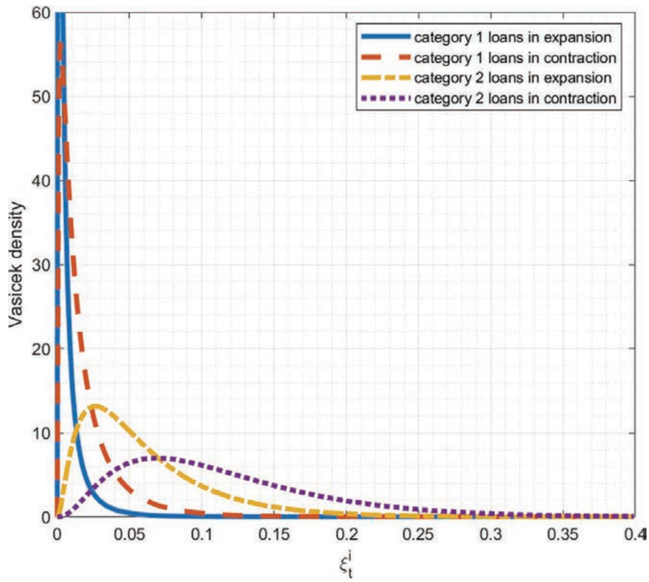
(*continued*)

**Table 1. (Continued)**

| Parameter | Description | Contraction | Expansion | Source |
|---|---|---|---|---|
| *C. Residual Parameters* | | | | |
| Capital Requirement | | | | |
| $\kappa_{s_t}^1$ | Minimum Capital Requirement for Stage 1 Loans | 8.50% | 8.50% | IRB approach; see Equation (B.6) |
| $\kappa_{s_t}^2$ | Minimum Capital Requirement for Stage 2 Loans | 14.4% | 14.4% | |
| $\kappa_{s_t}$ | Total Minimum Capital Requirement | 9.70% | 9.40% | Equation (B.7) |
| Provisioning Rates | | | | |
| $\theta_{s_t}^{1,ILM}$ | Stage 1 Loan Provisioning Rate under ILM (IRB) | 0.34% | 0.34% | Equation (23) |
| $\theta_{s_t}^{2,ILM}$ | Stage 2 Loan Provisioning Rate under ILM (IRB) | 2.92% | 2.92% | |
| $\theta_{s_t}^{ILM}$ | Average (Portfolio) Loan Provisioning Rate under ILM (IRB) | 0.84% | 0.73% | Equation (24) |
| $\theta_{s_t}^{1,IFRS9}$ | Stage 1 Loan Provisioning Rate under IFRS 9 | 0.44% | 0.24% | Equation (25) |
| $\theta_{s_t}^{2,IFRS9}$ | Stage 2 Loan Provisioning Rate under IFRS 9 | 8.84% | 7.83% | Equation (26) |
| $\theta_{s_t}^{IFRS9}$ | Average (Portfolio) Loan Provisioning Rate under IFRS 9 | 2.06% | 1.38% | Equation (27) |
| $\theta_{s_t}^{1,GAAP}$ | Stage 1 Loan Provisioning Rate under U.S. GAAP | 1.35% | 1.09% | Equation (26) |
| $\theta_{s_t}^{2,GAAP}$ | Stage 2 Loan Provisioning Rate under U.S GAAP | 8.68% | 7.61% | |
| $\theta_{s_t}^{GAAP}$ | Average (Portfolio) Loan Provisioning Rate under IFRS 9 | 2.77% | 2.07% | Equation (28) |

**Note:** This table summarizes the parameters of the model, their values, and the sources of their calibration. The values of some parameters vary with the aggregate state. Parameters listed in panel A have been calibrated outside the model due to the observability of their data counterparts. Panel B lists the parameters which were calibrated inside the model to match the moments in the real data; the data counterparts of these parameters are directly observable. Finally, panel C presents the residual parameters; the values of these parameters are determined by the value of the parameters set outside the model.

**Figure 1. Loan Default Rate Density**




**Note:** This figure plots the calibrated Vasicek density function for the aggregate loan default rate $\xi_t^i$.

are consistent with the alignment of stage 1 loans with corporate bonds with ratings AAA to BB in the S&P classification and stage 2 loans with ratings B to C. Furthermore, in line with Abad and Suarez (2018), we set the fraction of stage 1 loans, $\omega_{s_t}$, to 0.85 and 0.81 in expansion and contraction, respectively. Finally, the loss given default rates $\lambda_{s_t}^i$ for both types of loans are set to 0.4 and 0.3 in contraction and expansion, respectively. Figure 1 depicts the calibrated Vasicek density function of the aggregate default rate $\xi_t^i$.

Given the parameterization of the loan default process, we can compute the implied values for the residual parameters: $(\rho_{s_t}^1, \rho_{s_t}^2, \kappa_{s_t}^1, \kappa_{s_t}^2, \theta_{s_t}^1, \theta_{s_t}^2)$. Equation (B.5) from Appendix B implies the value of the loan default correlation coefficient for stage 1 (2) loans, $\rho_{s_t}^1$ ($\rho_{s_t}^2$), is 0.166 (0.12) in contractions and 0.212 (0.126) in expansions. Similarly, Equation (B.6) from Appendix B implies the minimum capital requirement for stage 1 and 2 loans, $\kappa_{s_t}^1$ and $\kappa_{s_t}^2$, is 8.5 percent and 14.4 percent, respectively. The overall capital requirement, $\kappa_{s_t}$, is then 9.4 percent in expansion and 9.7 percent in contraction. Finally, the values of the provisioning rates, $\theta_{s_t}$, are assigned according to Equations (23)–(26).[33]

We set the interest rate on debt, $r$, to 1.0 percent. To calibrate the interest on the loan portfolio, $r^L_{s_t}$, we match the first and second moments of the interest margins, $r^L_{s_t} - r_{t-1}$, to their data counterparts. For the U.S. banks, the mean and the standard deviation of the bank interest margins are 3.45 percent and 0.29 percent, respectively.[34] Imposing a restriction that $r_g < r_b$, which reflects the pricing of risk, we thus set $r^L_{s_t}$ to 4.29 percent and 5.00 percent in expansion and contraction, respectively. Finally, consistent with the U.S. banks' Reports of Condition and Income (Call Reports), we set the average loan maturity to five years, which implies $\delta = 0.20$. The corporate tax rate, $\tau$, is 0.20.[35]

Following De Nicolò, Gamba, and Lucchetta (2014), we set the flotation cost of equity conditional on expansion, $\eta_g$, to 0.06 and the banker's discount factor, $\beta_t$, to 0.95. Empirical evidence suggests that banks seldom issue new equity during a downturn (Dinger and Vallascas 2016). To accommodate this stylized fact, we make issuing equity in a bad aggregate state prohibitively expensive setting $\eta_b$ to infinity—that is, we effectively impose a non-negativity constraint on $X_t$ when the aggregate state is bad.

The remaining two parameters, namely $\phi$ and $\iota$, are calibrated inside the model to match the relevant data moments. The parameter $\phi$, which is from the loan lending cost function, directly relates to the volatility of bank loans. The higher $\phi$ is, the costlier it is to increase the stock of loans through new lending. This in turn lowers the volatility of loan growth. This parameter is thus calibrated to match the volatility of the annual loan growth rate, which

[33] Note that since provisioning rates under the EL approaches exceed those under the IRB approach, we assume that the regulator accepts accounting-expected provisions under the EL approach as prudential provisions of the IRB approach—that is, under the EL approach the bank no longer has to recognize the prudential losses since those are already covered by the accounting provisions.

[34] Data source: Federal Reserve Economic Database (FRED) time series on U.S. banks' net interest margins "USNIM."

[35] It is important to note that since this is a partial equilibrium model, where the bank takes prices as given, we cannot comment on how provisioning requirements may affect loan demand, and therefore the indirect effect coming from loan prices that are general equilibrium outcomes.

**Table 2. Data and Model Moments under Benchmark Calibration**

| Moments | Model | Data | Source |
|---|---|---|---|
| *Matched Moments* | | | |
| Mean Interest Margins | 3.45% | 3.45% | FRED (Time Series: "USNIM") |
| St. D. Interest Margins | 0.29% | 0.29% | FRED (Time Series: "USNIM") |
| Bank Failure Rate | 0.39% | 0.37% | Mankart, Michaelides, and Pagratis (2020) |
| St. D. of Loan Growth Rate | 3.90% | 3.70% | FRED (Time Series: "TOTLL") |
| *Not Matched Moments* | | | |
| Mean Charge-Off Rate | 0.66% | 0.86% | FDIC: Charge-Off and Delinquency Rates |
| St. D. Charge-Off Rate | 0.49% | 0.60% | On Loans and Leases at Commercial Banks |
| Mean ROE | 10.2% | 11.2% | FRED (Time Series: "USROE") |
| Mean ROA | 0.95% | 0.99% | FRED (Time Series: "USROA") |

**Note:** This table presents the matched and not matched moments implied by the model and real data. The moments implied by the model are computed under the benchmark—that is, the ILM case. The model moments are computed based on the data from simulating the model for 80,000 periods and excluding the first 200 observations. The sources for the real data moments are representative of U.S. banks.

is about 3.8 percent in the data.[36] To that end, we set $\phi = 0.6$. Finally, the fixed cost of running the bank, $\iota$, needs to be set sufficiently high to ensure that the bank's profits are not too large and, thus, the bank occasionally fails. We set $\iota$ to 0.0045 to match the bank (annual) failure rate of 0.37 percent (Mankart, Michaelides, and Pagratis 2020).

To assess the results of our calibration, we report some relevant moments implied by our model under the benchmark case of the ILM and the corresponding real data moments in Table 2. Despite its parsimonious structure, the model matches the data moments reasonably well.

[36]Data source: FRED, Federal Reserve Bank of St. Louis, time series "TOTLL"—Loans and Leases in Bank Credit, All Commercial 1975–2019.

Note that under the calibrated parameter values, our model predicts that the minimum capital requirement is binding all the time.[37] We verify this numerically using the simulated data from the model when the bank's choice consists of both $E_t$ and $L_t$. Therefore, to increase the precision of the numerical solution of our model, we solve the model by imposing that the capital constraint is binding. See Appendix C for more details on this matter.

## 6. Quantitative Results

### *6.1 Cyclical Effect of the EL Approach*

First, we examine the effect of the EL approach on the cyclicality of the key endogenous variables of the model, such as loan loss provisions (LLPs), profits, lending, and bank failure rate. Table 3 reports the moments of the endogenous variables, conditional on the aggregate state. These are obtained by simulating the model for 80,000 periods under the three scenarios: the ILM (benchmark) and two variations of the ELM, namely, IFRS 9 and U.S. GAAP.

The last two columns of Table 3, which provide a relative comparison between ILM and ELM, suggest a profoundly large procyclical effect of the EL approach on bank lending in our model. For example, while, on average, the bank lending is about 3.6 percent (2.7 percent) lower under IFRS 9 (U.S. GAAP) than ILM, conditional on a contraction the bank originates, on average, as much as 7.1 percent (5.9 percent) fewer new loans under IFRS 9 (U.S. GAAP). The procyclicality of the EL approach can also be assessed by examining the ratio of new loans to outstanding loans or loan growth rate.

[37]The bank's shareholders are relatively impatient (low $\beta$) and deposits are cheap (due to mispriced deposit insurance and the tax deductibility of the interest expense on deposits). Thus, holding an equity buffer is costly. That is why in our calibration the bank does not optimally hold buffer. The benefit of holding the buffer comes from the insurance it provides against having to increase equity following a large loss. Thus, when equity is costly to issue, and when the probability of facing a high loss is sufficiently high, then the bank might find it optimal to hold equity buffer. If we increase the likelihood of large losses and make the cost of issuing equity prohibitively expensive even in good times ($s_t = g$), then we could generate some capital buffers. However, the limited liability constraint makes it much harder to obtain a voluntary capital buffer in the model—the ability to walk away from the bank with insufficient capital reduces the incentives of the bankers to hold the buffer.

**Table 3. Expected Loss Approach: Cyclicality and Stability**

| Description | Variable | Aggregate State | ILM | IFRS 9 | U.S. GAAP | $\Delta_{ILM}^{IFRS9}$ | $\Delta_{ILM}^{USGAAP}$ |
|---|---|---|---|---|---|---|---|
| Total LLP | $\frac{R_t - R_{t-1} + \lambda_{s_t}\xi_t L_{t-1}}{L_t}$ | Unconditional | 0.69% | 0.70% | 0.69% | 0.00 pp | 0.00 pp |
| | | Contraction | 1.68% | 1.94% | 1.93% | 0.26 pp | 0.25 pp |
| | | Expansion | 0.41% | 0.33% | 0.34% | –0.07 pp | –0.07 pp |
| Profits | $\pi_t / L_{t-1}$ | Unconditional | 1.21% | 1.22% | 1.22% | 0.01 pp | 0.02 pp |
| | | Contraction | 0.48% | 0.28% | 0.29% | –0.20 pp | –0.18 pp |
| | | Expansion | 1.42% | 1.49% | 1.50% | 0.07 pp | 0.08 pp |
| New Loans | $N_t$ | Unconditional | 0.1288 | 0.1241 | 0.1253 | –3.64% | –2.74% |
| | | Contraction | 0.1219 | 0.1132 | 0.1148 | –7.13% | –5.85% |
| | | Expansion | 0.1308 | 0.1273 | 0.1283 | –2.69% | –1.89% |
| Total Loans | $L_t$ | Unconditional | 0.5983 | 0.5766 | 0.5819 | –3.63% | –2.74% |
| | | Contraction | 0.5764 | 0.5497 | 0.5555 | –4.64% | –3.63% |
| | | Expansion | 0.6047 | 0.5844 | 0.5897 | –3.35% | –2.48% |
| New Loans/ Outstanding Loans | $N_t / L_{t-1}$ | Unconditional | 21.60% | 21.60% | 21.60% | 0.00 pp | 0.00 pp |
| | | Contraction | 20.78% | 20.14% | 20.21% | –0.64 pp | –0.57 pp |
| | | Expansion | 21.87% | 22.07% | 22.05% | 0.20 pp | 0.18 pp |
| Loan Growth Rate | $\Delta L_t$ | Unconditional | 0.00% | 0.00% | 0.00% | 0.00 pp | 0.00 pp |
| | | Contraction | –2.08% | –2.73% | –2.71% | –0.66 pp | –0.63 pp |
| | | Expansion | 0.77% | 0.97% | 0.95% | 0.20 pp | 0.18 pp |
| Failure Rate | $\mathbb{P}(V_t < 0)$ | Unconditional | 0.39% | 0.49% | 0.35% | 0.10 pp | –0.04 pp |
| | | Contraction | 1.73% | 2.16% | 1.54% | 0.43 pp | –0.18 pp |
| | | Expansion | 0.00% | 0.00% | 0.00% | 0.00 pp | 0.00 pp |

**Note:** This table presents unconditional and conditional on the aggregate state first moments of various endogenous variables implied by the model under the incurred (ILM) and expected (IFRS 9 and U.S. GAAP) loss approach. The model is solved and simulated under the ILM (benchmark), IFRS 9, and U.S. GAAP provisioning approaches. The moments are constructed based on simulating the model for 80,000 periods (with the first 200 observations excluded). $\Delta_j^i$ denotes the relative difference between approach $i$ and $j$, which is measured either in terms of percentage (%) or percentage points (pp).

Both of these measures also indicate increased procyclicality under the EL approach.

Table 3 also helps to understand the mechanics behind the procyclicality of the EL approach. As we discussed earlier, the PiT default probabilities of the EL approach amplify the cyclical movement of the total LLPs. This, in turn, raises the volatility of the bank's profits over the cycle, which can be seen in Table 3. With the combination of the minimum capital requirement and costly external equity issuance, increased profit volatility translates into more severe lending procyclicality.

Our model further predicts that IFRS 9 is slightly more procyclical than U.S. GAAP. While the volatility of the provisioning rate, $\theta_{s_t}$, under both variants of the EL approach is roughly the same, which is about 0.29 percent, because of its mixed-horizon approach, IFRS 9 produces smaller loan loss reserves (LLRs), thus providing a weaker loss-absorption capacity than U.S. GAAP. As a result, the bank lends more procyclically under IFRS 9. Relatedly, our model also predicts that U.S. GAAP does a better job in terms of improving bank stability than IFRS 9. In fact, we find that with the adoption of IFRS 9, the bank failure rate may even increase. Again, this has to do with IFRS 9 being characterized by both larger procyclicality and lower loss-absorption capacity relative to U.S. GAAP. Recall that, on the one hand, since the bank holds larger LLRs under the EL approach, it should lower the bank failure rate. On the other hand, the procyclicality of the EL approach effectively increases the volatility of banks' profits, which increases bank failure rate.

Next, we examine the cyclical implication of the EL approach when the bank is subject to the CCyB. The CCyB is one of the most prominent features of Basel III that has been introduced to combat lending procyclicality by requiring the banks to hold extra capital during good times to support their lending activities upon the arrival of a contraction. Thus, it is particularly important to assess the joint cyclical effect of the EL approach and the CCyB. To do so, we report in Table 4 the moments of various endogenous variables under the ILM (benchmark), IFRS 9, and U.S. GAAP scenarios (conditional on the aggregate state), when the bank is subject to the CCyB.

First, Table 4 predicts a sizable effect of the CCyB on bank lending. By comparing the first ("ILM") and second ("ILM+CCyB")

## Table 4. Expected Loss Approach and the CCyB: Cyclicality and Stability

| Description | Variable | Aggregate State | ILM | ILM+ CCyB | IFRS 9 + CCyB | U.S. GAAP + CCyB | $\Delta_{ILM}^{ILM-CCyB}$ | $\Delta_{ILM}^{IFRS9+CCyB}$ | $\Delta_{ILM}^{USGAAP+CCyB}$ |
|---|---|---|---|---|---|---|---|---|---|
| New Loans | $N_t$ | Unconditional | 0.1288 | 0.1260 | 0.1232 | 0.1225 | –2.16% | –4.34% | –4.88% |
| | | Contraction | 0.1219 | 0.1251 | 0.1176 | 0.1179 | 2.61% | –3.49% | –3.27% |
| | | Expansion | 0.1308 | 0.1263 | 0.1248 | 0.1238 | –3.45% | –4.57% | –5.31% |
| Total Loans | $L_t$ | Unconditional | 0.5983 | 0.5853 | 0.5723 | 0.5691 | –2.16% | –4.34% | –4.88% |
| | | Contraction | 0.5764 | 0.5719 | 0.5529 | 0.5510 | –0.79% | –4.09% | –4.41% |
| | | Expansion | 0.6047 | 0.5893 | 0.5780 | 0.5744 | –2.55% | –4.42% | –5.01% |
| New Loans/ Outstanding Loans | $N_t/L_{t-1}$ | Unconditional | 21.60% | 21.60% | 21.60% | 21.60% | 0.00 pp | 0.00 pp | 0.00 pp |
| | | Contraction | 20.78% | 21.65% | 20.93% | 21.07% | 0.87 pp | 0.15 pp | 0.30 pp |
| | | Expansion | 21.87% | 21.58% | 21.80% | 21.75% | –0.29 pp | –0.07 pp | –0.12 pp |
| Loan Growth Rate | $\Delta L_t$ | Unconditional | 0.00% | 0.00% | 0.00% | 0.00% | 0.00 pp | 0.00 pp | 0.00 pp |
| | | Contraction | –2.08% | –1.32% | –2.06% | –1.92% | 0.76 pp | 0.02 pp | 0.15 pp |
| | | Expansion | 0.77% | 0.48% | 0.70% | 0.65% | –0.29 pp | –0.07 pp | –0.12 pp |
| Failure Rate | Default | Unconditional | 0.39% | 0.17% | 0.16% | 0.12% | –0.22 pp | –0.23 pp | –0.27 pp |
| | | Contraction | 1.73% | 0.76% | 0.69% | 0.55% | –0.97 pp | –1.04 pp | –1.18 pp |
| | | Expansion | 0.00% | 0.00% | 0.00% | 0.00% | 0.00 pp | 0.00 pp | 0.00 pp |

**Note:** This table presents unconditional and conditional on the aggregate state first moments of various endogenous variables implied by the model under the incurred (ILM) and expected (IFRS 9 and U.S. GAAP) loss approach with and without the countercyclical capital buffer (CCyB). The model is solved and simulated under the ILM (benchmark) with and without the CCyB, IFRS 9 with the CCyB, and U.S. GAAP with the CCyB. The moments are constructed based on simulating the model for 80,000 periods (with the first 200 observations excluded). $\Delta_j^i$ denotes the relative difference between approach $i$ and $j$, which is measured either in terms of percentage (%) or percentage points (pp).

columns in the table, we can see that while unconditional on the aggregate state, the bank originates about 2 percent fewer loans, it is able to increase its lending in a contraction by about 2.6 percent, on average. Thus, the model suggests that the countercyclical capital buffer quantitatively smooths aggregate loan dynamics and it also attenuates bank failures in the contractionary aggregate state. Second, the last two columns in Table 4 suggest that the CCyB is indeed able to considerably dampen the procyclical effect of the EL approach on bank lending. In particular, when the bank is subject to both IFRS 9 (U.S. GAAP) and the CCyB, it originates, on average, about 3.5 percent (3.3 percent) fewer new loans in a contraction compared to that under the ILM without the CCyB. Nevertheless, our model does suggest that the introduction of the EL approach considerably reduces the efficacy of the CCyB to smooth lending dynamics over the cycle.

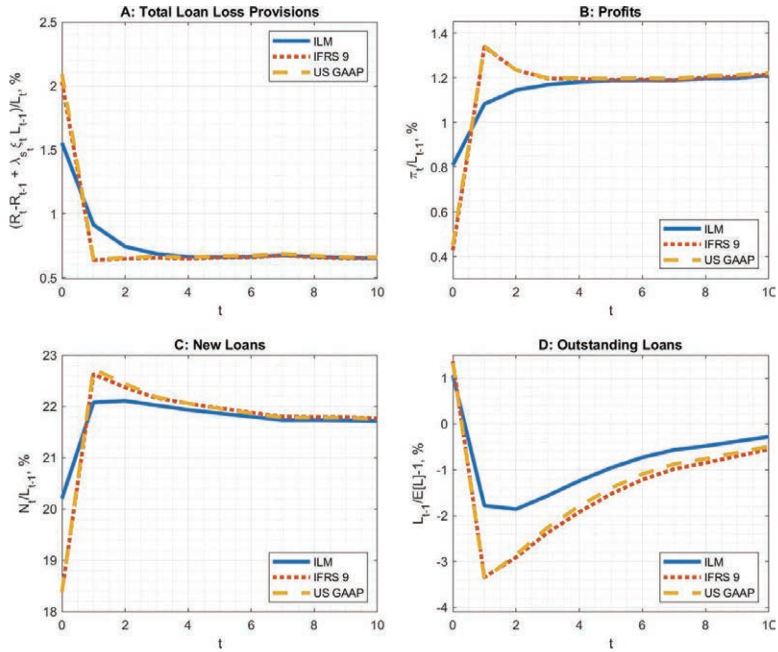
### *6.2 Effect of the Arrival of a Contraction*

Next, we examine a dynamic (i.e., multi-period) response of the key endogenous variables of our model to the arrival of a contraction. Since our model is solved fully non-linearly, we analyze the dynamic response to the arrival of a contraction using the generalized impulse response analysis (Koop, Pesaran, and Potter 1996).

A generalized impulse response of the variable $Y_t$ to a contractionary aggregate shock at time $t = 0$ constitutes a sequence of conditional expectations of the form $\mathcal{Y}_i = \mathbb{E}[Y_i|L_{-1}, s_{-1} = g, s_0 = b]$ for $i = 0, 1, 2\ldots$ The bank's endogenous initial state is set to the average values in an expansion—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$. The condition $s_{-1} = g$ implies that prior to the arrival of a contraction the bank is in expansionary aggregate state. Appendix C provides more details on the numerical procedure to evaluate $\{\mathcal{Y}_i\}_0^T$.

Figure 2 depicts the impulse response functions of the total LLPs, profits, and new and outstanding loans to the arrival of a contraction at $t = 0$. The impulse response functions are evaluated under the following three scenarios: ILM (benchmark), IFRS 9, and U.S. GAAP. Panel A shows that the total LLPs react much stronger to the arrival of a contraction under the EL approach. When learning about the deterioration of the aggregate state, the bank revises its point-in-time estimates of default probabilities upward and has

**Figure 2. Effect of the Arrival of a Contraction**




**Note:** This figure depicts the (generalized) impulse response functions of total loan loss provisions, profits, and new and outstanding loans to the arrival of a contraction at date $t = 0$. The impulse response functions are presented for three scenarios: incurred loss model (ILM) and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP. The impulse response of outstanding loans is in terms of relative changes to the (unconditional) mean $\mathbb{E}[L]$. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean value—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

to abruptly front-load the increased expected losses. As a result, the bank's profits drop sharper under the EL approaches upon the arrival of a contraction, as can be seen in panel B. Since the bank is subject to the minimum capital requirement and issuing external equity is too costly, we see in panel C that the bank cuts on new loans more aggressively under the EL approaches. As a result, the bank's outstanding loans plunge deeper under the EL approaches relative to their unconditional mean, as can be seen in panel D. We show that these results are qualitatively robust to setting the cost of external equity issuances to zero (Figure A.2), reducing an average duration of a contraction (Figure A.3), and imposing symmetric transition probabilities of the aggregate state (Figures A.4).

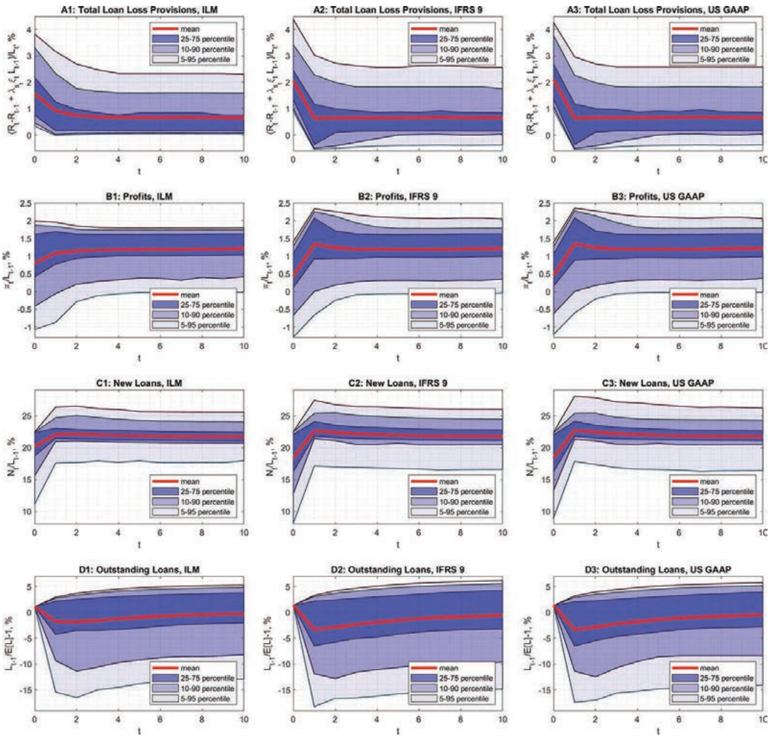
To gain better understanding of the dynamics, Figure 3 depicts the (generalized) impulse response functions (in red) and their confidence bounds (in the shades of blue) of total LLPs, profits, and new and outstanding loans to the arrival of a contraction at date $t = 0$. The confidence bounds of the impulse responses are computed as 25–75, 10–90, and 5–95 percentiles of the response to the arrival of a contraction. This figure allows us to see that not only do the EL approaches worsen the procyclicality of bank lending, but they also increase the volatility of the responses, which can be seen from the widened bounds.

To follow up on our earlier discussion about the two channels of the provisioning requirement for future losses, we try to disentangle the procyclical effects of the EL approaches that are due to the tax deductibility and the minimum capital regulation. Figure 4 plots the impulse response functions of the new and outstanding loans under the two EL approaches when the expected provisions are tax deductible and when they are not. As seen from the figure, lending procyclicality is only modestly increased when the tax deductibility of the expected provisions is assumed. Thus, we conclude that the procyclicality of an EL approach comes primarily from the capital regulation channel rather than the tax channel.

Lastly, we examine the impulse responses to the arrival of a contraction when the bank is subject to the CCyB. Figure 5 depicts the impulse response functions of profits, and new and outstanding loans to the arrival of a contraction at $t = 0$ when the bank must hold the CCyB of 1.5 percent.[38] First, by comparing the impulse responses of the new and outstanding loans under the ILM with and without the CCyB, we note a quantitatively strong countercyclical effect of the CCyB on bank lending. For example, the on-impact effect of the contraction on the ratio of new to total loans improves from

[38]Note, we do not plot the impulse response of the LLPs since their response is not directly affected by the CCyB.

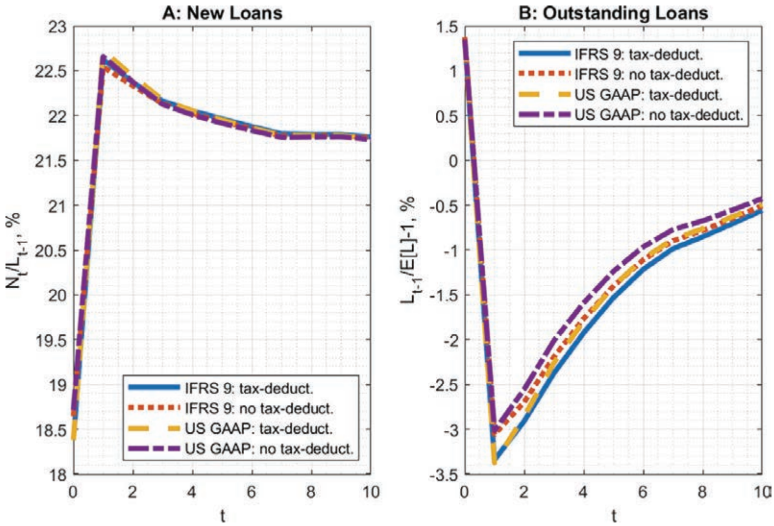
**Figure 3. Effect of the Arrival of a Contraction: Confidence Bounds**




**Note:** This figure depicts the (generalized) impulse response functions (in red) and their confidence bounds (in shades of blue) of total loan loss provisions, profits, and new and outstanding loans to the arrival of a contraction at date $t = 0$. The impulse response functions are presented for three scenarios: incurred loss model (ILM) and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP. The impulse response of outstanding loans is in terms of relative changes to the (unconditional) mean $\mathbb{E}[L]$. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

20.25 percent to 21.2 percent. At the same time, panel A shows that even when the introduction of an EL approach is accompanied by the simultaneous adoption of the CCyB, new lending falls sharper

**Figure 4. Effect of the Arrival of a Contraction: Tax vs. Capital Regulation Channel**

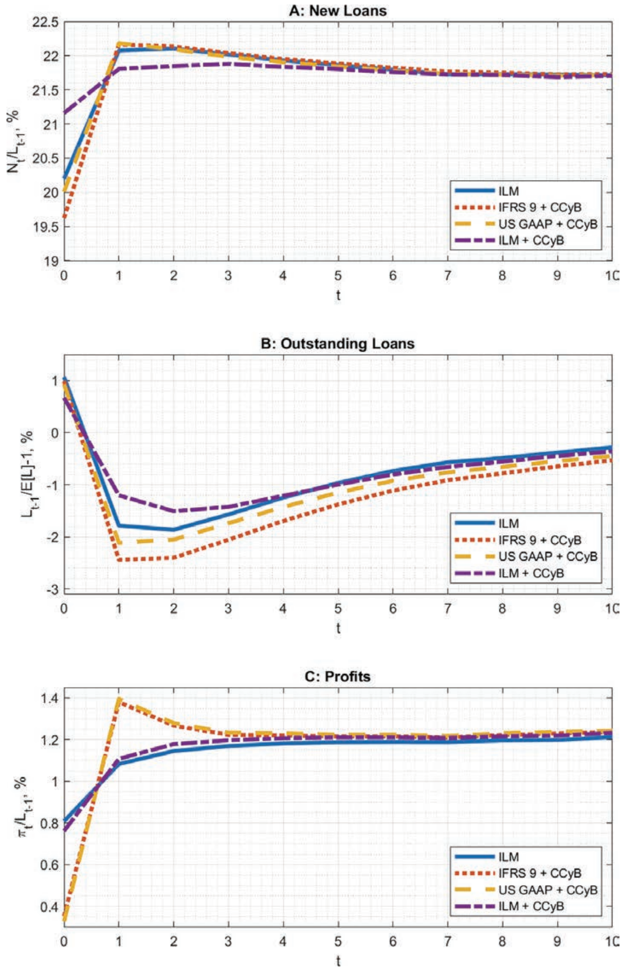



**Note:** This figure depicts the (generalized) impulse response functions of new and outstanding loans to the arrival of a contraction at date $t = 0$ when the expected provisions are tax deductible (blue and yellow plots) and when they are not (red and purple plots). The impulse response functions are presented for two variants of the EL approach: IFRS 9 and U.S. GAAP. The impulse response of outstanding loans is in terms of relative changes to the (unconditional) mean $\mathbb{E}[L]$. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

on impact. Figure 6 depicts the same impulse response when the CCyB is set at a higher level of 2.5 percent of RWA.[39] In this case, while the procyclical effect of the EL approach is largely mitigated

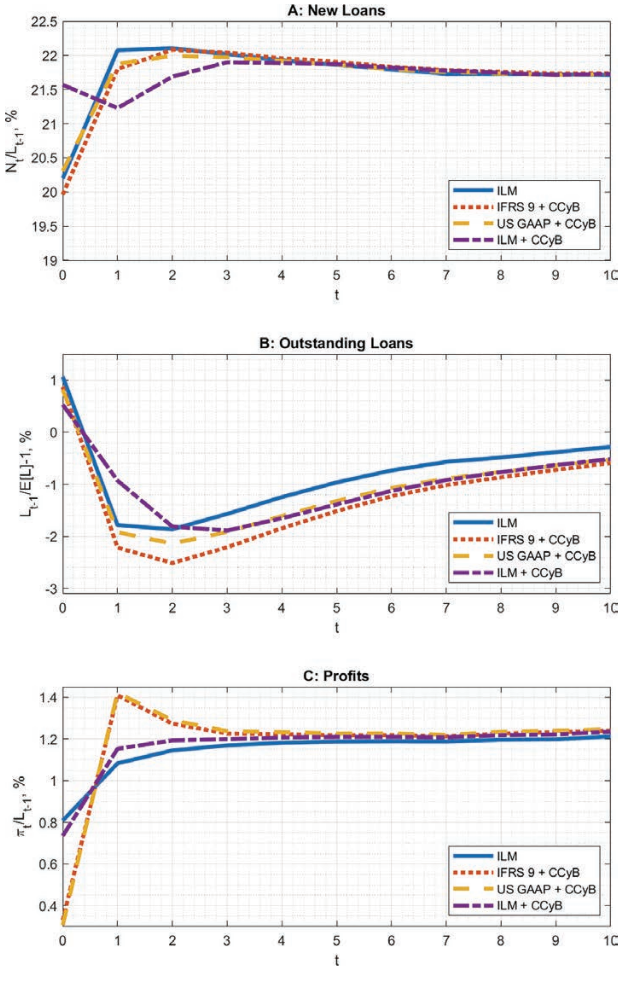
[39]Since in our model the CCyB is fully released once the aggregate state deteriorates and must be fully accumulated right upon the improvement of the aggregate state, a higher level of the CCyB suppresses lending activity following the net period after the shock.

**Figure 5. Effect of the Arrival of a Contraction under the 1.5 Percent CCyB**




**Note:** This figure depicts the (generalized) impulse response functions of new and outstanding loans, and profits to the arrival of a contraction at date $t = 0$. The impulse response functions are presented for four scenarios: incurred loss model (ILM) with and without the 1.5 percent CCyB, and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP with the CCyB. The impulse response of outstanding loans is in terms of a relative changes to the (unconditional) mean $\mathbb{E}[L]$. The CCyB is characterized by an increase in the minimum capital requirement conditional on the aggregate state being good. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

**Figure 6. Effect of the Arrival of a Contraction under the 2.5 Percent CCyB**




**Note:** This figure depicts the (generalized) impulse response functions of new and outstanding loans, and profits to the arrival of a contraction at date $t = 0$. The impulse response functions are presented for four scenarios: incurred loss model (ILM) with and without the 2.5 percent CCyB, and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP with the CCyB. The impulse response of outstanding loans is in terms of a relative changes to the (unconditional) mean $\mathbb{E}[L]$. The CCyB is characterized by an increase in the minimum capital requirement conditional on the aggregate state being good. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

(at least in the case of U.S. GAAP), this comes at a large contraction in the average level of outstanding loans of 3–4 percent, which we do not report in the paper.

### *6.3 Effect of the Arrival of a Prolonged Contraction*

We have so far shown that having to recognize the bulk of expected losses at the start of a contraction can impede the bank's lending. It does, however, improve the bank's loss-absorption capacity in the following periods, thus allowing the bank to lend more later on. It is natural then to examine the bank's lending activities when a contraction persists for a longer period. Thus, we proceed to examine the lending response to a prolonged contraction that lasts for at least two periods—that is, a contraction that arrives at $t = 0$ and persists at least until $t = 1$.

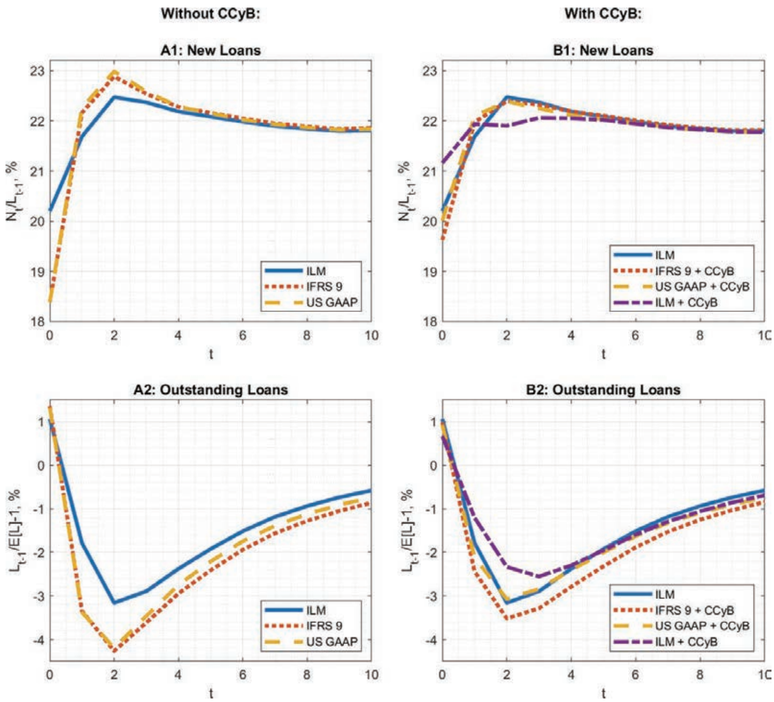
Figure 7 reports the impulse responses of the new and outstanding loans to the arrival of the prolonged contraction at $t = 0$ under the same three provisioning approaches, with and without the CCyB. The figure shows that the EL approach produces less procyclicality during the later stages of a contraction, which is consistent with our intuition outlined above.

### *6.4 Effect of the Arrival of a Contraction under a Delayed Response of Balance Sheet to Aggregate Shock*

So far we have maintained an assumption that the arrival of a contraction has a contemporaneous effect on the distribution of the bank's losses. Under this assumption, the EL approach effectively implies a "double blow" to the bank's profitability, as both realized and expected losses increase simultaneously upon the deterioration of the aggregate state. This assumption can be questioned since empirical evidence suggests that banks often report positive profits at the start of a recession.[40] Likewise, there might be some time lag between the deterioration of the aggregate state and an increase in consumer and corporate defaults. To account for this, we modify the timing of our model so that the distribution of the bank's

[40]For example, the return on average assets for U.S. banks was positive in 2007. Even Lehman Brothers reported a net income of a record $4.2 billion in 2007.

**Figure 7. Effect of the Arrival of a Prolonged Contraction with and without the CCyB**




**Note:** This figure depicts the (generalized) impulse response functions of new and outstanding loans to the arrival of a contraction at date $t = 0$ that persists for at least two periods—that is, $s_0 = s_1 = b$. The impulse response functions are presented for six scenarios: incurred loss model (ILM) with and without the CCyB, and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP with and without the CCyB. The impulse response of outstanding loans is in terms of a relative changes to the (unconditional) mean $\mathbb{E}[L]$. The CCyB is characterized by an increase in the minimum capital requirement conditional on the aggregate state being good. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

losses responds with a one-period delay to the arrival of a contraction. While a one-year delay is admittedly an exaggeration, it should really be viewed as an upper bound for the length of such a delay.

**Table 5. Provisioning Rates under Delayed Response of Profits**

| | | ILM | IFRS 9 | U.S. GAAP |
|---|---|---|---|---|
| Stage 1 in Expansion | $\theta_g^1$ | 0.34% | 0.16% | 1.19% |
| Stage 1 in Contraction | $\theta_b^1$ | 0.34% | 0.72% | 1.99% |
| Stage 2 in Expansion | $\theta_g^2$ | 2.92% | 7.37% | 8.38% |
| Stage 2 in Contraction | $\theta_b^2$ | 2.92% | 10.36% | 11.54% |
| Average (Portfolio) in Expansion | $\theta_g$ | 0.73% | 1.24% | 2.27% |
| Average (Portfolio) in Contraction | $\theta_b$ | 0.84% | 2.59% | 3.83% |
| Difference across Aggregate State | $\theta_b - \theta_g$ | 0.11% | 1.35% | 1.56% |

**Note:** This table reports the calibrated values of the provisioning rates, $\theta_{st}$ (%), under various provisioning approaches when the bank's losses respond with a one-year delay to the change in the aggregate state.

Formally, we denote the aggregate loan default rate at $t$ by $\hat{\xi}_t$ and assume that its distribution is given by

$$\hat{\xi}_t \sim F(\hat{\xi}_t; s_{t-1}) \tag{29}$$

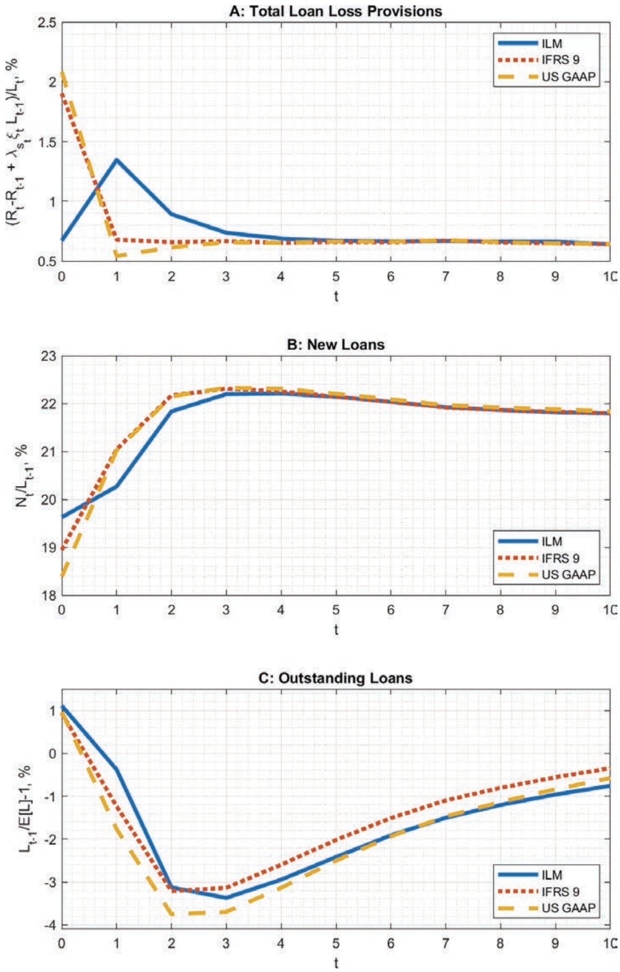
so that the distribution of the loss rate at time $t$ now depends on the previous-period aggregate state. This effectively implies that from the point of view of the current period, the next-period losses are determined up to the aggregate state.

Since the delay in the response of loan loss distribution affects the conditional expected losses, we have to recompute provisioning rates under the EL approach. The one-year discounted expected loss for a loan stage $i$ is now given by $\hat{\theta}_{s_t}^{1Y,i} = 1/(1+d_{s_t})\lambda_{s_t}^i p_{s_t}^i$, whereas the lifetime discounted expected loss is given recursively by $\hat{\theta}_{s_t}^{LT,i} = 1/(1+d_{s_t})(\lambda_{s_t}^i p_{s_t}^i + (1-p_{s_t}^i)(1-\delta)\mathbb{E}[\hat{\theta}_{s_{t+1}}^{LT,^i}|s_t])$.

Table 5 presents the recalibrated provisioning rates under IFRS 9 and U.S. GAAP, which reflects the modified version of the loan loss distribution in Equation (29). As a result of this modification, the provisioning rates under IFRS 9 and GAAP become even more countercyclical than before. Intuitively, the delay in the response of loan losses implies that the bank anticipates the next-period losses better; therefore, it provisions for expected losses more when times are bad and less when they are good.

Figure 8 depicts the generalized impulse responses of the total LLPs, and new and outstanding loans key to the arrival of a

## Figure 8. Effect of the Arrival of a Contraction under Delayed Losses




**Note:** This figure depicts the (generalized) impulse response functions of total loan loss provisions and new and outstanding loans to the arrival of a contraction at date $t = 0$ when the bank's losses respond with a one-year delay to the change in the aggregate state. The impulse response functions are presented for three scenarios: incurred loss model (ILM) and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP. The impulse response of outstanding loans is in terms of a relative changes to the (unconditional) mean $\mathbb{E}[L]$. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

contraction at $t = 0$ under the ILM, IFRS 9, and U.S. GAAP when the bank's losses respond with a one-year delay to the change in the aggregate state. Overall our results suggest that even when the arrival of a contraction erodes the bank's balance sheet with a one-year delay, which allows the bank to anticipate the upcoming losses, the ELM is still more procyclical than the ILM, at least, on impact. Intuitively, as the bank learns about the increase in its expected losses, it must recognize them. This erodes the bank's profits and forces it to cut new loans more than under the ILM. However, this time the effect is not as pronounced, because the current losses are smaller and, thus, they do not lower the current profits too much. Thus, the procyclicality of the ELM is now partially mitigated, as the bank recognizes the bulk of expected losses before these losses actually realize. This allows the bank to originate more new loans in the following periods after the arrival of a contraction.

Nevertheless, even with the delayed response of losses, the EL approach produces a stronger procyclical effect on lending upon the arrival of a contraction than the ILM. If we were to allow a delayed response over a number of years, which would be equivalent to assuming that the bank could anticipate or forecast the increase in expected losses well in advance, then in this case the EL would be able to smooth lending procyclicality. Intuitively, in this case, the EL approach would be very similar to the CCyB, as it would allow the bank to build up the reserves well in advance of the arrival of a contraction. However, neither theoretically nor empirically would it be possible to justify either such long delays in loss responses or such great ability of banks to foresee the future losses.

## 7. Conclusion

Our quantitative dynamic model of a bank predicts that under the expected provisioning approach of IFRS 9 and the new U.S. GAAP, banks lend substantially more procyclically than under the incurred loss approach. Moreover, the procyclicality of the EL approach can worsen the bank's stability despite providing an extra loss-absorption capacity. Naturally, the ultimate question is whether the ELM is better or worse than the ILM. Our partial equilibrium model cannot answer this question, as it does not allow for welfare analysis.

However, the literature on optimal capital regulation helps to shed some light on that issue.

It is rather well understood that the countercyclicality of capital requirements is likely to amplify the business cycle (Kashyap and Stein 2004; Repullo, Saurina, and Trucharte 2010). Moreover, most scholars advocate in favor of procyclical capital requirements—that is, to tighten the capital requirement during good times (Kashyap and Stein 2004, Dewatripont and Tirole 2012, Repullo 2013, Gersbach and Rochet 2017, and Malherbe 2020). In line with these studies, the increased procyclicality of bank lending under the ELM would lead to welfare losses.

The welfare analysis of expected provisioning is further complicated by one important aspect of the ELM that we do not consider in our analysis—that is, the information content of expected provisions. One of the potential benefits of the ELM as argued in Financial Stability Forum (2009) is that it "is consistent with financial statement users' needs for transparency regarding changes in credit trends." When there is asymmetric information such that the bank insiders know more about the state of the bank than other market participants, expected provisions, provided that they are properly estimated and truthfully disclosed, can be informative for the outsiders. Therefore, any potential cost of expected provisioning should be further compared to a potential benefit it may create by increasing the transparency about the credit risk of the bank. However, the mere fact that there will be more information disclosed under the ELM does not necessarily translate into welfare benefits either. There is theoretical literature suggesting that more transparency is not necessarily beneficial (Goldstein and Sapra 2014). Mahieux, Sapra, and Zhang (2023) show that expected provisioning may improve efficiency by allowing for timely regulatory intervention to curb inefficient ex post asset substitution. They also argue that banks, however, may respond to timely intervention by originating riskier loans so that timely intervention induces timelier risk-taking.

## Appendix A. Proof of Proposition 2

The first statement of the proposition is proved by taking the derivatives of $L_0$ and $L_{1|z}$ with respect to $\theta_0$. Recall that we let

$\theta_g := \theta_{1|g} = \theta_0 > 0$, while $\theta_b := \theta_{1|b} = \theta_0 + \epsilon$, where $\epsilon > 0$. Using Equations (9) and (10), it follows that

$$\frac{\mathrm{d}}{\mathrm{d}\theta_0} L_0^e = -\frac{L_0^e}{\theta_0 + \kappa_0} < 0, \tag{A.1}$$

while

$$\frac{\mathrm{d}}{\mathrm{d}\theta_0} L_{1|z}^e = \frac{L_{1|z}^e}{L_0^e}\frac{\mathrm{d}L_0^e}{\mathrm{d}\theta_0} + \frac{(1-\tau(\pi_1))}{\kappa_1 + \theta_{1|z}(1-\tau(\pi_1))} L_0^e - \frac{(1-\tau(\pi_1))}{\kappa_1 + \theta_{1|z}(1-\tau(\pi_1))} L_{1|z}^e. \tag{A.2}$$

The last term in the above equation is positive, and it is only present when $z = b$. Thus, to prove that $\frac{\mathrm{d}}{\mathrm{d}\theta_0} L_{1|z}^e < 0$, it is sufficient to show that the sum of the first two terms in Equation (A.2) are negative, which is the case since

$$\frac{L_{1|z}^e}{L_0^e}\frac{\mathrm{d}L_0^e}{\mathrm{d}\theta_0} + \frac{(1-\tau(\pi_1))}{\kappa_1 + \theta_{1|z}(1-\tau(\pi_1))} L_0^e =$$
$$-\frac{\kappa_0 + (1-\tau(\pi_1))(\theta_0 + r_1^L)}{\kappa_1 + \theta_{1|z}(1-\tau(\pi_1))}\frac{L_0^e}{\theta_0+\kappa_0} + \frac{(1-\tau(\pi_1))L_0^e}{\kappa_1 + \theta_{1|z}(1-\tau(\pi_1))} \propto$$
$$(1-\tau(\pi_1))(\theta_0+\kappa_0) - \kappa_0 - (1-\tau(\pi_1))(\theta_0 + r_1^L) =$$
$$-\tau(\pi_1)\kappa_0 - (1-\tau(\pi_1)) r_1^L < 0.$$

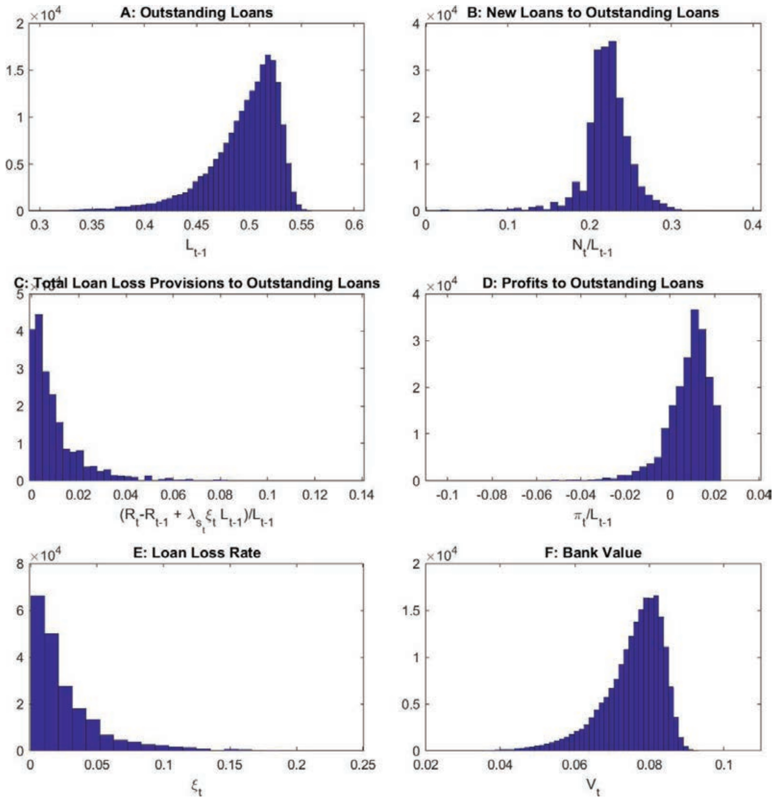
The second statement of the proposition is proved by taking the derivative of $L_{1|g} - L_{1|b}$ with respect to $\epsilon$—that is,

$$\frac{\mathrm{d}}{\mathrm{d}\epsilon}\left(L_{1|g}^e - L_{1|g}^e\right) = -\frac{\mathrm{d}}{\mathrm{d}\epsilon} L_{1|b}^e = \frac{(1-\tau(\pi_1))L_{1|b}^e}{\kappa_1 + \theta_b(1-\tau(\pi_1))} > 0. \tag{A.3}$$

To prove the last statement of the proposition, first, write the probability of bank failure at $t = 2$ as

$$\begin{aligned} P_2 &:= \mathbb{P}\left(X_2 < 0|z\right) \\ &= \mathbb{P}\left((1-\tau(\pi_2))\left((r_2^L + \theta_{1|z}) + \kappa_1\right) < 0|z\right) \\ &= \mathbb{P}\left(r_2^L < -\frac{\kappa_1}{1-\tau(\pi_2)} - \theta_{1|z}|z\right) \end{aligned}$$

**Figure A.1. Distributions of the Key Endogenous Variables**




**Note:** This figure depicts distributions of the model's key endogenous variables obtained from simulating the model under the incurred loss approach for 80,000 periods (with the first 200 observations excluded).

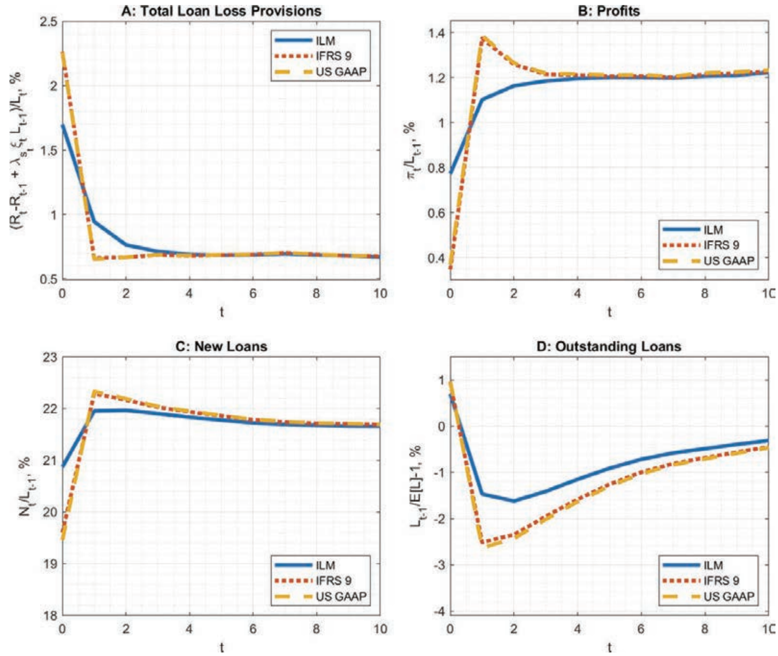
$$= \mathbb{P}\left(\frac{r_2^L - \mu_1}{\sigma_1} < -T_1|z\right) = \Phi\left(-T_1\right) = 1 - \Phi\left(T_1\right),$$

where $T_1 = \frac{\frac{\kappa_1}{1-\tau(\pi_2)} + \theta_{1|z} + \mu_1}{\sigma_1}$ and $\Phi(.)$ denotes the standard normal CDF. Then it follows that

$$\frac{\mathrm{d}}{\mathrm{d}\theta_{1|z}} P_2 = -\frac{\phi(T_1)}{\sigma_1} < 0, \tag{A.4}$$

where $\phi(.)$ denotes the standard normal density function.

**Figure A.2. Effect of the Arrival of a Contraction when Cost of External Equity Issuance Is Zero**

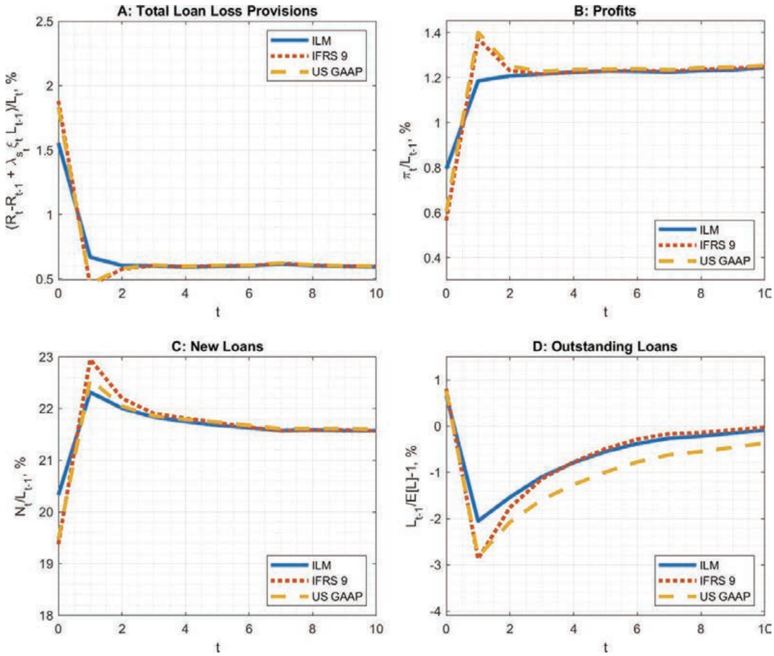



**Note:** This figure depicts the (generalized) impulse response functions of total loan loss provisions, profits, and new and outstanding loans to the arrival of a contraction at date $t = 0$ when the cost of external equity issuance are set to zero—that is, $\eta_{s_t} = 0$. The impulse response functions are presented for three scenarios: incurred loss model (ILM) and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP. The impulse response of outstanding loans is in terms of relative changes to the (unconditional) mean $\mathbb{E}[L]$. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

Similarly, one proves $\frac{\mathrm{d}}{\mathrm{d}\theta_0} P_1 < 0$. First, write

$$
\begin{aligned}
P_1 &:= \mathbb{P}\left(X_1 < 0\right) \\
&= \mathbb{P}\left((1 - \tau(\pi_1))\left((r_1^L + \theta_0) + \kappa_0\right) < 0\right)
\end{aligned}
$$

**Figure A.3. Effect of the Arrival of a Lower Persistency Contraction**



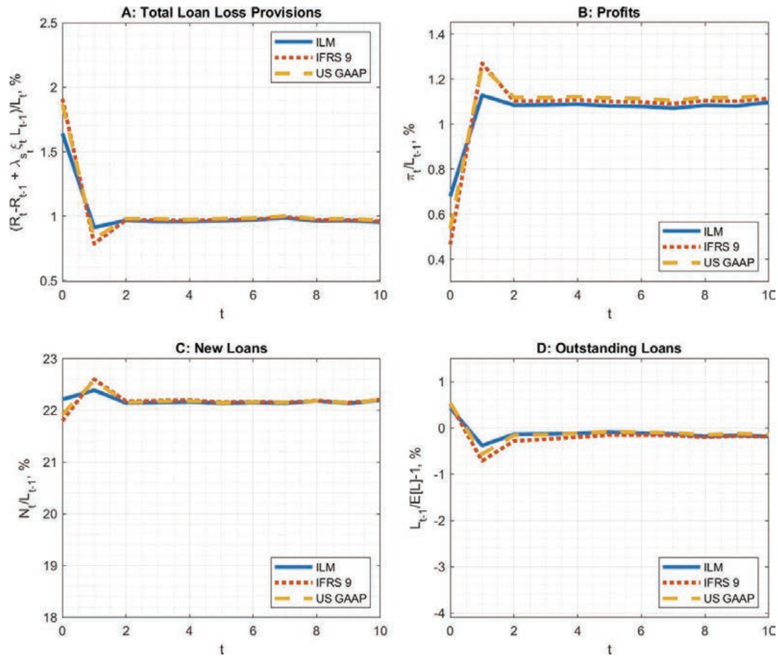

**Note:** This figure depicts the (generalized) impulse response functions of total loan loss provisions, profits, and new and outstanding loans to the arrival of a contraction at date $t = 0$ when the probability of remaining in a contraction is 0.2, implying that an average duration of a contraction is 1.25 year. The impulse response functions are presented for three scenarios: incurred loss model (ILM) and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP. The impulse response of outstanding loans is in terms of relative changes to the (unconditional) mean $\mathbb{E}[L]$. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

$$= \mathbb{P}\left(r_1^L < -\frac{\kappa_0}{1-\tau(\pi_1)} - \theta_0 | z\right)$$

$$= \mathbb{P}\left(\frac{r_1^L - \mu_0}{\sigma_0} < -T_0\right) = \Phi\left(T_0\right) = 1 - \Phi\left(T_0\right),$$

where $T_0 = \frac{\frac{\kappa_0}{1-\tau(\pi_1)} + \theta_0 + \mu_0}{\sigma_0}$.

**Figure A.4. Effect of the Arrival of a Contraction under Symmetric Distribution of Aggregate States**




**Note:** This figure depicts the (generalized) impulse response functions of total loan loss provisions, profits, and new and outstanding loans to the arrival of a contraction at date $t = 0$ when the probability of remaining in either a contraction or an expansion is 0.5. The impulse response functions are presented for three scenarios: incurred loss model (ILM) and two variants of the EL approach, namely, IFRS 9 and U.S. GAAP. The impulse response of outstanding loans is in terms of relative changes to the (unconditional) mean $\mathbb{E}[L]$. The impulse responses are evaluated by taking the average across 30,000 simulated paths of the variables of interest, with each path having the length of 11 periods and the identical initial condition $(L_{-1}, s_{-1})$. The initial condition is such that prior to $t = 0$ the bank is in an expansionary aggregate state, $s_{-1} = g$, and its endogenous state is given by the conditional on an expansionary aggregate state mean values—that is, $L_{-1} = \mathbb{E}[L_t|s_t = g]$.

Then it follows immediately that

$$\frac{\mathrm{d}}{\mathrm{d}\theta_0} P_1 = -\frac{\phi(T_0)}{\sigma_0} < 0. \tag{A.5}$$

## Appendix B. Calibration Details

### *B.1 Vasicek Distribution*

Following Vasicek (2002), we assume that the failure of an individual loan $j$ at time $t$ is driven by the realization of a latent random variable:

$$y_j = \Phi^{-1}(p_{s_t}) + \sqrt{\rho_{s_t}} z_t + \sqrt{1-\rho_{s_t}} u_{j_t}, \tag{B.1}$$

where $\Phi(.)$ is the standard normal CDF, $z_t \sim \mathcal{N}(0,1)$ is the common risk, $u_{j_t} \sim \mathcal{N}(0,1)$ is idiosyncratic risk, and $\rho_{s_t}$ is the correlation coefficient that determines a correlation between the performance of individual loans.

The loan defaults when $y_j < 0$, which happens with probability

$$\begin{aligned}\mathbb{P}(y_j < 0) &= \mathbb{P}\left(\sqrt{\rho_{s_t}} z_t + \sqrt{1-\rho_{s_t}} u_{j_t} < -\Phi^{-1}(p_{s_t})\right) \\ &= \Phi\left(\Phi^{-1}(p_{s_t})\right) = p_{s_t}.\end{aligned} \tag{B.2}$$

Since the probability of failure $p_{s_t}$ is identical for all loans, by the law of large numbers, the failure rate $\xi_t$ for a given realization of the systematic risk factor $z_t$ equal to the probability of failure of a (representative) project $j$ conditional on $z_t$. Thus,

$$\begin{aligned}\xi_t = \xi_t(z_t, s_t) &= \mathbb{P}\left(\sqrt{\rho_{s_t}} z_t + \sqrt{1-\rho_{s_t}} u_{j_t} < -\Phi^{-1}(p_{s_t}) \,|z_t\right) \\ &= \Phi\left(\frac{\Phi^{-1}(p_{s_t}) - \sqrt{\rho_{s_t}} z_t}{\sqrt{1-\rho_{s_t}}}\right).\end{aligned} \tag{B.3}$$

We can now easily derive the distribution of $\xi_t(z_t, s_t)$, which is given by

$$F(\xi_t|s_t) = \mathbb{P}(\xi_t(z_t, s_t) \le \xi_t) = \Phi\left(\frac{\sqrt{1-\rho^i_{s_t}}\Phi^{-1}(\xi^i_t) - \Phi^{-1}(p^i_{s_t})}{\sqrt{\rho^i_{s_t}}}\right), \tag{B.4}$$

where the last equality comes from substituting Equation (B.3) for $\xi_t(z_t, s_t)$ above and rearranging terms.

Note that the distribution function in Equation (B.4) has two parameters: $p^i_{s_t}$ and $\rho^i_{s_t} \in (0,1)$. $p^i_{s_t}$ is the stage $i$ loan default probability. $\rho^i_{s_t} \in (0,1)$ is the correlation parameter, which captures the dependence of individual loan on the common risk factor and, thus, determines the degree of correlation between individual loan defaults. While we calibrate $p^i_{s_t}$ from the data, the correlation coefficient is computed consistent with the Basel approach (paragraph (53) of the section Internal Ratings-Based Approach for Credit Risk in Basel Committee on Banking Supervision 2017) such that $\rho^i_{s_t} = \rho\left(p^i_{s_t}\right)$, where

$$\rho\left(p^i_{s_t}\right) = 0.12\frac{1-\exp^{-50p^i_{s_t}}}{1-\exp^{-p^i_{s_t}}} + 0.24\left(1-\frac{1-\exp^{-50p^i_{s_t}}}{1-\exp^{-p^i_{s_t}}}\right). \quad \text{(B.5)}$$

*B.2 Capital Requirement*

Under the internal ratings-based approach, the capital requirement for corporate and bank exposures is meant to ensure sufficient capital to cover loan losses with a confidence level of 99.9 percent. The formula for $\kappa^i_{s_t}$ is taken from paragraph (53) of Internal Ratings-Based Approach for Credit Risk in Basel Committee on Banking Supervision (2017) and is given by

$$\kappa^i_{s_t} = \left[\lambda_b \Phi\left(\frac{\Phi^{-1}(\bar{p}_i)}{\sqrt{1-\bar{\rho}_i}} + \sqrt{\frac{\bar{\rho}_i}{1-\bar{\rho}_i}}\Phi^{-1}(0.999)\right) - \bar{p}\lambda_b\right] \times \frac{1+(M-2.5)b_i}{1-1.5b_i}, \quad \text{(B.6)}$$

where $\bar{p}_i := q_g p^i_g + q_b p^i_b$ is the through-the-cycle (i.e., unconditional on the aggregate state) default probability of stage $i$ loans; $\bar{\rho}_i = \rho(\bar{p}_i)$ is the through-the-cycle loan default correlation coefficient of stage $i$ loans; $M$ is effective maturity in years, which in our model is given by $1/\delta$; $b_i = [0.11852 - 0.05478\ln(\bar{p}_i)]$ is the maturity adjustment coefficient. Under the IRB approach, Basel III specifies the use of downturn loss given default in computing the capital requirement, which in our model corresponds to $\lambda_b$. The overall capital requirement is then given by

$$\kappa_{s_t} = \omega_{s_t}\kappa^1_{s_t} + (1-\omega_{s_t})\kappa^2_{s_t}. \quad \text{(B.7)}$$

### *B.3 Discounted Lifetime Losses*

The discounted lifetime losses on a unit size stage $i$ loan can be written recursively as

$$\theta_{s_t}^{LT} = \frac{1}{1+d_{s_t}} \mathbb{E}[\lambda_{s_{t+1}} \xi_{t+1} + (1-\xi_{t+1})(1-\delta)\theta_{s_{t+1}}^{LT} | s_t]. \qquad \text{(B.8)}$$

The above equation can be written in matrix form as

$$\bar{\theta}^{LT} = A\bar{\theta}^{LT} + \mu, \qquad \text{(B.9)}$$

where

$$A = \frac{1-\delta}{1+d_{s_t}} Q \circ \begin{bmatrix} 1-p_g & 1-p_b \\ 1-p_g & 1-p_b \end{bmatrix}, \qquad \text{(B.10)}$$

and

$$\mu = \frac{1}{1+d_{s_t}} Q \begin{bmatrix} \lambda_g p_g \\ \lambda_b p_b \end{bmatrix}, \qquad \text{(B.11)}$$

where $Q$ is the $2 \times 2$ transition probability matrix and "$\circ$" denotes the Hadamard (element-wise) product. Thus,

$$\bar{\theta}^{LT} = (I_{2\times 2} - A)^{-1} \mu,$$

where $I_{2\times 2}$ is a $2 \times 2$ identity matrix.

## Appendix C. Numerical Solution Method

### *C.1 Model*

We obtain a fully non-linear solution to the model numerically using the value function iteration method. In general, the model has two endogenous state variables, $E_t$ and $L_t$. However, given the calibrated values of the parameters, we find that the minimum capital requirement $E_t \geq \kappa_{s_t} L_t$ is binding on the simulation path. Therefore, we solve our model under assumption that $E_t = \kappa_{s_t} L_t$. Thus, effectively, the model has one endogenous state variable $L_t$. The grids for $L_{t-1}$ consist of 120 points and include 119 equispaced points between 0.17 and 0.65, and 0. Furthermore, we use a linear interpolation method for the grid of choice variables $L_t$ (implemented by applying the *interp1* MATLAB function to the original grids of $L_{t-1}$ with the query point equal to 0.1). As a result of linear interpolation, the grids for $L_t$ consist of 1,201 points. The high density of the grid for the choice variable is highly important to obtain a reliable approximation of the solution to our model. This is because the loss rate $\xi_t$ and, thus, the provisioning rate $\theta_{s_t}$ have relatively small magnitudes. Therefore, to pick up any effect from a relatively small change in $\theta_{s_t}$ (say the difference between IFRS 9 and U.S. GAAP), it is crucial that the grid for $L_t$ is sufficiently dense.

For the numerical representation of the exogenous state the random variable $\xi_t$ is discretized. The grid of the $\xi_t^i$'s support consists of 41 points (in each aggregate state). As we show in Appendix B, the default rate $\xi_t^i$ can be written as a function of the standard normal distribution:

$$\xi_t^i = g(u; s_t) = \Phi\left(\frac{\Phi^{-1}(p_{s_t}^i) - \sqrt{\rho_{s_t}^i}u}{\sqrt{1-\rho_{s_t}^i}}\right),$$

where $\Phi(.)$ is the standard normal $p_{s_t}^i$ and $\rho_{s_t}^i$ are defined in the text, and $u \sim \mathcal{N}(0,1)$. Therefore the discrete approximation of $\xi_t^i$ is obtained by discretizing $u$ which is performed using the approach of Tauchen (1986) (we set the bounds of the support of $u$ to [–3.5;3.5] allowing for extreme realizations of $u$). Because we have two possible realizations of aggregate states and also record the one-period history of the aggregate state ($s_{t-1}$), the space of exogenous state consists of $2 \times 2 \times 41 = 164$ points.

To compute the moments implied by the model, we simulate our model for 80,000 periods. The first 200 observations are dropped when computing the moments to avoid the initial value having any effect. When the bank defaults on the simulation path, it is replaced starting from the next period with a new bank with the average size (i.e., with $L_t$ given by unconditional means). Given that default is a rare event, the replacement rule does not have any profound effect on the moments.

### *C.2 Generalized Impulse Response Functions*

The generalized impulse response is approximated using a simulation method. That is, given the initial state variable, we perform $N = 30,000$ simulations of the model each with the length of $T = 20$ periods. Averaging the variable of interest across simulated paths for each period $t \in [0, T]$ then produces its generalized impulse response in that period. Taking $p$-th and 100-$p$-th percentile across the simulated paths produces the $p$ percent confidence bounds. In our figures, we only plot the approximated responses for the first 11 periods.

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