Optimal Credit, Monetary, and Fiscal Policy under Occasional Financial Frictions and the Zero Lower Bound*

Shifu Jiang
Hong Kong Monetary Authority

I study optimal credit, monetary, and fiscal policy under commitment in a model where financial intermediaries face an occasionally binding financial constraint; the monetary authority faces a zero lower bound; and the fiscal authority faces a budget constraint. Financial and productivity shocks can generate a trade-off between inflation stability and financial stability, which is resolved in favor of the latter. As the ZLB prevents full-scale monetary easing and financial distress disrupts the transmission mechanism, monetary policy should be relatively tight in normal times for precautionary reasons. However, monetary policy should be eased in response to large productivity shocks regardless of the sign. The policy based on optimized simple rules features too-aggressive credit interventions and insufficient monetary easing relative to the Ramsey policy.

JEL Codes: E44, E52, E6, C61.

1. Introduction

New developments after the 2007–09 global financial crisis (GFC) induced central banks to rethink their monetary policy frameworks. For example, neutral interest rates have been falling globally for years, and this trend is expected to persist (Holston, Laubach, and

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Williams 2017). Thus, monetary policy is more likely to hit the zero lower bound (ZLB). In addition, financial shocks that disrupt financial intermediation (Ivashina and Scharfstein 2010) and possibly the transmission mechanism of monetary policy (Altavilla, Canova, and Ciccarelli 2016) have received much attention. Indeed, Schularick and Taylor (2012) conclude that the financial system not only amplifies macroeconomic shocks but is also an independent source of volatility, while Jermann and Quadrini (2012) find financial shocks to be an important driver of business cycles. To ease financial crunches, unconventional monetary policies such as quantitative easing (QE) have been made popular with the hope of reducing long-term interest rates, boosting lending, and stimulating real activity.[1] In this course, there are ongoing debates on how the current policy framework should evolve and if the policy toolkit should be expanded.

This paper tries to shed some new light on this topic from a specific angle. I study optimal credit, monetary, and fiscal policy under commitment (Ramsey policy) in a low interest rate environment with financial and macroeconomic disturbances. Credit policy is modeled as private asset purchases; monetary policy controls the nominal interest rate subject to the ZLB; and fiscal policy sets a labor tax subject to the government budget constraint. Despite a large literature on each of these policies (summarized in the next section), the normative aspect of the joint policy has not yet been fully understood. For example, credit policy may restore the functioning of financial markets on which the transmission mechanism of monetary policy depends. But the literature often only considers credit policy in a liquidity trap or, when credit policy is not available, debates whether monetary policy should respond to financial conditions (Curdia and Woodford 2010). On the fiscal side, many

[1] It is relatively well established that unconventional monetary policy reduces the long-term interest rates. See, among many others, Gagnon et al. (2011) and Krishnamurthy and Vissing-Jorgensen (2011) for the Federal Reserve's QE, and Joyce et al. (2011) and Christensen and Rudebusch (2012) for the Bank of England's QE. However, unconventional monetary policy may have insignificant or unintended real effects through a bank lending channel, as shown by Acharya et al. (2017) and Chakraborty, Goldstein, and MacKinlay (2017). Overall, it is widely believed that this kind of policy played a key role during the GFC; see Cahn, Matheron, and Sahuc (2017), Del Negro et al. (2017), Quint and Rabanal (2017), etc.

countries are left with high levels of public debt after the GFC (see, e.g., Oh and Reis 2012; Caruso, Reichlin, and Ricco 2018), which must be stabilized by either inflation or fiscal surpluses going forward. In this context, potential losses on the central bank's balance sheet can increase the fiscal burden and make it more difficult to raise interest rates when the time comes (Evans et al. 2015).

In studying these issues, I focus on the Ramsey policy because the ability to commit has become more relevant in recent years, thanks to improved communication and active forward guidance. Moreover, expectation management has been at the center of recent policy revisions[2] because, e.g., a flattened Phillips curve downplays the role of aggregate demand and emphasizes the role of inflation expectations in controlling inflation. Svensson (2019) argues that central banks can adopt a "forecast-targeting" strategy. Forecast targeting means that policy instruments are set such that the resulting forecasts of target variables, e.g., inflation, are desirable. With this strategy, forward guidance is the default when central banks publish the paths of policy instruments and the forecasts of target variables that justify the policy decision.

In this paper, I employ a simple New Keynesian model augmented with Gertler and Kiyotaki (2010) style financial frictions. Financial intermediaries (referred to as banks) face a financial constraint derived from an agency problem between banks and depositors. A key feature of this model is that the financial constraint depends on banks' future profitability, which can be affected by the entire path of policy instruments. The constraint is slack in normal times but binds endogenously in periods of financial distress, which can be triggered by a "Minsky moment." That is, agents in the economy suddenly realize that the leverage is too high. Such moments are captured by a financial shock that directly tightens the financial constraint.[3] When the constraint is binding, banks have difficulties

[2]For example, Bernanke (2017)'s temporary price-level targeting, Svensson (2019)'s average inflation targeting, and Reifschneider and Williams (2000)'s risk-management rule all are techniques to exploit expectations and have received much attention from central banks.

[3]Bordalo, Gennaioli, and Shleifer (2018) and, more generally, the literature of behavioral finance provide the microfoundation. López-Salido, Stein, and Zakrajŝek (2017) discuss how Minsky moments are complementary to financial frictions in understanding the role of credit risks in macroeconomic

rolling over their short-term debt, which leads to a collapse in asset prices and investment. The consequent deleveraging process continues to weigh on aggregate demand and inflation. Since the root of the problem is a disruption to financial intermediation, credit policy is designed to replace constrained intermediaries (banks) by an unconstrained intermediary (the government). Moreover, monetary policy can relax the financial constraint by lowering banks' real borrowing costs. Put differently, the lack of monetary easing due to the ZLB tightens the financial constraint. The ensuing widening of the credit spread (i.e., the premium in the expected return on capital over the risk-free interest rate) limits the benefits of monetary easing at the ZLB (e.g., through a commitment to future interest rates). The tax policy is helpful because it gives the government an extra margin to affect inflation. However, the government cannot fully stabilize inflation and the credit spread simultaneously even with all three policies. Thus, the model features a trade-off between inflation stability and financial stability.

My main findings are as follows. Relative to a laissez-faire equilibrium, the Ramsey equilibrium features a stochastic steady state with higher output and a remarkably stable credit spread. The government's incentive to stabilize the credit spread depends primarily on labor market efficiency in the steady state. In the Ramsey equilibrium where the steady-state labor tax rate is fixed exogenously, the optimal credit spread approaches zero quickly as the steady-state labor tax rate increases. Quantitatively, any realistic level of the steady-state labor tax rate ($\geq$10 percent) would imply virtually zero volatility of the credit spread. In this environment, banks are encouraged to choose a higher leverage level that is associated with greater risk of hitting the financial constraint. In turn, the central bank is required to hold a positive amount of private assets and set a lower nominal interest rate on average. However, when the ZLB is slack, the risk that both the financial constraint and the ZLB can bind together gives the central bank a precautionary incentive to keep the nominal interest rate relatively high. On the fiscal front, I do not find that the government budget is an important constraint on

dynamics. Similar financial shocks are also considered in, e.g., Dedola and Lombardo (2012); Eggertsson and Krugman (2012); Del Negro et al. (2017); and Perri and Quadrini (2018).

optimal policy, because the discounted sum of cash flows stemming from the government's asset purchases is small.[4]

Next, I try to understand how optimal policy responds to different shocks. A contractionary financial shock has a much larger effect on output than on inflation. As the traditional Taylor-type rule puts more weight on inflation than on output, the prescribed monetary policy is largely unresponsive. By contrast, the optimal monetary policy is more dovish by focusing on financial distress while inflation is allowed to rise modestly. A labor tax rebate is employed to help curb inflation. And the central bank should ramp up its asset purchase program if the financial shock is large enough to make the ZLB binding. My model also contains a total factor productivity (TFP) shock. An unexpected improvement in productivity should relax the financial constraint thanks to a higher rate of return on bank assets. However, it could also be damaging when a poor policy drives the economy into the liquidity trap in such a way that the shortfall in demand widens suddenly and the financial constraint binds. To escape from the spiral of Fisherian deflation, the key is to lower the real interest rate, which is needed to stimulate aggregate demand and relax the financial constraint. In other words, there is no trade-off between inflation stability and financial stability in this case. However, the trade-off is prominent under a negative TFP shock. On the one hand, inflation stability requires a tightening of monetary policy. On the other hand, stable inflation induces a binding financial constraint, which calls for monetary easing. Fortunately, the government is equipped with the credit policy to ease the financial strain and the tax policy to mitigate inflation. The trade-off is found to be resolved in favor of monetary easing, regardless of the availability of the tax policy. In summary, monetary policy should be eased in response to large, both positive and negative, productivity shocks around the stochastic steady state. However, while monetary easing in the state of high productivity is consistent with conventional wisdom, it depends crucially on the central bank's past commitments. When the central bank is less constrained by its past

[4]To be clear, this does not exclude the government budget constraint from playing an important role when, e.g., the economy is hit by a government spending shock.

commitments, the nominal interest rate tends to rise in response to unexpected productivity improvements.

Can the optimal policy be implemented by a familiar set of simple rules? I focus on the rules that let monetary policy respond to inflation and output, let credit policy respond to the credit spread, and let the labor tax rate be fixed. A more comprehensive study of optimal rules is left to future research. The optimized monetary rule echoes several findings in the literature, including a strong response to inflation but a muted response to output. Moreover, the inertia parameter exceeds but is close to 1, thus suggesting that the optimal monetary policy is forward looking and close to price-level targeting. The optimized credit rule is found to be modestly persistent, suggesting a slow unwinding of the central bank's balance sheet. The associated welfare losses are small, but the trade-off between inflation stability and financial stability is prominent. Relative to the Ramsey policy, the optimized rules feature too-aggressive credit interventions but insufficient monetary easing.

2. Related Literature

One of the main novelties of this paper is to jointly study two occasionally binding constraints (OBCs)—the financial constraint and the ZLB. The emphasis on the former is in line with Del Negro, Hasegawa, and Schorfheide (2016), Swarbrick, Holden, and Levine (2017), and Jensen et al. (2020), who have shown that such nonlinearity helps capture the sudden and discrete nature of financial crises and eliminate the financial acceleration mechanism in normal times. While these papers treat the financial constraint in a perfect-foresight manner, uncertainties surrounding the states of the constraint (binding or not) can have important implications. For example, Bocola (2016) finds that a liquidity facility like the European Central Bank's LTRO is ineffective when banks deem that the likelihood of hitting the financial constraint is high. In this paper, this kind of behavior is internalized by the Ramsey planner.

There is a large literature on monetary policy subject to the ZLB. A key lesson from this literature is that the nominal interest rate should be kept at the ZLB for a longer period of time than what a Taylor rule typically suggests (Eggertsson and Woodford 2003). Even when the nominal interest rate is positive, the presence of the ZLB calls for a more dovish monetary policy (Adam and Billi 2006; Nakov 2008) because the possibility of hitting the ZLB in the future reduces the output and inflation expectations today. In the early literature, the duration of the ZLB episode is largely exogenous, depending on a shock to the natural interest rate. Drawing on experience during the GFC, more recent work (Del Negro et al. 2017; Benigno, Eggertsson, and Romei 2020) models the origin of the ZLB episode as financial shocks that disrupt financial intermediation. This paper makes two contributions in this regard. First, I show that both positive and negative productivity shocks can drive the economy to the ZLB. Second, in contrast to the literature, the ZLB risk induces a relatively high nominal interest rate in normal times.

This paper also belongs to the growing literature on normative unconventional (credit) policy. Particularly, I share Bianchi (2016)'s emphasis on the risk-taking channel of unconventional policy. The idea is that (financial) firms need to balance the desire to invest today with the risk of becoming financially constrained in the future. They have an incentive to borrow more, knowing that the more they borrow, the larger the transfers they can receive from bailouts. The bailout policy faces the trade-off between the ex ante overborrowing and the ex post benefit of a faster recovery from a credit crunch. While this literature primarily focuses on time-inconsistent policy, Harrison (2017) studies optimal QE under discretion. He assumes a portfolio adjustment cost such that aggregate demand depends on both the short- and long-term interest rates. Hence, unlike in my model, QE works through a portfolio rebalancing channel and is effective only when the ZLB is binding.

A number of papers study optimized simple rules for unconventional policy. Foerster (2015) proposes a credit-spread-targeting rule with inertia. Conditional on monetary policy following a traditional Taylor rule, he concludes that a slow unwinding of the central bank's balance sheet is welfare improving. This is also found to be true in this paper provided that the credit policy is not too persistent. More generally, the optimal unconventional policy depends on the assumed monetary policy. Carrillo et al. (2017) study the interaction between conventional and unconventional monetary policy in a Bernanke–Gertler financial accelerator model. They focus on the relevance of Tinbergen's rule by comparing a monetary policy rule responding to both inflation and credit spreads with a dual-rule regime comprising a Taylor rule and a credit-spread-targeting financial rule. They find that the former responds too much to inflation and not enough to spreads, i.e., tight money and tight credit. In my model, the optimized monetary and credit rules are found to be too tight on money but too loose on credit.

Finally, this paper takes seriously the government budget constraint by excluding the government from access to lump-sum taxation. In most papers studying unconventional policy, it is assumed either explicitly or implicitly that the government budget constraint is not binding. The exceptions include Bianchi (2016), in which the government finances its bailout policy using a payroll tax and potentially a debt tax. However, Bianchi (2016) does not allow the government to borrow, because this would allow it to "lend" its borrowing capacity to financially constrained firms. Jiao (2019) considers an emerging economy relying on inflation and currency depreciation to finance unconventional policy. The focus of this paper is on advanced economies where the government finances its asset purchases by the optimal combination of distortionary taxes, seigniorage, and inflation. In this regard, this paper extends the optimal fiscal and monetary policy literature (e.g., Christiano, Chari, and Kehoe 1991; Schmitt-Grohé and Uribe 2004b; Siu 2004, among many others) by including a credit dimension. In this literature, the policy trade-off is between tax smoothing and price stability, which is resolved in favor of price stability even with small degrees of price rigidity. I find this result robust to the presence of financial frictions.

The rest of the paper is organized as follows. In the next section I present the model and the optimal policy problems. The quantitative method is described in section 4, followed by the main results in section 5. I examine the optimal simple rules in section 6. The last section concludes the paper.

3. Model

The model is based on a small version of Gertler and Karadi (2011), in which I abstract from a number of standard features that only matter quantitatively, e.g., working capital, variable capital utilization, and price indexation. The economy is populated by households, intermediate good producers, capital producers, financial intermediaries (referred to as banks), and a government. Intermediate good producers acquire labor and capital to produce differentiated goods, and set prices optimally when receiving a Calvo (1983) signal. Fixed investment is financed by state-contingent securities. Banks collect deposits from households subject to an agency problem and invest in the state-contingent securities, but their role in other important markets, e.g., mortgage, is abstracted. The government controls the nominal interest rate, purchases private securities, sets tax rates, and issues government bonds. The government may be able to vary lump-sum taxes, which can be used to remove the government budget from the Ramsey planner's constraints.

I depart from Gertler and Karadi (2011) in two important ways. First, I assume that the central bank sets the risk-free nominal interest rate, instead of the real rate. An important implication of this (more realistic) assumption is that monetary policy generating unanticipated inflation can affect the real borrowing cost of banks and the government. In this way, monetary policy interacts with credit and fiscal policy. Second, my model is a monetary economy with money demand and supply. Money demand encourages the central bank to stabilize the nominal interest rate rather than inflation, and money supply generates seigniorage incomes for the government.

3.1 Households

There is a unit-continuum of infinitely lived households. Households consume final goods c_t and supply labor l_t. They save in bank deposits D_t and fiat money M_t. Deposits are risk-free one-period nominal bonds carrying a gross rate of return R_t. Money facilitates consumption purchases. Households also own financial and non-financial firms.

Each household consists of workers and bankers who pool consumption risk perfectly. Workers are hired by intermediate good producers and bring wages to the household. Bankers manage a bank and transfer profits to the household. It is convenient to assume that households do not save in their own banks. The complete consumption insurance allows me to work with a consolidated representative household. The household chooses consumption, labor supply, and savings to maximize its life-time utility

$$\mathbb{W}_t = \left[\frac{(c_t - hc_{t-1})^{1-\sigma}}{1-\sigma} - \chi\frac{l_t^{1+\varphi}}{1+\varphi}\right] + \mathbb{E}_t\beta\mathbb{W}_{t+1}, \tag{1}$$

where $\sigma > 0$ is the measure of relative risk aversion, h is the habit parameter, $\chi > 0$ is the disutility weight on labor, $\varphi > 0$ is the (inverse of) Frisch elasticity of labor supply, and $0 < \beta < 1$ is the subjective discount factor. The household faces a budget constraint:

$$c_t[1 + s(v_t)] + \frac{M_t}{P_t} + \frac{D_t}{P_t} + \tau_t \leq w_t l_t(1 - \tau_{w,t}) + D_{t-1}\frac{R_{t-1}}{P_t} + \frac{M_{t-1}}{P_t} + \mathcal{F}_t,$$

where $s(v_t)$ is a proportional transaction cost of consumption purchases, P_t is the price of final goods, w_t is the real wage rate, $\tau_{w,t}$ is the labor tax rate, τ_t is lump-sum taxes, and $\mathcal{F}_t$ are the net real transfers from firms. The transaction cost takes the same function form as in Schmitt-Grohé and Uribe (2004b):

$$s(v_t) = \mathcal{A}v_t + \frac{\mathcal{B}}{v_t} - 2\sqrt{\mathcal{A}\mathcal{B}},$$

where $v_t = \frac{P_t c_t}{M_t}$ is consumption-based money velocity, and $\mathcal{A}$ and $\mathcal{B}$ are parameters.

The first-order necessary conditions are

$$(c_t - hc_{t-1})^{-\sigma} - \mathbb{E}_t\beta h(c_{t+1} - hc_t)^{-\sigma} = \lambda_t^h(1 + 2\mathcal{A}v_t - 2\sqrt{\mathcal{A}\mathcal{B}}),$$

$$\chi l_t^{\varphi}/\lambda_t^h = w_t(1 - \tau_{w,t}), \tag{2}$$

$$\mathbb{E}_t[\Xi_{t,t+1} r_{t+1}] = 1, \tag{3}$$

$$v_t^2 = \frac{\mathcal{B}}{\mathcal{A}} + \frac{R_t - 1}{\mathcal{A}R_t}, \tag{4}$$

where $\Xi_{t,t+1} \equiv \beta\frac{\lambda_{t+1}^h}{\lambda_t^h}$ is the stochastic discount factor and $r_{t+1} = \frac{R_t P_t}{P_{t+1}}$ is the real interest rate.

3.2 Non-financial Firms

There are two types of non-financial firms: capital producers and intermediate good producers.

3.2.1 Intermediate Good Producers

There is a continuum of intermediate good firms indexed by $m \in [0,1]$. They have access to a Cobb-Douglas technology $y_{m,t} = A_t(\xi_t k_{m,t-1})^\alpha l_{m,t}^{1-\alpha}$, where $0 < \alpha < 1$ is the capital share, A_t is total factor productivity, and $k_{m,t}$ is the capital stock at the end of period t. Let δ be the depreciation rate and ξ_t the quality of capital. Firm m acquires additional capital $i_{m,t} = k_{m,t} - (1-\delta)\xi_t k_{m,t-1}$. To finance its fixed investment, the firm issues securities $s_{m,t}$. Each unit of securities is a state-contingent claim to the future returns of one unit of capital. Following Gertler and Karadi (2011), capital and the securities have the same real price q_t under the assumption that $s_{m,t} = k_{m,t}$.[5] The real rate of return of holding securities for one period is given by

$$r_{k,t+1} \equiv \frac{z_{t+1} + (1-\delta)\xi_{t+1}q_{t+1}}{q_t}, \tag{5}$$

where z_t is the dividend rate on capital.

Let μ_t denote the real marginal cost. Cost minimization gives

$$w_t = (1-\alpha)A_t\left(\frac{\xi_t k_{m,t-1}}{l_{m,t}}\right)^\alpha \mu_t, \tag{6}$$

$$z_t = \alpha A_t(\xi_t)^\alpha\left(\frac{k_{m,t-1}}{l_{m,t}}\right)^{\alpha-1} \mu_t. \tag{7}$$

Firm m faces a downward-sloping demand function $y_{m,t} = \left(\frac{P_{m,t}}{P_t}\right)^{-\varepsilon_t} y_t$ derived from a final good aggregator $y_t = \left[\int_0^1 y_{m,t}^{\frac{\varepsilon_t - 1}{\varepsilon_t}} dm\right]^{\frac{\varepsilon_t}{\varepsilon_t - 1}}$, where $P_{m,t}$ is the price of intermediate good m and $\varepsilon_t > 0$ is the elasticity of substitution. With probability $1-\gamma$, firm m can optimize price $P^*_{m,t}$ subject to the demand function by solving

[5]This assumption implies that firms cannot borrow directly from households by paying a negative dividend. Otherwise the banking sector becomes trivial. Similar assumptions have been made in, e.g., Bianchi (2016), where the dividend payment is constrained from below.

$$\max \mathbb{E}_t \sum_{j=0}^{\infty} \gamma^j \Xi_{t,t+j} \left[\frac{P^*_{m,t}}{P_{t+j}} - (1+\tau_{y,t+j})\mu_{t+j} \right] y_{m,t+j},$$

where $\tau_{y,t}$ is a production tax. Focusing on a symmetric equilibrium, the first-order condition (FOC) is given by

$$\mathbb{E}_t \sum_{j=0}^{\infty} \gamma^j \Xi_{t,t+j} \left[(1-\varepsilon_t) \left(\frac{1}{\Pi_{s=1}^{j} \Pi_{t+s}} \right)^{1-\varepsilon_t} p^*_t \right.$$
$$\left. + \varepsilon_t \left(\frac{1}{\Pi_{s=1}^{j} \Pi_{t+s}} \right)^{-\varepsilon_t} (1+\tau_{y,t+j})\mu_{t+j} \right] y_{t+j} = 0, \qquad (8)$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$ is inflation and $p^*_t = p^*_{m,t} = \frac{P^*_{m,t}}{P_t}$ is the optimized real price of intermediate goods.

3.2.2 Capital Producers

Capital producers face a cost function $f(\cdot) = i_t + \frac{\eta}{2}\left(\frac{i_t}{\delta k_{t-1}} - 1\right)^2 \delta k_{t-1}$ with $\eta \geq 0$[6] and price new capital optimally according to

$$q_t = 1 + \eta \left(\frac{i_t}{\delta k_{t-1}} - 1 \right). \qquad (9)$$

3.3 Banks

Banks are financial intermediaries engaging in maturity and liquidity transformation. A bank receiving deposits amounting to D_t from households and purchasing s_t units of securities from intermediate good producers has the balance sheet

$$q_t s_t = \frac{D_t}{P_t} + n_t,$$

[6] Another popular specification of the cost function is $f(\cdot) = i_t + \frac{\eta}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 i_t$, which renders a more complicated FOC. However, the results under both specifications are quantitatively similar.

where n_t is the bank's real net worth at the beginning of period t.[7] The net worth evolves according to

$$\begin{aligned} n_t &= q_{t-1}s_{t-1}r_{k,t} - D_{t-1}\frac{R_{t-1}}{P_t} \\ &= q_{t-1}s_{t-1}(r_{k,t} - r_t) + n_{t-1}r_t, \end{aligned}$$

where in the second line I use the balance sheet equation to substitute for $\frac{D_t}{P_t}$. The bank's leverage is defined as

$$\phi_t = \frac{q_t s_t}{n_t}.$$

As in Gertler and Karadi (2011), each bank shuts down with probability r_n at the end of each period, upon which the bank distributes its net worth to its household.[8] Then, bankers become workers. In the meantime, a similar number of workers from the same household randomly become new bankers. New bankers receive "start-up" funds from their household as a proportion ϖ of the total value of capital in the economy.[9]

Each bank chooses an investment plan s_t to maximize its expected present value of net worth upon closure:

$$\begin{aligned} V_t(n_t) &= \max \mathbb{E}_t \sum_{j=0}^{\infty} r_n(1-r_n)^j \Xi_{t,t+j+1} n_{t+1+j} \\ &= \max \mathbb{E}_t \Xi_{t,t+1}[r_n n_{t+1} + (1-r_n)V_{t+1}(n_{t+1})] \\ &= \nu_{n,t} n_t, \end{aligned}$$

where the third equality follows a conjecture that the value function is linear in net worth with an unknown time-varying coefficient $\nu_{n,t}$. The bank faces an agency problem that implies an upper bound

[7] It is easy to show that each bank is a scaled version of the others. The heterogeneity in their net worth and asset holdings does not affect their aggregate behaviors. See Gertler and Karadi (2011).

[8] The notation r_n follows the idea that the probability of shutting down can be interpreted as an exogenous dividend rate.

[9] In Gertler and Karadi (2011), the start-up funds are proportional to the assets held by incumbent banks. I make this minor change to ensure that start-up funds are not affected by the central bank's asset purchasing.

on its leverage level (i.e., the financial constraint; see Gertler and Karadi 2011 for details):

$$\frac{\nu_{n,t}}{\theta_t} - \phi_t \geq 0, \tag{10}$$

where $\theta_t \in [0,1]$ is an exogenous process controlling the tightness of the constraint, and shocks to θ_t are referred to as financial shocks capturing "Minsky moments" in a reduced form (e.g., disturbances to haircuts that change the effective value of net worth).

Let the multiplier associated with (10) be $\lambda_t \geq 0$. The necessary conditions of the bank's problem include the complementary slackness condition

$$\left(\frac{v_{n,t}}{\theta_t} - \phi_t\right)\lambda_t = 0, \tag{11}$$

and the first-order condition

$$\begin{aligned}\mathbb{E}_t \Xi_{t,t+1}(r_n + (1 - r_n)\nu_{n,t+1})(r_{k,t+1} - r_{t+1}) &\equiv \nu_{s,t} \\ &= \frac{\lambda_t}{1 + \lambda_t}\theta_t \geq 0. \end{aligned} \tag{12}$$

The unknown coefficient $\nu_{n,t}$ can be solved using (10) and (12):

$$\nu_{n,t} = \nu_t \left(\frac{\nu_{s,t}}{\theta_t - \nu_{s,t}} + 1\right), \tag{13}$$

where $\nu_t \equiv \mathbb{E}_t \Xi_{t,t+1}(r_n + (1 - r_n)\nu_{n,t+1})r_t$. Note that $\nu_{s,t}$ is forward looking when the financial constraint is binding and equal to zero (i.e., independent of future states) otherwise. It follows that successful policy can narrow the credit spread today by reducing the probability of hitting the financial constraint in the future.

3.4 The Government

Following the standard approach in the public finance literature, the specific agency that implements each policy is abstracted from the model. By focusing on a consolidated government, it is implicitly assumed that the central bank can receive fiscal support for its balance sheet, which could be particularly necessary when the balance sheet is large (Del Negro and Sims 2015; Benigno and Nisticò 2020). The government holds a proportion $\mathcal{P}_t \in [0, 1]$ of the total securities issued by intermediate good producers,[10] which renders a quadratic resource cost

$$\tau_{\mathcal{P}}(\mathcal{P}_t q_t s_t)^2,$$

where $\tau_{\mathcal{P}} \geq 0$ is a parameter. Following the literature (Gertler and Karadi 2011; Dedola, Karadi, and Lombardo 2013; Foerster 2015), this cost represents inefficient public activities in private financial markets or the cost of strengthened financial surveillance.[11] Because of this cost, the government's asset purchases may increase the fiscal burden even when the credit spread is positive.

The consolidated budget constraint is given by

$$g_t + \frac{R_{t-1}}{\Pi_t} b_{t-1} + \frac{m_{t-1}}{\Pi_t} + \mathcal{P}_t q_t s_t + \tau_{\mathcal{P}}(\mathcal{P}_t q_t s_t)^2 =$$
$$\tau_t + w_t l_t \tau_{w,t} + \int_0^1 \tau_{y,t} \mu_t y_{m,t} dm + b_t + m_t + \mathcal{P}_{t-1} q_{t-1} s_{t-1} r_{k,t}, \tag{14}$$

where tax revenues include labor taxes $w_t l_t \tau_{w,t}$, production taxes $\int_0^1 \tau_{y,t} \mu_t y_{m.t} dm$, and lump-sum taxes τ_t; g_t is exogenous wasteful government consumption; $m_t = \frac{M_t}{P_t}$ are real money balances; $b_t = \frac{B_t}{P_t}$; and B_t is a one-period state-noncontingent nominal asset. As in Gertler and Karadi (2011), B_t can be interpreted as either government bonds or reserves. In the former case, D_t denotes the sum of bank deposits and government bonds held by households. In the latter case, B_t is part of the bank assets. Assuming that the agency problem does not apply to reserves, B_t simply drops out of the bank's problem.

[10] In an early version of this paper, I compare the three credit measures laid out by Gertler and Kiyotaki (2010), namely asset purchases, liquidity facilities, and liquity injections. It can be shown that without any further distortions introduced in the model, these measures only differ in a trivial way. I focus on an asset purchase program in this paper because it is the easiest to understand.

[11] Dedola, Karadi, and Lombardo (2013) add a linear term in the cost function, but they only find the coeffcient on the quadratic term playing an important role.

3.5 Competitive Equilibrium

DEFINITION 1. *Given policies* $\{\tau_{w,t}, \tau_{y,t}, R_t, \mathcal{P}_t, \tau_t\}$, *exogenous processes* $\{A_t, \xi_t, \theta_t, g_t, \varepsilon_t\}$, *and initial conditions, a competitive equilibrium of aggregate dynamics is a set of plans*

$$\{c_t, l_t, m_t, P_t^*, \Pi_t, \iota_t, y_t, \mu_t, k_t, s_t, w_t, z_t, q_t, i_t, \nu_{n,t}, n_t, b_t\},$$

satisfying the FOCs of the household (2, 3, 4), the FOCs of non-financial firms (6, 7, 8, 9), the Karush–Kuhn–Tucker conditions and value function of the bank ($\lambda_t \geq 0$, *10, 11, 12, 13), the aggregate production function*

$$y_t \iota_t = A_t(\xi_t k_{t-1})^\alpha l_t^{1-\alpha}, \tag{15}$$

the following laws of motion (for, respectively, the price index, price dispersion, capital, and the aggregate net worth):

$$1 = (1-\gamma)p_t^{*1-\varepsilon_t} + \gamma \Pi_t^{\varepsilon_t - 1}, \tag{16}$$

$$\iota_t = (1-\gamma)p_t^{*-\varepsilon_t} + \gamma \Pi_t^{\varepsilon} \iota_{t-1}, \tag{17}$$

$$k_t = i_t + (1-\delta)\xi_t k_{t-1}, \tag{18}$$

$$n_t = (1-r_n)(q_{t-1}s_{t-1}\mathcal{P}_{t-1}(r_{k,t} - r_t) + n_{t-1}r_t) + \varpi q_{t-1}s_{t-1}, \tag{19}$$

the government budget constraint (14), and finally two market clearing conditions

$$y_t = c_t[1 + s(\upsilon_t)] + f(k_{t-1}, i_t) + \tau_{\mathcal{P}}(\mathcal{P}_t q_t s_t)^2 + g_t, \tag{20}$$

$$s_t = k_t, \tag{21}$$

where λ_t^h, υ_t, $r_{k,t}$, $\nu_{s,t}$, *and* ν_t *are defined in the text, and* $\iota_t \equiv \int_0^1 \left(\frac{P_{m,t}}{P_t}\right)^{-\varepsilon_t} d_m$.

3.6 Policy

The jointly optimal credit, monetary, and fiscal policy is a set of plans $\{\tau_{w,t}, \tau_{y,t}, R_t, \mathcal{P}_t, \tau_t\}$ that maximizes (1) subject to the competitive equilibrium.[12] There are three sources of inefficiency in the

[12]The problem can be somewhat simplified by noting that (12) is a redundant constraint at least locally around the chosen steady state. This can be

model, namely the financial constraint, nominal rigidity, and imperfect competition.[13] I focus on the first two sources and assume throughout the paper that the inefficiency of imperfect competition is offset by a constant production subsidy $\tau_y = -\frac{1}{\bar{\varepsilon}}$.[14]

Formally, I consider the following Ramsey problem.

DEFINITION 2. *A debt Ramsey equilibrium solves* $\{\tau_{w,t}, R_t, \mathcal{P}_t\}$ *to maximize (1) subject to the competitive equilibrium and the ZLB,* $\ln R_t \geq 0$. *There is a production subsidy* $\tau_y = -\frac{1}{\bar{\varepsilon}}$ *financed by fixed lump-sum taxes. The net government deficit is financed by public debts.*

Since the first-order condition with respect to public debt features a unit root, the local approximation technique used to solve the model (to be discussed later) is inaccurate in long simulations, which are necessary to compute most interesting statistics in my highly nonlinear model. Moreover, the accuracy can be particularly poor when I calculate welfare using a second-order approximation. Therefore, it is convenient to consider a stationary "lump-sum Ramsey equilibrium," in which the government budget is not a binding constraint.

DEFINITION 3. *A lump-sum Ramsey equilibrium solves* $\{\tau_{w,t}, R_t, \mathcal{P}_t\}$ *to maximize (1) subject to the competitive equilibrium and the ZLB,* $\ln R_t \geq 0$. *There is a production subsidy* $\tau_y = -\frac{1}{\bar{\varepsilon}}$. *Lump-sum taxes are set to balance the government budget period by period. The steady-state labor tax rate is not chosen optimally but set equal to that of the debt Ramsey equilibrium, which equates the steady states of both equilibria. Effectively, the lump-sum Ramsey planner chooses deviations of the labor tax rate from its steady states.*

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confirmed in a quantitative analysis, as the Lagrange multiplier associated with this constraint always equals zero. Intuitively, the government has no incentive to overinvest in physical capital.

[13] One may consider money demand motivated by a transaction cost and the costly capital production as extra sources of distortion.

[14] This assumption is unlikely to change my main results. As shown by Schmitt-Grohé and Uribe (2004a), imperfect competition only shifts average optimal inflation upwards. This is because the social planner would like to tax money balances as an indirect way to tax monopoly profits.

In the lump-sum Ramsey equilibrium, the main difference between the chosen steady state and its optimal steady state concerns the labor tax rate, which is 30 percent in the former and −0.05 percent in the latter under my calibration. I focus on the high-tax steady state for three reasons: (i) the average tax wedge across OECD countries is about 37 percent between 2000 and 2019 according to OECD Tax Statistics; (ii) to make the debt and lump-sum Ramsey equilibria more comparable; and (iii) to capture labor market imperfections that are not explicitly modeled. In Appendix A, I show that the lump-sum Ramsey equilibrium behaves similarly to the debt Ramsey equilibrium provided that they share the same steady state. Therefore, the lump-sum Ramsey model is employed as the workhorse model throughout the paper and is referred to simply as the Ramsey equilibrium/model for convenience. In solving the Ramsey equilibrium, I follow the "timeless" perspective advocated by Woodford (2003). First-order conditions are derived using MATLAB's symbolic toolbox. Then, the equilibrium is represented by a system of difference equations, which can be solved numerically using the method discussed in the next section. I compare the Ramsey equilibrium to a laissez-faire equilibrium defined as follows:

DEFINITION 4. *A laissez-faire equilibrium is a competitive equilibrium where $\mathcal{P}_t = 0, \tau_{w,t} = \bar{\tau}_w$, and the monetary policy follows a conventional Taylor rule*

$$\log \frac{R_t}{\bar{R}} = \max \left\{ 0.8 \log \frac{R_{t-1}}{\bar{R}} + (1 - 0.8) \left(1.5 \log \frac{\Pi_t}{\bar{\Pi}} + 0.125 \log \frac{y_t}{\bar{y}} \right), \right. \\ \left. - \log \bar{R} \right\},$$

where $\bar{R}_t$, $\bar{\tau}_w$, $\bar{\Pi}$, and $\bar{y}$ are the steady-state variables. Once more, lump-sum taxes are set to balance the government budget period by period. The steady-state labor tax rate and inflation are set equal to those of the debt Ramsey equilibrium so that both equilibria have the same steady state.

Now I briefly discuss policy trade-offs and then move to quantitative exercises.

3.7 Policy Trade-Offs

By purchasing private securities, the government acts as a financial intermediary. Since the government faces no financial constraint, credit policy effectively replaces inefficient financial intermediaries (banks) with an efficient one (the government). The policy pass-through is as follows. When the financial constraint is binding, banks are forced to deleverage by selling their assets. This creates a decline in aggregate demand, lowering both output and inflation. Credit policy makes up for the shortfall in asset demand, which improves asset prices and hence the bank net worth through a capital gain. Consequently, the financial constraint is relaxed and the credit spread narrows. However, the government may not absorb all assets sold off because of the recourse cost. At the margin, there could be a small yet positive credit spread. In this case, banks are crowded out from profitable investment and need more time to rebuild their net worth.

When the output gap and inflation move in the same direction, monetary policy ought to be a powerful tool. However, as noted in Carrillo et al. (2017), monetary policy may not be able to simultaneously stabilize both the output gap and inflation in the presence of a financial accelerator mechanism. In addition to the standard Euler equation channel, monetary policy also affects the financial constraint through its ability to adjust the real interest rate; see (19) and (10).[15] To minimize the credit spread, the central bank may tolerate positive inflation at the margin. This trade-off between

[15]How monetary policy affects the financial constraint is a key determinant of its effectiveness. In Brunnermeier and Koby (2017), monetary easing relaxes the constraint until reaching a reversal rate, below which further easing tightens the constraint and reduces lending. In Cavallino and Sandri (2019), monetary easing tightens the constraint when the economy faces a premium on international financial markets. In this paper, I focus on the ZLB as a liquidity trap rather than the reversal bound of Brunnermeier and Koby (2017). Indeed, the reversal rate seems to be somewhere below the ZLB (or some small negative number if the lower bound is not zero). See, for example, a speech by Benoît Cœuréthe in 2016: https://www.ecb.europa.eu/press/key/date/2016/html/sp160728.en.html. Above the reversal rate, empirical work (e.g., Alessandri and Nelson 2015) finds that monetary easing can strengthen the balance sheet condition of financial intermediation. In Brunnermeier and Sannikov (2016), this positive effect originates from capital gains. In my model and Carrillo et al. (2017), this positive effect is also captured by the ability of monetary policy to control the short-term real interest rate.

financial stability and inflation stability can be particularly significant if an inflationary shock tightens the financial constraint, e.g., a negative TFP shock. In these cases, it is helpful to have the labor tax policy that gives the government an extra margin to affect inflation. The distortionary labor tax can also be used to affect asset prices through the capital-labor ratio, i.e., an increase in labor supply must be matched by an increase in investment demand. Since movements in asset prices are key to the financial accelerator mechanism, this tax policy can be used to ease the financial strain.

If the government commits to addressing financial frictions, banks expect higher asset prices and lower borrowing costs under financial distress. Knowing that future financial crises will have a smaller impact on them, banks are willing to take on higher leverage in normal times, resulting in more fixed investment. This is the risk-taking channel that is relevant to all three policies. However, the more deeply banks are leveraged, the more likely they are to hit the financial bound. Consequently, the government has to conduct costly interventions more often. In this way, the government faces a trade-off in encouraging risk-taking behavior (or discouraging precautionary behavior). As noted by Bianchi (2016), the risk-taking channel makes optimal policy time-inconsistent. The government is tempted to announce a relatively small stimulation package ex ante, which is not optimal ex post.

4. Quantitative Method

Ideally the model should be solved by global methods. However, the Ramsey equilibrium contains too many state variables, some of which are multipliers associated with forward-looking constraints.[16] The model is therefore difficult to solve even using methods that are explicitly designed to deal with large state space, such as that of Maliar and Maliar (2015). Fast algorithms such as that of Guerrieri

[16] Bianchi (2016) solves the Ramsey policy in a model with occasionally binding financial constraints by policy function iteration. When there are not enough instruments to render constrained-efficient allocations, the system contains seven state variables in total, two of which are multipliers associated with forward-looking constraints.

and Iacoviello (2015) based on piecewise linearization give, however, certainty equivalent results.

I employ the approach of Holden (2016), which can easily be implemented by Holden's DynareOBC toolkit.[17] The core algorithm is based on Holden (2019), which solves models that are linear apart from OBCs under perfect foresight. The idea of this algorithm is to hit the inequality-constrained variables with endogenous news (anticipated) shocks such that the inequality constraint is always satisfied. Solving the model amounts to finding the appropriate news shocks, which can be represented by a linear complementarity problem. The solution is virtually the same as the one computed by Guerrieri and Iacoviello (2015)'s algorithm. The main advantage of Holden (2016)'s generalized algorithm is to allow me to capture the role of risk. First, it can solve models that are nonlinear apart from OBCs by high-order approximations. Second, the risk of hitting OBCs can be taken into account in the spirit of Adjemian and Juillard (2013), i.e., by integrating the model over a certain period of future uncertainties to approximate rational expectations. To balance between accuracy and speed, I use 50 periods in practice.

Throughout the paper, I compute second-order approximations of the model under rational expectations (RE, with integration over future uncertainties). Hence, I capture the precautionary effects stemming from both OBCs and second-order terms. To see how OBC-related risks affect model behavior, I also compute a "perfect-foresight" (PF) solution by assuming that economic agents ignore the possibility of hitting OBCs in the future and are always surprised when hitting OBCs.[18]

4.1 Calibration

The calibration goal is not to match statistical moments of a wide range of macroeconomic variables, but rather to generate enough uncertainty such that the precautionary effects are quantitatively reasonable. Most parameters take their conventional values in the

[17] DynareOBC is available at https://github.com/tholden/dynareOBC.

[18] I abuse the term "PF" slightly because the "PF" solution still captures precautionary effects stemming from second-order terms. In practice, the "PF" solution is computed without integrating future uncertainties.

Table 1. Fixed and Calibrated Parameters

Description	Parameter	Value
Fixed Parameters		
Relative Risk Aversion	σ	2
Habit	h	0.7
Frisch Elasticity (Inverse)	φ	0.4
Parameter of Consumption Transaction Cost	$\mathcal{A}$	0.0111
Parameter of Consumption Transaction Cost	$\mathcal{B}$	0.07524
Calvo Parameter	γ	0.779
Markup (Steady State)	$\frac{\bar{\varepsilon}}{\bar{\varepsilon}-1}-1$	0.2
Capital Share	α	0.33
Depreciation Rate	δ	0.025
Elasticity of Investment (Inverse)	η	1.728
Survival Probability of Banks	$1-r_n$	0.972
Transfer Rate from Households to New Banks	ϖ	$\frac{1-(1-r_n)/\beta}{4}$
Fraction of Divertible Assets (Steady State)	$\bar{\theta}$	0.247
Gov. Consumption-to-GDP Ratio (Steady State)	$\frac{\bar{g}}{\bar{y}}$	0.2
Credit Policy Cost	$\tau_{\mathcal{P}}$	0.0005
TFP Persistence	ρ_A	0.094
TFP St. D.	σ_A	0.0035
Calibrated Parameters		
Labor Disutility Weight	χ	48
Gov. Debt-to-GDP Ratio (Steady State)	$\frac{\bar{b}}{\bar{y}}$	0.7
Discount Factor	β	0.9987
Financial Shock Persistence	ρ_θ	0.8
Financial Shock St. D.	σ_θ	0.017

literature, which are summarized in the upper panel of table 1. The inverse Frisch elasticity φ is set to 0.4 and the relative risk aversion is set to 2, both within typical ranges in the literature. The Calvo parameter γ and the inverse elasticity of investment η are borrowed from Gertler and Karadi (2011). The parameters of the consumption transaction cost are borrowed from Schmitt-Grohé and Uribe (2004b). The parameter of the resource cost is set to 0.0005. As there is no hard evidence to quantify this cost, $\tau_{\mathcal{P}}$ is picked rather arbitrarily only to ensure that credit policy is not dominated by other policies. But my results are robust to reasonable variations in $\tau_{\mathcal{P}}$.

There are three parameters in the financial sector, namely r_n, $\bar{\theta}$, and ϖ. Following Gertler and Karadi (2011), I choose the survival rate $1-\bar{r}_n$ that implies a decade of banks' average lifetime. I set the steady-state leverage ratio $\bar{\phi}$ to 4, which is considered as an average across sectors with vastly different financial structures.[19] Next, I choose a deterministic steady state where the financial constraint is slack and the credit spread is zero.[20] This choice is supported by Bocola (2016)'s estimate in a similar model where the Lagrange multiplier associated with the financial constraint is close to zero on average. My choices of η and r_n are also broadly consistent with Bocola (2016)'s estimates. The transfer rate to new banks is pinned down by the leverage ratio $\varpi = \frac{1-(1-r_n)/\beta}{\bar{\phi}}$. The steady-state proportion of divertable assets $\bar{\theta}$ is adjusted such that the financial constraint is close to its bound in the steady state ($\bar{\theta} = 0.247$). This is to ensure reasonable accuracy of approximation when the financial constraint is binding.

Calibrated parameters are shown in the lower panel of table 1. There are two parameters affecting the optimal labor taxes. I pick $\chi = 48$ to match the steady-state working hours of about 40 hours (i.e., 24 percent) per week. The government debt-to-GDP ratio is set to 0.7, in line with the relatively high levels of public debt in many advanced economies in recent years.[21] To quantify the ZLB risk, I use a relatively large discount factor to capture a low neutral interest rate. $\beta = 0.9987$ implies a steady-state real interest rate of 0.52 percent, matching the average yield on U.S. 10-year Treasury inflation-indexed securities between 2009 and 2019.

The behavior of nonlinear models crucially depends on the specification of shocks. To avoid making the model too difficult to solve,

[19] The literature has suggested alternative calibrations. For example, $\bar{r}_n$ can be set to match a dividend rate of 5.15 percent made by the 20 largest U.S. banks during 1965–2013 (Swarbrick, Holden, and Levine 2017). The steady-state leverage can be set to 16, the estimate of Quint and Rabanal (2017) in which the authors use GMM to estimate a similar model with the financial constraint always binding. These values change my results quantitatively but not qualitatively.

[20] It is well known that kinks of either the ZLB or borrowing constraints can introduce multiple equilibria. First, there are multiple deterministic steady states. I focus on a normal steady state with positive nominal interest rates and a silent credit policy. Second, there can be multiple paths reverting to a given steady state. Holden (2019)'s method allows one to test and select from these paths. Throughout the paper, should multiple paths emerge, I choose the one that escapes the bound as soon as possible.

[21] Note that B_t denotes government bonds held by the public, excluding those held by the central bank. The relevant ratio in the United States is between 0.7 and 0.8 in recent years.

I only consider two shocks: a TFP (supply) shock A_t and a financial (demand) shock θ_t. I assume both shocks following log-AR(1) processes. The specification of the TFP shock is fixed (not calibrated) to the post-1983 estimates of Smets and Wouters (2007) and fits the Solow residuals reasonably well (see, e.g., Jermann and Quadrini 2012), with an autocorrelation coefficient equal to 0.94 and the standard deviation of its innovations equal to 0.35 percent. Next, the persistence of θ_t is 0.8, following Romer and Romer (2017)'s finding that financial distress itself is fairly persistent. To pin down the standard deviation of the financial shock, I solve the laissez-faire equilibrium, ignoring the ZLB, and match the standard deviation of the annualized credit spread (0.7 percent).[22] However, without features such as true default risk, I inevitably underestimate the average credit spread (2.07 percent in data versus 0.18 percent in the model). Or I would overestimate the standard deviation if I matched the mean. Since the financial constraint is occasionally binding, the standard deviation appears to be the more natural choice for calibration.[23]

5. Quantitative Results

5.1 Simulations

Table 2 reports key statistics of the Ramsey and laissez-faire equilibrium. Rows (a) and (c) present the ergodic mean and standard deviations under rational expectations. Rows (b) and (d) present the same ergodic statistics under perfect foresight.

First consider the laissez-faire equilibrium. Rows (a) and (b) show that precautionary effects stemming from OBCs induce the financial constraint less often binding in the RE model (19.01 percent) than in the PF model (27.33 percent). Since the financial constraint imposes an upper bound on leverage, the average level of leverage is lower in the PF model. On average, the precautionary

[22] The data is Moody's seasoned Bbb corporate bond yield relative to the yield on 10-year treasury, 1983:Q1–2019:Q1. I ignore the ZLB here mainly because simulating the laissez-faire equilibrium with the ZLB is extremely slow.

[23] When the financial constraint is always binding, Gertler and Kiyotaki (2010) and Dedola, Karadi, and Lombardo (2013) target the average spread of 1 percent.

Table 2. Long-Run Properties of the Ramsey and Laissez-Faire Equilibrium

	Log y_t	***Log*** Π_t	***Log*** R_t	***ZLB***	***Spread***	ϕ_t	***FC***	$\mathcal{P}_t$
Laissez-faire								
(a) RE	−10.90	0.15	0.31	5.16	0.21	4.12	19.01	0.00
	(0.55)	(0.39)	(0.19)	—	(0.55)	(0.45)	—	(0.00)
(b) FF	−10.67	0.12	0.27	9.29	0.25	4.10	27.33	0.00
	(0.63)	(0.39)	(0.19)	—	(0.62)	(0.47)	—	(0.00)
Ramsey								
(c) RE	−9.70	0.02	0.12	11.81	0.00	4.00	51.29	0.95
	(0.51)	(0.02)	(0.11)	—	(0.00)	(0.08)	—	(0.99)
(d) PF	−9.81	0.00	0.07	31.41	0.00	3.89	15.58	0.12
	(0.53)	(0.01)	(0.08)	—	(0.00)	(0.11)	—	(0.39)

Note: Rows labeled RE (PF) are ergodic statistics under rational expectations (perfect foresight), calculated using simulated series of 10,000 periods. Numbers outside (inside) the parentheses are the mean (standard deviations). The column labeled ZLB (FC) is the frequency when the ZLB (financial constraint) is binding. The log transformed variables are multiplied by 100; ratios and rates are in percentage points; the leverage is in level.

effects reduce output by 0.23 percent but improve economic stability (reducing volatility) and financial efficiency (narrowing the credit spread). The RE economy also experiences fewer ZLB episodes. This is because deleveraging under financial distress leads to low inflation, which prompts the central bank to cut the nominal interest rate.

In the Ramsey equilibrium, rows (c) and (d) show that optimal policy raises the average output by 1.2 percent or 0.86 percent relative to the laissez-faire policy, depending on how expectations are calculated. Moreover, the average nominal interest rate is lower, suggesting a more dovish monetary policy in general. A key feature of the Ramsey equilibrium is that the optimal credit spread is virtually zero at all times. To further investigate this outcome, I solve the credit spread in Ramsey equilibria with different steady-state labor tax rates. I find that both the mean and standard deviation of the optimal credit spread approaches zero quickly as the steady-state labor tax increases (a plot of this result is left to Appendix B). Quantitatively, a country with a labor tax rate greater than 10 percent should fully stabilize its credit spread. The intuition is that financial distress becomes increasingly painful when the labor market is more distorted because the markets for production factors—labor and capital—are inefficient. Hence, the benefits of narrowing the credit spread dominate the associated cost. Given the expectation of a zero credit spread, banks have an incentive to take on higher leverage. Therefore, relative to the PF model, the RE model features higher output, leverage, and a more frequently binding financial constraint which, in turn, requires more asset purchases and tax rebates on average.

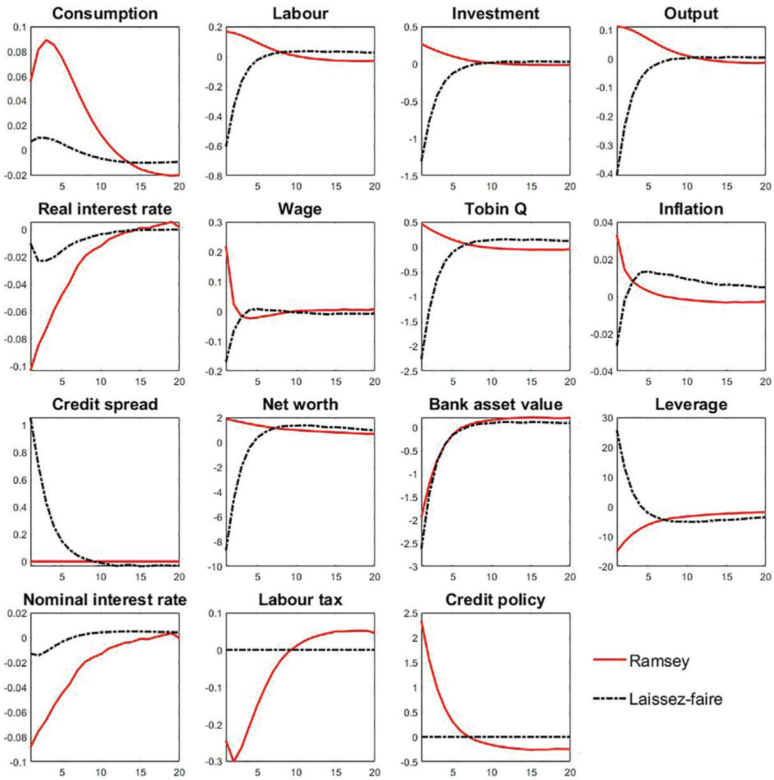
Surprisingly, the average nominal interest rate is higher in the RE model. One possible explanation is that the Ramsey model simply hits the ZLB less often. But the causality can also be reversed. I argue that the central bank intends to keep monetary policy relatively tight, which leads to fewer ZLB episodes. To illustrate this point, I consider the risky steady state (RSS) defined as in Coeurdacier, Rey, and Winant (2011), which is the fixed point of the economy when expectations take into account future risk.[24] I calculate four RSSs (left to Appendix B) based on the economy with none, one, or both of the OBCs, respectively. If there is only one OBC, either the financial constraint or the ZLB, I find the same result as in the literature (e.g., Adam and Billi 2006) that the central bank loosens its monetary policy relative to the no-OBC case. However, the presence of the ZLB and the financial constraint together constitute a much more significant risk. In this case, the RSS features a permanent credit intervention, a lower labor tax rate, but a higher nominal interest rate relative to the no-OBC case. The fact that this policy mix is found to be optimal must mean that the monetary policy is less effective when both OBCs bind simultaneously: the benefits of monetary easing at the ZLB (e.g., through a commitment to future interest rates) is limited by the partial transmission from r_t to $r_{k,t}$.

5.2 Impulse Response Analysis

To take a closer look at optimal policy, I consider impulse responses to a positive financial shock, a positive TFP shock, and a negative TFP shock, all of three standard deviations. Figures 1–3 show

[24]In practice, RSSs are obtained by simulating the economy under rational expectations with all realized shocks equal to zero until reaching a fixed point.

Figure 1. Impulse Response to a Positive Financial Shock



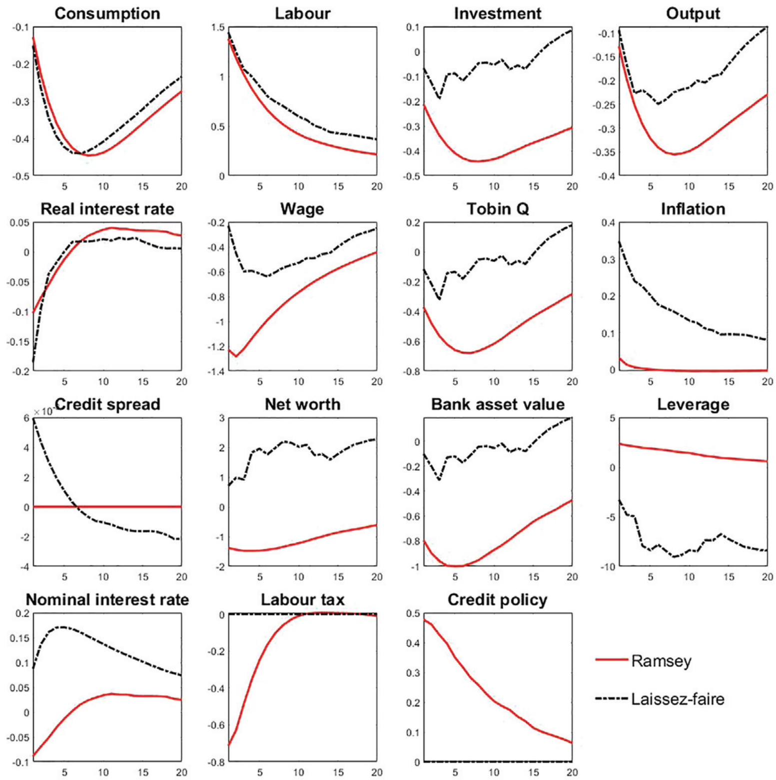
Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations.

the mean expected impulse response functions (generalized IRFs of Koop, Pesaran, and Potter 1996) to each shock as deviations from the stochastic steady state.[25] In each figure, rows from top to bottom show real activity, relative prices, financial variables, and policy instruments, respectively.

First consider responses to the financial shock shown in figure 1. Given the binding financial constraint, banks fire-sell their assets. In the laissez-faire equilibrium, this makes the asset prices sharply

[25]Generalized IRFs are calculated using 500 simulations with 500 periods of burn-in. Since the path of the OBCed variable is averaged across varying initial states, the kinks are largely smoothed out.

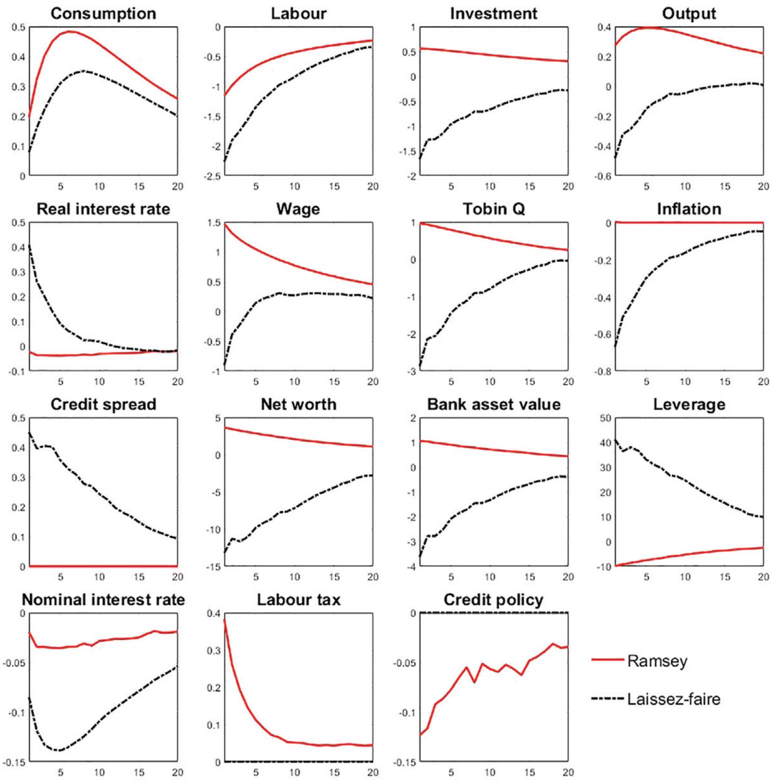
Figure 2. Impulse Response to a Negative TFP Shock



Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations. The response of the laissez-faire equilibrium is volatile because the reported path is the average of a large number of simulations, some of which involve a binding financial constraint and/or the ZLB.

lower, which feeds back into bank net worth and further tightens the financial constraint. The inefficiency in financial intermediation forces households to increase their consumption. The surge in credit spread is supportive towards the marginal cost, mitigating disinflationary pressure (inflation down by 0.02 percent). Since the standard Taylor rule responds primarily to inflation, the reaction of monetary policy is largely muted. By contrast, the optimal monetary policy focuses more on relaxing the financial constraint by tolerating a modest increase in inflation. Nonetheless, thanks to a labor tax rebate,

Figure 3. Impulse Response to a Positive TFP Shock



Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations.

the increase in inflation is manageable (a little more than 0.03 percent). Regarding credit policy, the asset purchase program is fairly aggressive (more so if the ZLB is binding) and unwinds as banks releverage. Unlike the laissez-faire equilibrium where banks deleverage slowly, the deleveraging process is instantly completed in the Ramsey equilibrium. This is thanks to the positive policy effects on bank net worth through a lower borrowing cost on bank liabilities and a capital gain on bank assets. Note that given a zero credit spread, the selling of assets to the central bank does not negatively affect banks' profitability.

Upon a negative TFP shock, the capital return should fall in the first-best equilibrium (under flexible prices and efficient financial markets) because $z_t = \alpha \frac{y_t}{k_{t-1}} \mu$ where the marginal cost is a constant. In the presence of nominal rigidity, the real interest rate is generally below its first-best level, meaning that the marginal cost and the capital return are above their first-best levels. However, these inefficient adjustments of the economy are beneficial to banks. Therefore, the laissez-faire equilibrium shown in figure 2 features improved net worth and a small credit spread. On the other hand, the Ramsey equilibrium tries to replicate the first-best allocation by raising the real interest rate. This is partially achieved by a labor tax rebate, which lowers wages and inflation. Naturally, both a higher real rate and a lower z_t tighten the financial constraint, making it necessary to employ credit policy. At a first glance, figure 2 seems to suggest that the highly expansionary Ramsey policy only worsens the economic performance. But the discussion above should make it clear that the Ramsey allocation is in fact closer to the first-best allocation.

At last, consider a positive TFP shock. In the laissez-faire equilibrium, higher productivity should relax the financial constraint thanks to the improved return on bank assets. However, when the shock is large enough to render a binding ZLB, the resulting demand shortfall widens suddenly. Consequently, asset prices fall and the financial constraint binds, dragging the economy into the spiral of Fisherian deflation. As shown in figure 3, the three-standard-deviation shock (or 1.05 percent) causes inflation and output slump by more than 0.6 percent and 0.4 percent, respectively. To avoid such a catastrophic consequence, the key is to lower the real interest rate, which is needed to both stimulate aggregate demand and relax the financial constraint. In other words, there is no trade-off between inflation stability and financial stability. Here, the Ramsey planner imposes a higher labor tax rate to support inflation while the nominal interest rate is kept relatively stable. Since the financial constraint is not expected to be binding, the central bank takes this opportunity to reduce its holdings of private assets.

Before moving to consider policy implementation, I study a few more IRFs under different setups without showing the results. First, I ask how much the results so far depend on the government's access to fiscal and credit policy. I solve the partial Ramsey equilibrium with a fixed labor tax rate and only find minor welfare losses.

Without fiscal policy to help stabilize inflation, the contemporary response of monetary policy is more aggressive but the subsequent normalization is faster. Overall, monetary policy can still maneuver the real interest rate in a similar manner as in the full Ramsey equilibrium. On the other hand, the absence of credit policy yields large welfare losses[26] with significantly prolonged ZLB episodes (e.g., doubled under the financial shock) in order to relax the financial constraint. Second, it is interesting to examine how the government's past commitments restrict today's policy. An emphasis is put on the commitments to ease financial strains. To this aim, I consider IRFs from the stochastic steady state except that the multiplier associated with (12) is one-standard deviation lower (i.e., weaker commitment). The resulting nominal interest rate is uniformly higher than in the baseline case, which creates space for future monetary easing when the economy is more in need. The lack of monetary easing today is made up for by a larger asset purchase program and a higher tax rate to support inflation.

6. Simple Policy Rules

I now consider how to implement the Ramsey policy using a familiar set of simple rules as below:

$$\log\frac{R_t}{\bar{R}} = \max\left\{\kappa_R \log\frac{R_{t-1}}{\bar{R}} + \kappa_\Pi \log\frac{\Pi_t}{\bar{\Pi}} + \kappa_y \log\frac{y_t}{\bar{y}}, -\log\bar{R}\right\}, \tag{22}$$

$$\mathcal{P}_t = \kappa_{\mathcal{P}}\mathcal{P}_{t-1} + \kappa_{rr}\mathbb{E}_t(\log r_{k,t+1} - \log r_{t+1}), \tag{23}$$

where the credit rule is borrowed from Foerster (2015) and the five "κ"s are parameters searched numerically to maximize welfare.[27]

[26] This case is of less interest, since the central bank should always be able to coordinate credit and monetary policy.

[27] Note that the responses to inflation and output are not scaled by the degree of persistence $1-\kappa_R$. Moreover, a shadow interest rate R_t^* can be introduced into the monetary rule:

$$\log\frac{R_t^*}{\bar{R}} = \kappa_R \log\frac{R_{t-1}^*}{\bar{R}} + \kappa_\Pi \log\frac{\Pi_t}{\bar{\Pi}} + \kappa_y \log\frac{y_t}{y},$$

$$\log R_t = \max(0, \log R_t^*),$$

Table 3. Optimized Simple Rule

Shock	$\boldsymbol{\kappa_R}$	$\boldsymbol{\kappa_\Pi}$	$\boldsymbol{\kappa_y}$	$\boldsymbol{\kappa_\mathcal{P}}$	$\boldsymbol{\kappa_{rr}}$	$\boldsymbol{\lambda^c}$**(bps)**
Financial	1.1	3	0	0.9	5	0.013
Positive TFP	1.1	3	0	0.9	5	0.012
Negative TFP	1.0	3	0	0.9	5	0.014

Searching κ in a five-dimensional space is extremely costly with OBCs. To make the problem doable, I limit attention to a grid of the parameter space: $\kappa_R \in [0 : 0.1 : 3]$, $\kappa_\Pi \in [0 : 0.1 : 3]$, $\kappa_y \in [0 : 0.1 : 3]$, $\kappa_\mathcal{P} \in [0 : 0.1 : 1]$, $\kappa_{rr} \in [0 : 0.5 : 5]$, where the expression $[a : s : b]$ denotes the lower bound, the step, and the upper bound. For simplicity, I assume that the tax policy is unresponsive because adjusting taxes promptly is difficult. Admittedly, if (22) struggles to stabilize inflation, even a rather naive tax rule may improve welfare considerably. Nevertheless, a comprehensive study of optimal rules is left to future research. As shown shortly, the Taylor-type rule can do impressively well if equipped with somewhat unconventional parameters. To further ease the computational burden, I calculate welfare conditional on (i) state variables equal to the ergodic median of the Ramsey equilibrium under a fixed tax policy and (ii) one of the following shocks in the first period: a three-standard-deviation positive financial shock, a five-standard-deviation negative TFP shock, or a three-standard-deviation positive TFP shock. Welfare losses are measured in consumption equivalence λ^c implicitly defined by

$$\mathbb{W}_1\left(\{c_t^S - hc_{t-1}^S, l_t^S\}_{t\geq 1}\right) = \mathbb{W}_1\left(\{(1-\lambda^c)(c_t^R - hc_{t-1}^R, l_t^R\}_{t\geq 1}\right),$$

where $\mathbb{W}_1\left(\{c_t^R - hc_{t-1}^R, l_t^R\}_{t\geq 1}\right)$ is the welfare evaluated by the contingent plans for consumption and labor in the Ramsey equilibrium (also with a fixed labor tax) in period 1; $\mathbb{W}_1\left(\{c_t^S - hc_{t-1}^S, l_t^S\}_{t\geq 1}\right)$ is defined similarly for a given set of policy rules.[28]

The optimized rules are reported in table 3 and the welfare surface near the optimal point is illustrated in figure 4. In all cases,

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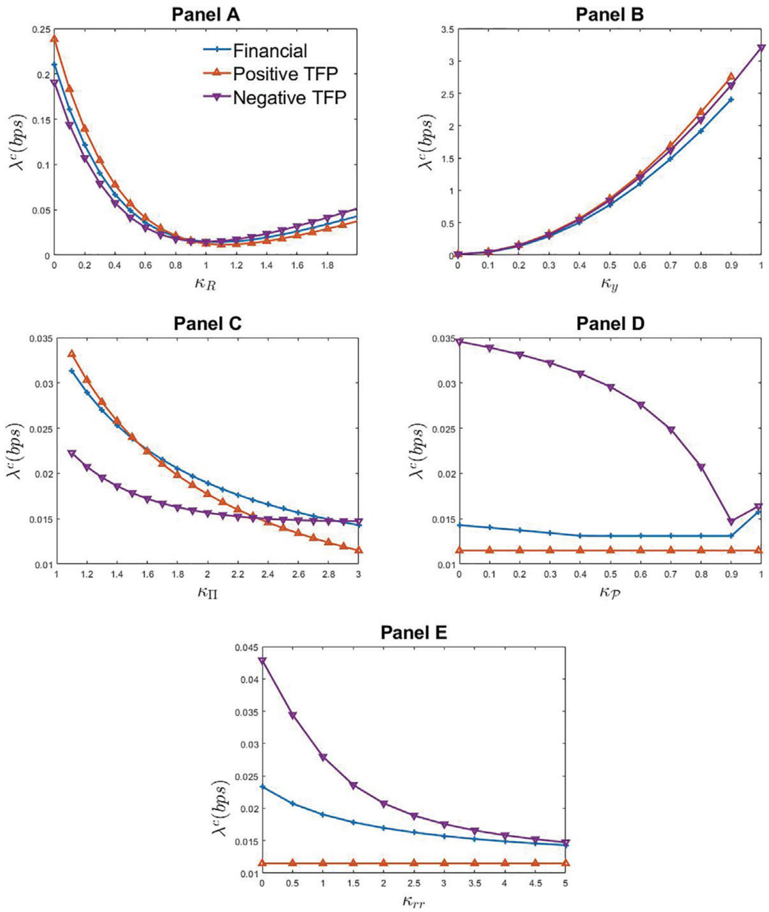
which is potentially welfare improving at the ZLB. The shadow rule does not change my results, because (22) rarely hits the ZLB regardless of its parameters.

[28]The utility function implies $\lambda^c = 1 - \left(\frac{\mathbb{W}_1^S + \mathbb{W}_1^{Rl}}{\mathbb{W}_1^{Rc}}\right)^{\frac{1}{1-\sigma}}$, where $\mathbb{W}_1^{Rc}$ and $\mathbb{W}_1^{Rl}$ are the discounted (dis)utility of consumption and labor, $\mathbb{W}_1^{Rc} - \mathbb{W}_1^{Rl} = \mathbb{W}_1^R$.

Figure 4. Welfare Losses Associated with Simple Rules Near the Optimal Point



Note: Parameters not shown on the x-axis are set to their optimal values.

the optimal parameters are essentially the same and the associated welfare losses are small.[29] The credit rule features a strong contemporary response to the credit spread with substantial persistence.

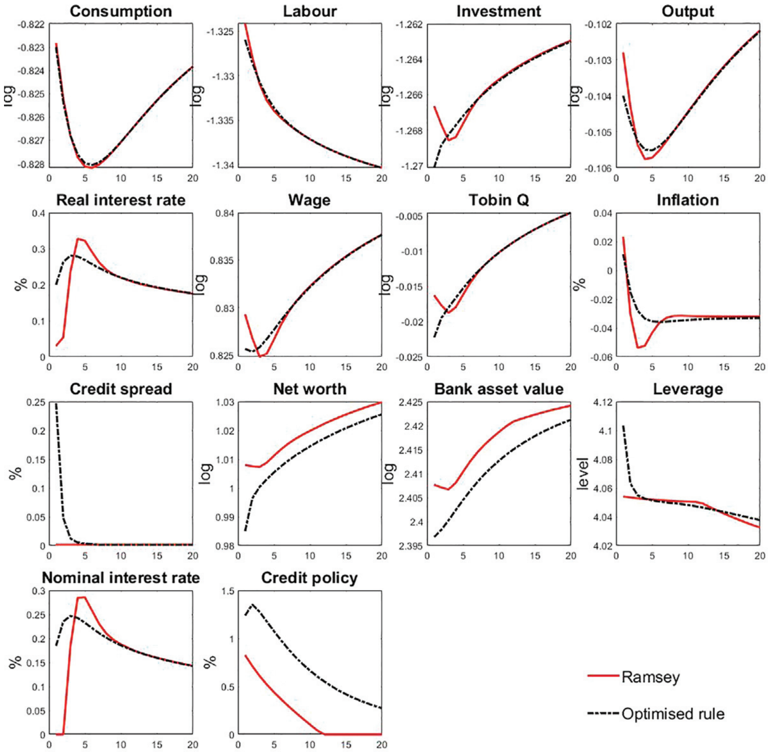
[29] $\kappa_\mathcal{P} \in [0.4, 0.9]$ yields virtually the same level of welfare under the TFP shock. I take $\kappa_\mathcal{P} = 0.9$ for consistency. The variation in κ_R across shocks is due to the fact that the parameter search is done over a grid. A finer search should reveal an optimal κ_R in the range of [1.0, 1.1].

While Foerster (2015) focuses more on extreme cases, i.e., $\kappa_{\mathcal{P}} = 0.99$ and $\kappa_{\mathcal{P}} = 0$, panel D of figure 4 shows that both are suboptimal. My results on the monetary rule echo a few findings in a standard New Keynesian model (Schmitt-Grohé and Uribe 2007), including a muted response to output and a strong response to inflation. The inflation coefficient reaches the upper bound of the search grid. But additional welfare gains from further increasing the inflation coefficient appear to be limited, especially when there is a trade-off between financial stability and inflation stability (i.e., under the financial shock and the negative TFP shock; see panel C of figure 4). The optimized monetary rule only differs from Schmitt-Grohé and Uribe (2007) in that the persistence coefficient exceeds but is close to 1, suggesting that the optimal monetary rule is forward looking and close to price-level targeting. This feature helps deal with the ZLB (Eggertsson and Woodford 2003)[30] without compromising the performance in normal times when the financial constraint and the ZLB are slack. As shown in Schmitt-Grohé and Uribe (2007), variations in the persistence coefficient affect welfare very little in normal times. Thus, my results should be robust to evaluations based on (computationally costly) unconditional welfare.

I now take a closer look at how the optimized rules respond to each shock. Upon a positive TFP shock, the simple-rule economy can largely replicate the Ramsey allocation. This is thanks to the strong response to inflation embedded in the monetary rule, which helps the economy avoid a binding financial constraint. Thus, the welfare gains of the optimized rule over the traditional Taylor rule are large, as the latter drives the economy into the spiral of Fisherian deflation (recall from subsection 5.2). On the other hand, under both the financial shock and the negative TFP shock, the government faces the trade-off between financial stability and inflation stability. To best illustrate this point, I show the simulated economy under the negative TFP shock, which raises both the credit spread and inflation. As shown in figure 5, the optimized rules prescribe too strong a credit intervention but insufficient monetary easing. The higher real interest rate in the

[30]The superinertial monetary policy also eliminates a equilibrium trapped permanently at the ZLB. See Sugo and Ueda (2008).

Figure 5. Simulation under the Optimized Rule and the Ramsey Policy



Note: The starting point of the simulation is the ergodic median of the Ramsey equilibrium except that TFP is five standard deviations below. The optimized rule contains the following parameters: $\kappa_R = 1.0, \kappa_\Pi = 3.0, \kappa_y = 0, \kappa_{\mathcal{P}} = 0.9, \kappa_{rr} = 5$.

simple-rule economy tightens the financial constraint. Given the positive credit spread, central bank asset purchases have a negative impact on bank net worth by crowding out banks from profitable investment opportunities.

There are potentially two simple ways of easing the policy trade-off. For example, the government can use a tax policy to restrain inflation. Alternatively, the monetary rule can be augmented to respond to the credit spread.

7. Conclusion

I study optimal credit, monetary, and fiscal policy under commitment using a model that is as standard as possible, i.e., a New Keynesian model augmented with Gertler and Kiyotaki (2010) style financial frictions. The nonstandard part is that I allow two OBCs, one financial and one on the nominal interest rate. The model is solved in a way that captures the precautionary effects stemming from the nonlinearity of both OBCs, which has two important implications. First, credit policy is permanent in the risky steady state, despite being inactive in the deterministic steady state. Second, the government needs to avoid dual-binding constraints by keeping the nominal interest rate relatively high when the ZLB is not binding. I consider a financial shock and a TFP shock that generate a trade-off between inflation stability and financial stability even when policymakers have access to all the three policy instruments. The trade-off is found to be resolved in favor of financial stability with the credit spread staying virtually constant at its steady-state value under reasonable calibration. The optimal monetary policy is a counter to the conventional wisdom by suggesting that the nominal interest rate should respond negatively to a large negative productivity shock while its response to a positive productivity shock depends on how much the central bank is constrained by its past commitments. Finally, I find that optimized simple rules feature too-aggressive credit interventions and insufficient monetary easing relative to the Ramsey policy although the associated welfare losses are small.

Several important topics are not covered in this paper. First, the cost of credit policy is not fully captured by my model; see, for example, Borio and Zabai (2016) and Kandrac (2018). The recent work of Cui and Sterk (2018) suggests that credit policy is associated with considerable welfare costs in terms of inequality. Second, reserves in my model are treated as a perfect substitute for government bonds. However, there have been many papers (e.g., Christensen and Krogstrup 2017) studying imperfect asset substitutability and giving reserves a special role. Third, I leave a full investigation of simple and implementable policy rules to future research.

Appendix A. The Debt Ramsey Equilibrium

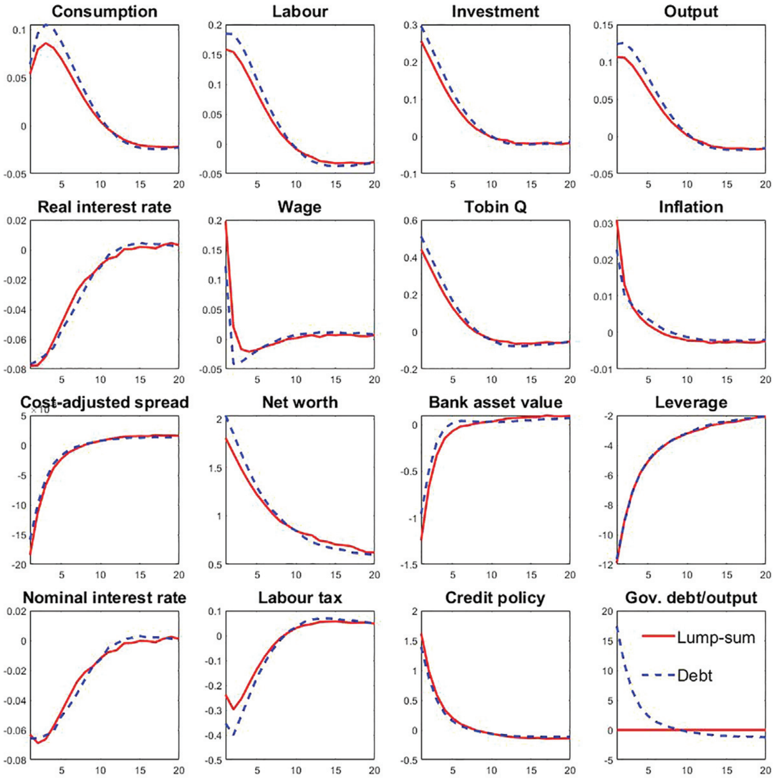
How does the government's asset purchase program affect its budget constraint? As the government issues government bonds (or reserves) to purchase private assets, the net gain of this operation is given by the credit spread. Recall that the credit spread is close to zero in the Ramsey equilibrium. The zero credit spread, together with the resource cost $\tau_{\mathcal{P}}(\mathcal{P}_t q_t s_t)^2$, means that the credit policy increases the fiscal burden although the effect might be quantitatively small. This adds interesting trade-offs to the policy problem but may not be true in reality.[31]

In the literature of optimal monetary and fiscal policy (e.g., Christiano, Chari, and Kehoe 1991; Schmitt-Grohé and Uribe 2004b; Siu 2004, among many others), the problem is how to finance an exogenous government spending shock. On the one hand, the government would like to smooth distortionary taxation by using unexpected inflation as a lump-sum tax on nominal wealth. On the other hand, the government would like to stabilize prices in the presence of nominal rigidity. This trade-off is found to be resolved in favor of price stability. In my model, however, public spending in the form of asset purchases is endogenous and the tax policy can adjust for reasons other than public finance.

Figures A.1 and A.2 show impulse responses of the lump-sum Ramsey equilibrium and the debt Ramsey equilibrium to shocks that trigger credit policy. The impulse responses are computed without burn-in to prevent the debt equilibrium from drifting too far away from the deterministic steady state. The cost-adjusted spread is the credit spread adjusted for the resource cost. Since credit policy generates incomes to finance itself, the debt level moves closely along the government's holding of private assets. The government budget constraint little changes the path of inflation but substantially changes the path of the tax rate. Hence, I conclude that the traditional trade-off between inflation stability and tax smoothing is still resolved in favor of the former. Particularly, high public debt does not make it difficult to raise interest rates, as Evans et al. (2015) suspect.

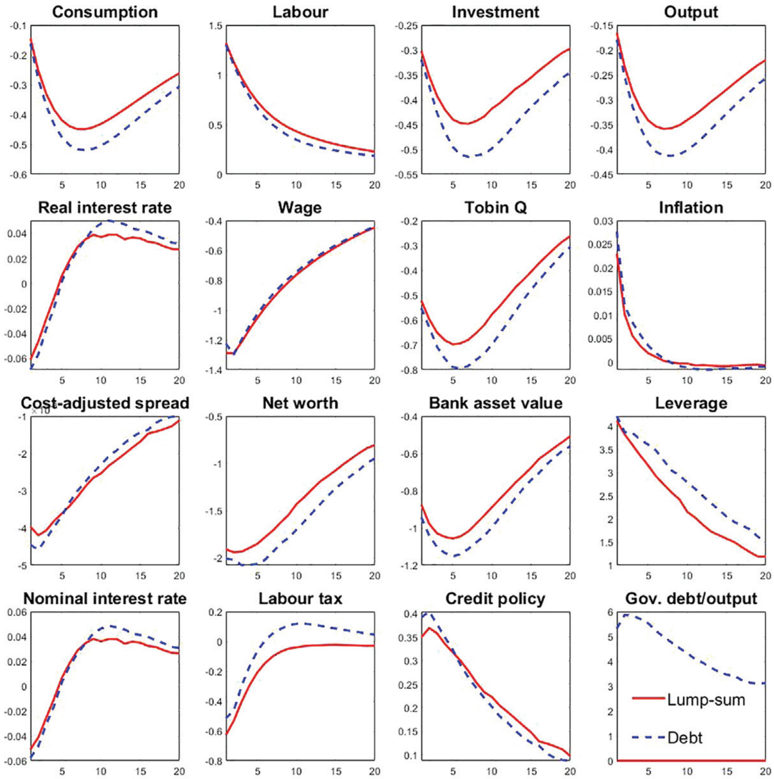
[31] See Reis (2016) for a discussion of this issue.

Figure A.1. Impulse Response to a Positive Financial Shock



Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations.

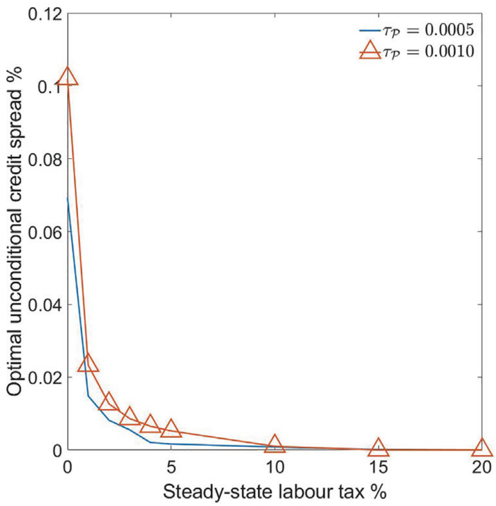
Figure A.2. Impulse Response to a Negative Financial Shock



Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations.

Appendix B. Additional Results

Figure B.1. Optimal Credit Spread and Steady-State Labor Tax



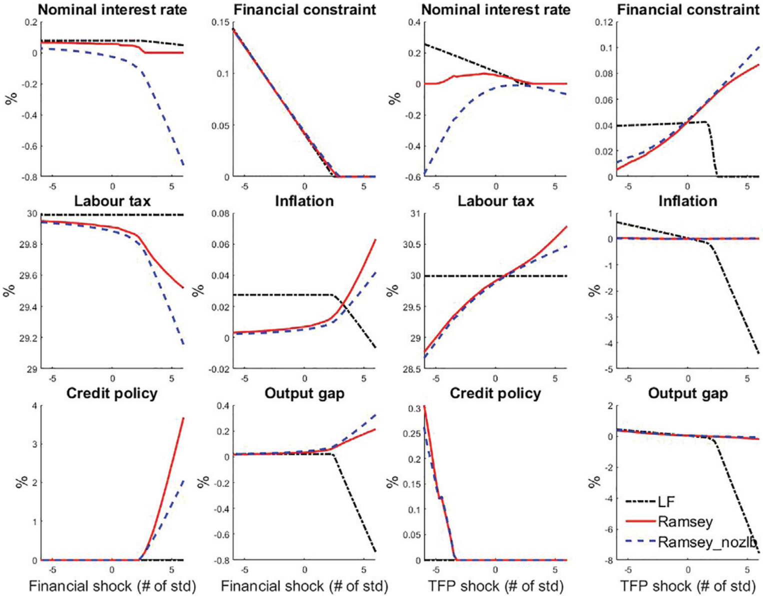
Note: This figure shows the unconditional mean of the credit spread in the Ramsey equilibrium when the steady-state labor tax is fixed at a given level.

Table B.1. Risky Steady States of the Ramsey and Laissez-Faire Equilibrium

	Log y_t	***Log*** Π_t	***Log*** R_t	***Spread***	ϕ_t	$\mathcal{P}_t$	$\tau_{w,t}$
Laissez-Faire							
Both OBCs	−10.38	0.03	0.15	0.04	4.00	0.00	29.99
FC Only	−9.96	0.03	0.13	0.00	3.96	0.00	29.99
ZLB Only	−11.47	−0.34	0.29	0.00	6.38	0.00	29.99
No OBC	−9.83	0.00	0.10	0.00	4.00	0.00	29.99
Ramsey							
Both OBCs	−9.64	0.02	0.14	0.00	4.02	1.85	29.91
FC Only	−9.80	0.00	0.08	0.00	3.91	0.21	29.98
ZLB Only	−9.81	0.00	0.09	0.00	3.98	0.00	29.99
No OBC	−9.82	0.00	0.10	0.00	3.99	0.00	29.99

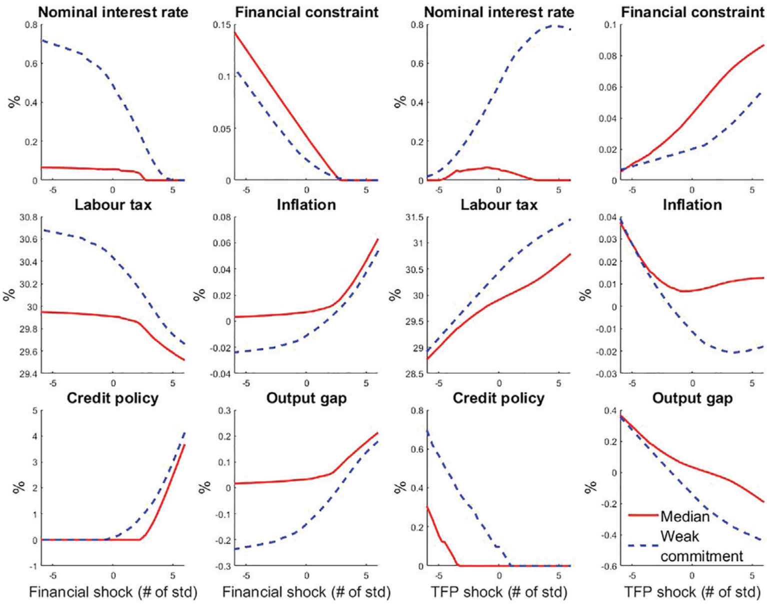
Note: Risky steady states are defined as in Coeurdacier, Rey, and Winant (2011). I calculate four RSSs based on the economy with none of the OBCs, one of the OBCs, or both of the OBCs, respectively. The log transformed variables are multiplied by 100; ratios and rates are in percentage points; the leverage is in level.

Figure B.2. Policy Functions in the Ramsey and Laissez-Faire Equilibrium



Note: Policy functions of key variables are plotted against either the financial or the productivity shock, while other state variables are set to their ergodic median in the Ramsey equilibrium. "LF" denotes the laissez-faire equilibrium. "Ramsey: no zlb" denotes the Ramsey equilibrium without the ZLB. The financial constraint is binding if it equals zero. The output gap is defined as deviations from the output level in the absence of both nominal rigidity and financial frictions.

Figure B.3. Policy Functions under Loose and Tight Commitment Constraint



Note: Policy functions of key variables are plotted against either the financial or the productivity shock, while other state variables are set to their ergodic median in the Ramsey equilibrium (red solid lines; for figures in color, see online version of paper at http://www.ijcb.org). Black dash-dotted lines are based on the same states except that the multiplier associated with (12) is one standard deviation below the median. The financial constraint is binding if it equals zero. The output gap is defined as deviations from the output level in the absence of both nominal rigidity and financial frictions.

References

Acharya, V. V., T. Eisert, C. Eufinger, and C. W. Hirsch. 2017. "Whatever It Takes: The Real Effects of Unconventional Monetary Policy."

Adam, K., and R. M. Billi. 2006. "Optimal Monetary Policy under Commitment with a Zero Bound on Nominal Interest Rates." *Journal of Money, Credit and Banking* 38 (7): 1877–1905.

Adjemian, S., and M. Juillard. 2013. "Stochastic Extended Path Approach." Unpublished Manuscript.

Alessandri, P., and B. D. Nelson. 2015. "Simple Banking: Profitability and the Yield Curve." *Journal of Money, Credit and Banking* 47 (1): 143–75.

Altavilla, C., F. Canova, and M. Ciccarelli. 2016. "Mending the Broken Link: Heterogeneous Bank Lending and Monetary Policy Pass-through."

Benigno, P., G. B. Eggertsson, and F. Romei. 2020. "Dynamic Debt Deleveraging and Optimal Monetary Policy." *American Economic Journal: Macroeconomics* 12 (2): 310–50.

Benigno, P., and S. Nisticò. 2020. "Non-neutrality of Open-market Operations." *American Economic Journal: Macroeconomics* 12 (3): 175–226.

Bernanke, B. S. 2017. "Monetary Policy in a New Era."

Bianchi, J. 2016. "Efficient Bailouts?" *American Economic Review* 106 (12): 3607–59.

Bocola, L. 2016. "The Pass-through of Sovereign Risk." *Journal of Political Economy* 124 (4): 879–926.

Bordalo, P., N. Gennaioli, and A. Shleifer. 2018. "Diagnostic Expectations and Credit Cycles." *Journal of Finance* 73 (1): 199–227.

Borio, C., and A. Zabai. 2016. "Unconventional Monetary Policies: A Re-appraisal." BIS Working Paper No. 570.

Brunnermeier, M. K., and Y. Koby. 2017. "The Reversal Interest Rate: An Effective Lower Bound on Monetary Policy."

Brunnermeier, M. K., and Y. Sannikov. 2016. "The I Theory of Money." NBER Working Paper No. 22533.

Cahn, C., J. Matheron, and J.-G. Sahuc. 2017. "Assessing the Macroeconomic Effects of LTROs during the Great Recession." *Journal of Money, Credit and Banking* 49 (7): 1443–82.

Calvo, G. A. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12 (3): 383–98.

Carrillo, J. A., E. G. Mendoza, V. Nuguer, and J. Roldán-Peña. 2017. "Tight Money-Tight Credit: Coordination Failure in the Conduct of Monetary and Financial Policies." NBER Working Paper No. 23151.

Caruso, A., L. Reichlin, and G. Ricco. 2018. "Financial and Fiscal Interaction in the Euro Area Crisis: This Time was Different."

Cavallino, P., and D. Sandri. 2019. "The Expansionary Lower Bound: Contractionary Monetary Easing and the Trilemma." BIS Working Paper No. 770.

Chakraborty, I., I. Goldstein, and A. MacKinlay. 2017. “Monetary Stimulus and Bank Lending.”

Christensen, J. H. E., and S. Krogstrup. 2017. “A Portfolio Model of Quantitative Easing.” Working Paper No. 2016-12, Federal Reserve Bank of San Francisco.

Christensen, J. H. E., and G. D. Rudebusch. 2012. “The Response of Interest Rates to US and UK Quantitative Easing.” *Economic Journal* 122 (564): F385–F414.

Christiano, V. V., L. J. Chari, and P. J. Kehoe. 1991. “Optimal Fiscal and Monetary Policy: Some Recent Results.” *Journal of Money, Credit and Banking* 23 (3): 519–39.

Coeurdacier, N., H. Rey, and P. Winant. 2011. “The Risky Steady State.” *American Economic Review* 101 (3): 398–401.

Cui, W., and V. Sterk. 2018. “Quantitative Easing.” Discussion Paper No. 1830, Centre for Macroeconomics (CFM).

Curdia, V., and M. Woodford. 2010. “Credit Spreads and Monetary Policy.” *Journal of Money, Credit and Banking* 42 (s1): 3–35.

Dedola, L., P. Karadi, and G. Lombardo. 2013. “Global Implications of National Unconventional Policies.” *Journal of Monetary Economics* 60 (1): 66–85.

Dedola, L., and G. Lombardo. 2012. “Financial Frictions, Financial Integration and the International Propagation of Shocks.” *Economic Policy* 27 (70): 319–59.

Del Negro, M., G. Eggertsson, A. Ferrero, and N. Kiyotaki. 2017. “The Great Escape? A Quantitative Evaluation of the Fed’s Liquidity Facilities.” *American Economic Review* 107 (3): 824–57.

Del Negro, M., R. B. Hasegawa, and F. Schorfheide. 2016. “Dynamic Prediction Pools: An Investigation of Financial Frictions and Forecasting Performance.” *Journal of Econometrics* 192 (2): 391–405.

Del Negro, M., and C. A. Sims. 2015. “When Does a Central Bank’s Balance Sheet Require Fiscal Support?” *Journal of Monetary Economics* 73 (July): 1–19.

Eggertsson, G. B., and P. Krugman. 2012. “Debt, Deleveraging, and the Liquidity Trap: A Fisher-Minsky-Koo Approach.” *Quarterly Journal of Economics* 127 (3): 1469–1513.

Eggertsson, G. B., and M. Woodford. 2003. “Optimal Monetary Policy in a Liquidity Trap.” NBER Working Paper No. 9968.

Evans, C., J. Fisher, F. Gourio, and S. Krane. 2015. "Risk Management for Monetary Policy Near the Zero Lower Bound." *Brookings Papers on Economic Activity* 46 (1, Spring): 141–219.

Foerster, A. T. 2015. "Financial Crises, Unconventional Monetary Policy Exit Strategies, and Agents' Expectations." *Journal of Monetary Economics* 76 (November): 191–207.

Gagnon, J., M. Raskin, J. Remache, and B. Sack. 2011. "The Financial Market Effects of the Federal Reserve's Large-scale Asset Purchases." *International Journal of Central Banking* 7 (1, March): 3–43.

Gertler, M., and P. Karadi. 2011. "A Model of Unconventional Monetary Policy." *Journal of Monetary Economics* 58 (1): 17–34.

Gertler, M., and N. Kiyotaki. 2010. "Financial Intermediation and Credit Policy in Business Cycle Analysis." *Handbook of Monetary Economics,* Vol. 3, ed. B. M. Friedman and M. Woodford, 547–99 (chapter 11). North-Holland.

Guerrieri, L., and M. Iacoviello. 2015. "OccBin: A Toolkit for Solving Dynamic Models with Occasionally Binding Constraints Easily." *Journal of Monetary Economics* 70 (March): 22–38.

Harrison, R. 2017. "Optimal Quantitative Easing." Working Paper No. 678, Bank of England.

Holden, T. D. 2016. "Computation of Solutions to Dynamic Models with Occasionally Binding Constraints."

———. 2019. "Existence and Uniqueness of Solutions to Dynamic Models with Occasionally Binding Constraints." Kiel, Hamburg: ZBW Leibniz Information Centre for Economics.

Holston, K., T. Laubach, and J. C. Williams. 2017. "Measuring the Natural Rate of Interest: International Trends and Determinants." *Journal of International Economics* 108 (Supplement 1): S59–S75.

Ivashina, V., and D. Scharfstein. 2010. "Bank Lending during the Financial Crisis of 2008." *Journal of Financial Economics* 97 (3): 319–38.

Jensen, H., I. Petrella, S. H. Ravn, and E. Santoro. 2020. "Leverage and Deepening Business-Cycle Skewness." *American Economic Journal: Macroeconomics* 12 (1): 245–81.

Jermann, U., and V. Quadrini. 2012. "Macroeconomic Effects of Financial Shocks." *American Economic Review* 102 (1): 238–71.

Jiao, Y. 2019. "Financial Crises, Bailouts and Monetary Policy in Open Economies."

Joyce, M., A. Lasaosa, I. Stevens, and M. Tong. 2011. "The Financial Market Impact of Quantitative Easing in the United Kingdom." *International Journal of Central Banking* 7 (3, September): 113–61.

Kandrac, J. 2018. "The Cost of Quantitative Easing: Liquidity and Market Functioning Effects of Federal Reserve MBS Purchases." *International Journal of Central Banking* 14 (5, December): 259–304.

Koop, G., M. H. Pesaran, and S. M. Potter. 1996. "Impulse Response Analysis in Nonlinear Multivariate Models." *Journal of Econometrics* 74 (1): 119–47.

Krishnamurthy, A., and A. Vissing-Jorgensen. 2011. "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy." NBER Working Paper No. 17555.

López-Salido, D., J. C. Stein, and E. Zakrajŝek. 2017. "Credit-market Sentiment and the Business Cycle." *Quarterly Journal of Economics* 132 (3): 1373–1426.

Maliar, L., and S. Maliar. 2015. "Merging Simulation and Projection Approaches to Solve High-dimensional Problems with an Application to a New Keynesian Model." *Quantitative Economics* 6 (1): 1–47.

Nakov, A. 2008. "Optimal and Simple Monetary Policy Rules with Zero Floor on the Nominal Interest Rate." *International Journal of Central Banking* 4 (2, July): 73–127.

Oh, H., and R. Reis. 2012. "Targeted Transfers and the Fiscal Response to the Great Recession." *Journal of Monetary Economics* 59 (Supplement): S50–S64.

Perri, F., and V. Quadrini. 2018. "International Recessions." *American Economic Review* 108 (4–5): 935–84.

Quint, M. D., and M. P. Rabanal. 2017. "Should Unconventional Monetary Policies Become Conventional?" International Monetary Fund.

Reifschneider, D., and J. C. Williams. 2000. "Three Lessons for Monetary Policy in a Low-inflation Era." *Journal of Money, Credit and Banking* 32 (4): 936–66.

Reis, R. 2016. "Can the Central Bank Alleviate Fiscal Burdens?" NBER Working Paper No. 23014.

Romer, C. D., and D. H. Romer. 2017. "New Evidence on the Aftermath of Financial Crises in Advanced Countries." *American Economic Review* 107 (10): 3072–3118.

Schmitt-Grohé, S., and M. Uribe. 2004a. "Optimal Fiscal and Monetary Policy under Imperfect Competition." *Journal of Macroeconomics* 26 (2): 183–209.

———. 2004b. "Optimal Fiscal and Monetary Policy under Sticky Prices." *Journal of Economic Theory* 114 (2): 198–230.

———. 2007. "Optimal Simple and Implementable Monetary and Fiscal Rules." *Journal of Monetary Economics* 54 (6): 1702–25.

Schularick, M., and A. M. Taylor. 2012. "Credit Booms Gone Bust: Monetary Policy, Leverage Cycles, and Financial Crises, 1870-2008." *American Economic Review* 102 (2): 1029–61.

Siu, H. E. 2004. "Optimal Fiscal and Monetary Policy with Sticky Prices." *Journal of Monetary Economics* 51 (3): 575–607.

Smets, F., and R. Wouters. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review* 97 (3): 586–606.

Sugo, T., and K. Ueda. 2008. "Eliminating a Deflationary Trap through Superinertial Interest Rate Rules." *Economics Letter*s 100 (1): 119–22.

Svensson, L. E. O. 2019. "Monetary Policy Strategies for the Federal Reserve."

Swarbrick, J., T. Holden, and P. Levine. 2017. "Credit Crunches from Occasionally Binding Bank Borrowing Constraints."

Woodford, M. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton University Press.