Capital Requirements in Light of Monetary Tightening[*]

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In 2021, euro-area inflation surged, prompting the European Central Bank to reverse its monetary stance. This paper argues that this shift did not generate significant financial stress, partly because of the bank capital requirements introduced in the 2010s. We develop a framework to assess their effects over the business cycle. Although capital requirements remained broadly stable, they shaped the transmission of the structural shocks underlying this episode. We find that while these requirements modestly constrained post-COVID growth, they successfully prevented the materialization of risks. Overall, capital requirements strengthened the economy's resilience to adverse shocks at a relatively low macroeconomic cost.
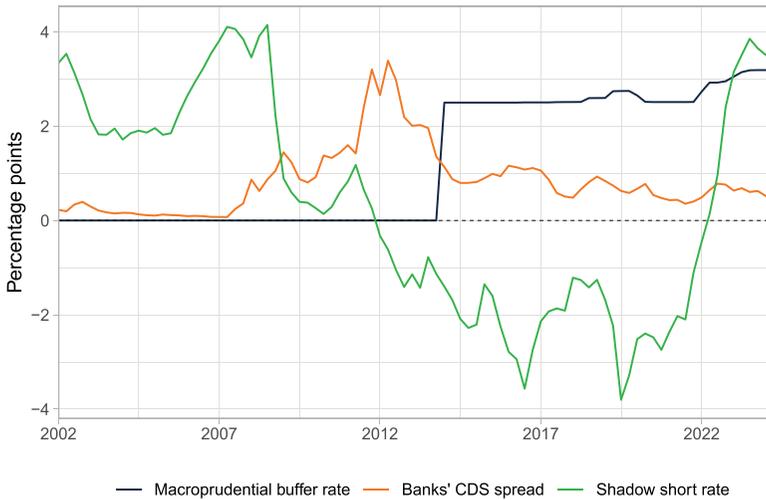
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1. Introduction

Starting in 2021, euro-area inflation surged, prompting the European Central Bank (ECB) to sharply tighten its monetary stance. The rapid increase in interest rates could have generated financial stress, for instance if lenders had imperfectly hedged fixed-income positions or if borrowers had been unable to absorb the rise in financing

Figure 1. Monetary Policy, Macroprudential Buffer, and Financial Risks

Source: ESRB, Bloomberg, Krippner (2013).
Note: The macroprudential buffer rate is the simple average of the capital conservation buffer (CCoB), systemic risk buffer (SyRB), and countercyclical capital buffer (CCyB) rates, measured at their announcement rather than implementation date. Banks' CDS spread corresponds to the average spread of a sample of euro-area banks, weighted by their market capitalization. The shadow short rate is an estimate of the implicit short-term interest rate derived from the yield curve, accounting for the unconventional monetary policies implemented over the period.

costs. Such risks were particularly salient given prevailing financial and macroeconomic conditions. First, Figure 1 shows a U-shaped ECB's stance over the past 15 years, a pattern historically associated with financial crises (Jiménez et al. 2022). Second, part of the surge in inflation stemmed from supply-side forces, another well-documented predictor of financial stress (Boissay et al. 2025). Yet, despite these regularities, the euro area did not experience a major financial disruption, as evidenced by the only modest increase in banks' credit default swap (CDS) spreads after 2022 (see Figure 1). This paper argues that a key reason lies in the bank capital requirements introduced during the 2010s.

Indeed, the prudential environment faced by banks today differs substantially from that prevailing during past monetary tightening

episodes. Following the 2008 Global Financial Crisis (GFC) and
the 2010 euro-area sovereign debt crisis, European authorities intro-
duced a range of prudential instruments that raised banks' capital
requirements from 8 percent to at least 10.5 percent of risk-weighted
assets (see Figure 1).[1] Although these tools were initially conceived
as countercyclical instruments, consistent with early academic con-
tributions on the topic (Mendoza 2010; Bianchi 2011), authorities
have since reassessed this view. During the monetary tightening of
2021–23, despite a marked slowdown in credit growth, these capi-
tal buffers were not released. In some jurisdictions, they were even
tightened. Overall, capital requirements have been used primarily
to bolster banks' resilience rather than to smooth the financial cycle
(Hempell, Scalone, and Silva 2024; ECB-ESRB 2025).

In this paper, we assess the implications of this new pruden-
tial paradigm in a context of monetary tightening. Although capital
requirements have remained relatively stable over time, they can
nonetheless shape the transmission of the structural shocks underly-
ing macroeconomic fluctuations. We develop a framework to quan-
tify the costs and benefits of time-invariant capital requirements
over the business cycle. Our analysis focuses on the post-COVID
period and the subsequent monetary tightening episode, which rep-
resents the most volatile macroeconomic environment in the euro
area since the post-GFC regulatory reforms. We find that while cap-
ital requirements modestly constrained post-COVID growth, they
also prevented the materialization of financial risks as the ECB
raised policy rates. Put differently, capital requirements acted as
automatic stabilizers, complementing monetary policy. Overall, they
have contributed to safeguarding macrofinancial resilience at a rela-
tively low macroeconomic cost.

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[1]The first measure strengthened time-invariant requirements through the cap-
ital conservation buffer (CCoB). The second introduced potentially time-varying
and sector-specific buffers, namely the systemic risk buffer (SyRB) and the coun-
tercyclical capital buffer (CCyB). A third measure established additional require-
ments for systemically important institutions. This last dimension lies beyond the
scope of the present paper, as it would require explicitly modeling heterogeneous
banks. While this framework is defined at the European level, its specific design
and activation are determined nationally. See the European Systemic Risk Board
(ESRB) website for details.

To evaluate the contribution of capital requirements to business cycle dynamics, we employ a medium-scale New Keynesian dynamic stochastic general equilibrium (DSGE) model with financial frictions, building on Clerc et al. (2015) and Mendicino et al. (2018). The model features two dynasties of households: patient households, who own banks and nonfinancial corporations, and impatient households, who borrow from banks. Both impatient households and nonfinancial corporations can default on their loans, which entails costly bankruptcies. Banks, in turn, borrow from patient households, who are assumed to be myopic with respect to banks' risk profile. A prudential authority therefore imposes a limit on banks' leverage through capital requirements. We estimate the model using euro-area data from 2002:Q1 to 2024:Q2 and recover the structural shocks over this period. Given that the model includes a broad set of standard structural disturbances, we can jointly fit a large number of macrofinancial series and identify the main drivers of the business cycle, particularly during the post-COVID monetary tightening. We then construct counterfactual scenarios altering the level and design of capital requirements to assess the effects of the current prudential framework.

We find that the post-COVID increase in interest rates was driven by a combination of consumption catch-up and cost-push shocks. Importantly, while standard markup shocks account for a non-negligible share of these cost-push shocks, the model attributes a substantial role to shocks to the marginal efficiency of investment (MEI) for nonfinancial corporations. This reflects the coexistence of high inflation and policy rates with resilient investment activity, a pattern that MEI shocks can naturally rationalize. By contrast, risk shocks in the spirit of Christiano, Motto, and Rostagno (2014) play only a limited role, consistent with the subdued volatility of bank credit. The MEI shock is typically interpreted as capturing variations in the effectiveness of financial intermediation (Justiniano, Primiceri, and Tambalotti 2011). In the present context, it may reflect, among other factors, the widening of banks' net interest margins and the growing role of nonbank intermediaries during the monetary tightening, consistent with the deposit channel of monetary policy (Drechsler, Savov, and Schnabl 2017).

Against this backdrop, our counterfactual exercise indicates that time-invariant capital requirements act as effective automatic

stabilizers. While they slightly dampened gross domestic product (GDP) growth during the 2022 expansion, they also reduced banks' probability of default at the start of 2023, thereby supporting credit and activity during the subsequent slowdown. These results stem from the specific combination of shocks characterizing this episode: although capital requirements somewhat attenuated the transmission of positive MEI shocks to GDP, they also limited the macroeconomic cost of banks' and firms' risk shocks. Even though risk shocks played a modest role during the period under study, this finding underscores the effectiveness of capital requirements in mitigating financial risks at a low macroeconomic cost. Moreover, we find that capital requirements generate heterogeneous effects across savers and borrowers, emphasizing their role in intertemporal risk sharing. Finally, we show that sectoral capital requirements on housing loans (such as those implemented in several European jurisdictions) are particularly effective: during the episode we analyze, they (would have) alleviated the dampening impact of broad-based capital requirements on the propagation of positive MEI shocks. Overall, our results highlight the role of capital requirements in ensuring macroeconomic resilience over the business cycle.

Literature Review. We contribute to a growing literature examining the link between monetary policy tightening and financial stress by highlighting the mitigating role of capital requirements. Boissay et al. (2021) and Jiménez et al. (2022) show that abrupt increases in interest rates following prolonged monetary accommodation tend to trigger financial stress. Boissay et al. (2025) further emphasize that the nature of inflationary shocks matters: supply-driven inflation raises financial stress, whereas demand-driven inflation does not. In contrast, we stress the role of a stabilizing factor in this relationship, namely, the level of bank capital requirements.

Our analysis also relates to the literature on the interaction between monetary and macroprudential policies, with a particular focus on a high-interest-rate environment. Much of the existing work studies *countercyclical* capital requirements in low-rate environments (Rubio and Carrasco-Gallego 2016; Rubio and Yao 2020). We instead focus on the dynamic properties of a *time-invariant* capital requirement in a context of high interest rates, when policymakers have reconsidered the macroprudential stance. Revelo and Levieuge (2022) show that monetary and macroprudential policies

may conflict in the presence of supply-side or bank-capital shocks. By contrast, our framework emphasizes how banks' resilience shapes macroeconomic dynamics, leading us to conclude that these policies can be complementary in such cases. Consistent with Boissay et al. (2023), we find that tighter capital requirements provide greater room for monetary policy to combat inflation.

We further contribute to the literature studying capital requirements in structural general equilibrium models by identifying which shocks are most affected by these prudential instruments. While these models necessarily simplify banks' balance sheets compared with stress-testing frameworks, they allow for the analysis of second-round effects of financial shocks on macroeconomic stability and enable normative evaluation of prudential tools (Jondeau and Sahuc 2022). Most existing studies focus on the effects of *changes* in capital requirements, either in the long run or in response to specific shocks (Clerc et al. 2015; Poutineau and Vermandel 2017; Mendicino et al. 2018, 2020; de Bandt et al. 2022; Bratsiotis and Pathirage 2023; Gasparini et al. 2024). In contrast, we examine the role of a given, *time-invariant level* of capital requirements in the propagation of a broad set of real and financial shocks, thereby identifying which shocks are most sensitive to prudential constraints.

Finally, we also contribute to the literature on the drivers of post-COVID inflation, though our focus is primarily on interest rate dynamics. Recent empirical work highlights the roles of price and wage rigidities (Arce et al. 2024; Giannone and Primiceri 2024; Bernanke and Blanchard 2025; Eickmeier and Hofmann 2025). We complement this evidence by estimating a New Keynesian DSGE model for the euro area that embeds financial frictions. In line with the literature, we find that the surge in inflation and interest rates resulted from a complex mix of supply and demand shocks. However, our results underscore the importance of positive MEI shocks, which help rationalize the resilience of investment and growth in the euro area despite the sharp monetary tightening.

The remainder of the paper is organized as follows. Section 2 presents the model. Section 3 describes the data and estimation strategy. Section 4 discusses the estimation results and the identified structural shocks, with a focus on the 2021–24 period. Section 5 quantifies the role of capital requirements in the transmission of these shocks. Section 6 concludes.

2.   Model

This section presents an overview of the model, which extends Clerc et al. (2015) to analyze the transmission mechanisms of capital requirements under various shocks. We describe the optimization problems faced by each type of agent. The complete set of equilibrium conditions, including optimality and market-clearing relations, is provided in the appendix.

The economy is populated by two dynasties of infinitely lived households (HH), patient (p) and impatient (i), which differ in their discount factors $(\beta^i < \beta^p)$. Within each dynasty, members perfectly share risk. Both types of households consume, supply labor, and accumulate housing. Patient households additionally accumulate productive capital and save through bank deposits. They own all firms in the economy and pay a lump-sum tax to finance the partial deposit insurance provided by the government. Impatient households, by contrast, borrow from banks and are subject to idiosyncratic housing-quality shocks that can lead to default, thereby giving rise to a borrowing constraint.

A continuum of monopolistic intermediate goods firms produce differentiated goods using rented physical capital and labor. Prices are sticky due to Calvo-type rigidity. Perfectly competitive final-good producers combine these intermediate goods into a homogeneous final output, which is either consumed or used by capital and housing producers who face dynamic adjustment costs. Productive capital is owned by both capital management firms and nonfinancial corporations (NFCs). NFCs, which are owned by entrepreneurs belonging to patient households, rely on bank loans and are exposed to idiosyncratic capital-quality shocks that can lead to default, thereby inducing a borrowing constraint.

There are two types of competitive banks. Both collect deposits from patient households and raise equity from bankers. One type extends loans to impatient households, while the other lends to NFCs.[2] Each bank faces portfolio management costs that may result

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[2]This specialization simplifies the pricing problem of each bank type and allows for a heterogeneous transmission of risks across sectors within a period, while still preserving intertemporal transmission through bankers' portfolio reallocation between the two bank types.

in default. Since savers are myopic to banks' individual risk profiles, they do not impose participation constraints. Consequently, banks have an incentive to overleverage, which calls for policy intervention through a capital requirement, limiting loans to a fixed fraction of equity. Banks are owned by bankers, who are members of the patient household and allocate resources so as to equalize expected returns across the two bank types. Banks' balance sheets affect the economy through two main channels: the *net worth channel*, whereby bank profitability influences the income accruing to patient households, and the *credit supply channel*, whereby bank profitability determines the tightness of borrowing constraints faced by debtors.

Finally, the public sector comprises three authorities. The government finances a stochastic stream of expenditures and the deposit insurance scheme through lump-sum taxation. The deposit insurance agency guarantees a fixed share of deposits. The monetary authority sets the short-term nominal interest rate according to a standard Taylor rule.

The model is subject to 11 structural shocks. Following Smets and Wouters (2007), six are standard real shocks: total factor productivity, labor productivity, price markup, monetary policy, time preference, and government spending shocks. In addition, five financial shocks are introduced: two shocks to the marginal efficiency of investment in housing and productive capital, and three risk shocks affecting housing, productive capital, and banks' portfolios. MEI shocks represent exogenous changes in the efficiency with which investment goods are transformed into productive capital, thereby capturing the overall effectiveness of the financial system's intermediation function, as in Justiniano, Primiceri, and Tambalotti (2011). Risk shocks correspond to shocks to the cross-sectional distribution of capital quality and are best interpreted as volatility shocks (Christiano, Motto, and Rostagno 2014).

2.1   Households

Patient Households. The economy features a mass $m^p \in (0,1)$ of infinitely lived patient households. Each household comprises a mass m^e of entrepreneurs, a mass m^b of bankers, and a mass $m^w = m^p - m^e - m^b$ of workers. In every period, an entrepreneur becomes a worker with probability $1 - \theta^e$, and a banker becomes

a worker with probability $1 - \theta^b$. A corresponding mass of workers is drawn to replace the exiting entrepreneurs and bankers, ensuring that the relative shares of each household member type remain constant over time. The household collects income from all of its members and provides perfect risk sharing among them.

The representative patient households has utility given by

$$\mathbb{E}_t \Bigg[\sum_{s=0}^{\infty} (\beta^p)^s e^{\zeta_{c,t+s}} \Bigg(\log(c_{t+s}^p - \psi \bar{c}_{t+s-1}^p) + v^p \log(h_{t+s}^p)$$
$$- \frac{\varphi^p}{1+\eta} \Theta_{t+s}^p (\ell_{t+s}^p)^{1+\eta} \Bigg) \Bigg],$$

where c_t^p denotes consumption of nondurable goods at time t, Ψ is the consumption-smoothing parameter, $\bar{c}_t^p$ is the aggregate counterpart of c_t^p, h_t^p is the total stock of housing held by the household's members, and ℓ_t^p denotes labor supply. The parameter $\varphi > 0$ is a scale factor, and $\eta > 0$ is the inverse of the Frisch elasticity of labor supply. The consumption preference parameter $\zeta_{c,t}$ is an exogenous taste shifter following an AR(1) process. Finally, we introduce an endogenous taste shifter Θ_t^p, which is taken as given by patient households and evolves according to

$$\Theta_t^p = \frac{J_t^p}{\bar{c}_t^p - \psi \bar{c}_{t-1}^p}, \tag{1}$$

where

$$J_t^p = (J_{t-1}^p)^{1-\zeta_J}[(\bar{c}_t^p - \psi \bar{c}_{t-1}^p)]^{\zeta_J}. \tag{2}$$

The specification of the endogenous taste shifter follows Galí (2011) and Galí, Smets, and Wouters (2012). Compared with Jaimovich-Rebelo preferences (Jaimovich and Rebelo 2009), it introduces a distinction between the short-run wealth effect on labor supply and its long-run counterpart, through the endogenous taste shifter parameter ζ_J.

The household maximizes the above objective subject to the sequence of budget constraints:

$$P_t c_t^p + D_t^p + Q_t^H h_t^p + (Q_t^K + P_t s_t^K)k_t^p + T_t^p \leq W_t \ell_t^p + \tilde{R}_t D_{t-1}^p$$

$$+ Q_t^H (1 - \delta^H) h_{t-1}^p + (P_t r_t^K + (1 - \delta^K)Q_t^K)k_{t-1}^P + \frac{1}{m^p} P_t \mathrm{Div}_t, \quad (3)$$

where P_t denotes the price of nondurable goods; Q_t^H and Q_t^K the prices of housing and capital goods, respectively; and W_t the nominal wage rate. T_t^p represents a lump-sum tax, and s_t^K is a per-unit real management cost, taken as given by the household and paid to capital management firms. Div_t denotes the total real dividends received by patient households from capital good producers, monopolistic firms, entrepreneurs, financial intermediaries, and capital management firms.

D_t denotes the stock of nominal deposits held at time t, which pay a gross nominal interest rate $\tilde{R}_t$. This return has two components. A fraction $\kappa \in [0, 1]$ represents insured deposits, remunerated at the contractual nominal rate R_{t-1}. The remaining fraction corresponds to uninsured debt, which pays (i) R_{t-1} in the absence of default, and (ii) the net recovery value of bank assets in the event of default. Because savers cannot observe individual banks' risk profiles, they value bank debt according to the expected credit risk of an average unit of bank liabilities. It follows that

$$\tilde{R}_t = R_{t-1} - (1 - \kappa)\Omega_t, \quad (4)$$

where Ω_t is the average default loss per unit of bank debt.

Impatient Households. There is a mass $m^i = 1 - m^p$ of infinitely lived, identical, impatient households. The representative impatient households has utility given by

$$\mathbb{E}_t \left[\sum_{s=0}^{\infty} (\beta^i)^s e^{\zeta_{c,t+s}} \left(\log(c_{t+s}^i - \psi \bar{c}_{t+s-1}^i) + v^i \log(h_{t+s}^i) \right. \right.$$

$$\left. \left. - \frac{\varphi^i}{1 + \eta} \Theta_{t+s}^i (\ell_{t+s}^i)^{1+\eta} \right) \right],$$

where the utility function and notations are identical to those introduced for patient households. Impatient households differ, however, in their budget constraint. At time t, the representative impatient household borrows a nominal amount B_t^i from banks, which

is evenly distributed across its members. Each household member purchases h_t^i units of housing at the nominal price Q_t^H. At the beginning of period $t + 1$, the housing stock is subject to an idiosyncratic shock ω_{t+1}^i, drawn from a log-normal distribution with mean $-\frac{1}{2}\exp(\zeta_{i,t})\bar{\sigma}_i^2$ and standard deviation $\exp(\zeta_{i,t})\bar{\sigma}_i$, where $\zeta_{i,t}$ follows an AR(1) process. These shocks are i.i.d. across time and household members. At time $t + 1$, the household member sells the undepreciated portion of the housing stock, earning the nominal amount $(1 - \delta^H)Q_{t+1}^H h_t^i$, and repays debt at the noncontingent gross nominal interest rate R_t^i. The household member retains the option to default on debt. The impatient household therefore maximizes expected lifetime utility subject to the following resource constraint:

$$
P_t c_t^i + Q_t^H h_t^i \leq P_t w_t \ell_t^i + B_t^i
$$
$$
+ \int_0^\infty \max\{\omega^i(1 - \delta^H)Q_{t+1}^H h_t^i - R_t^i B_t^i; 0\}f_{t+1}^i(\omega^i)d\omega^i
$$

and banks' participation constraint.

2.2 Production

Final Good Production. The final good is produced by perfectly competitive firms by combining a continuum of intermediate goods according to the constant-returns-to-scale (CES) production technology

$$
y_t = \left(\int_0^1 y_t(f)^{\frac{1}{\mu_t}} df\right)^{\mu_t}, \tag{5}
$$

where $\mu_t = \mu e^{\zeta_{\mu,t}}$ is the markup of intermediary good producers with $\zeta_{\mu,t} \sim ARMA(1,1)$. Let P_t denote the nominal price of the final good and let $P_t(f)$ denote the nominal price of good f. Firms are price takers and seek to maximize nominal profits

$$
P_t y_t - \int_0^1 P_t(f)y_t(f)df.
$$

Intermediary Goods Production. Intermediate good f is produced by monopolist f by combining labor and capital according to

$$y_t(f) = e^{\zeta_{a,t}}(k_t(f))^\alpha (e^{\zeta_{z,t}}\ell_t(f))^{1-\alpha}, \tag{6}$$

where $\alpha \in (0,1)$ is the elasticity of gross production with respect to capital, $\zeta_{a,t}$ a stochastic total factor productivity, and $\zeta_{z,t}$ a stochastic labor productivity. Both these variables follow an $AR(1)$ process. The rental rate of capital r_t^K and the wage rate w_t are taken as given by firm f. In a first step, firm f seeks to minimize production costs, given a production level $y_t(f)$:

$$\min_{k_t(f),\ell_t(f)} \{r_t^K k_t(f) + w_t \ell_t(f)\}$$

$$\text{s.t.} \quad e^{\zeta_{a,t}}(k_t(f))^\alpha (e^{\zeta_{z,t}}\ell_t(f))^{1-\alpha} = y_t(f),$$

$$k_t(f) \geq 0, \quad \ell_t(f) \geq 0.$$

In a second step, firm f chooses its nominal price $P_t(f)$ to maximize the value to its shareholders (the patient households), taking into account the demand schedule of final good producers. At time t, firms discount payoffs at $t+s$ by $(\beta^p)^s \lambda_{t+s}^p$, where λ_{t+s}^p denotes the marginal utility of consumption of patient households at $t+s$. Firm f faces nominal rigidities à la Calvo: in each period, it can reset its price with probability $1-\xi$, where $\xi \in (0,1)$. If not allowed to reset its price at t, firm f mechanically updates its price according to

$$P_t(f) = (\Pi_*)^{1-\iota}(\Pi_{t-1})^\iota P_{t-1}(f),$$

where $\iota \in (0,1)$, $\Pi_t \equiv P_t/P_{t-1}$, and Π_* denotes the steady-state inflation rate. Accordingly, firm f selects $P_t^\star(f)$ to maximize. Firm f thus selects $P_t^\star(f)$ so as to maximize

$$\mathbb{E}_t \sum_{s=0}^\infty (\beta^p \xi)^s \frac{\lambda_{t+s}^p}{\lambda_t^p} y_{t+s} \left[\left(\frac{\Delta_{t,t+s}P_t^\star(f)}{P_{t+s}} \right)^{\frac{1}{1-\mu_t}} \right.$$

$$\left. - mc_{t+s} \left(\frac{\Delta_{t,t+s}P_t^\star(f)}{P_{t+s}} \right)^{\frac{\mu_t}{1-\mu_t}} \right],$$

where

$$\Delta_{t,t+s} = \prod_{j=t}^{t+s-1} (\Pi_*)^{1-\iota}(\Pi_j)^{\iota},$$

and where mc_t is the real marginal cost solution to the cost minimization problem.

Housing Good and Capital Good Production. Capital and housing goods producers face a similar problem. Let $J \in \{K, H\}$ denote the type of durable good produced, H standing for housing and K for capital. These firms produce i_t^J new units sold at nominal price Q_t^J and are owned by the patient households. The firm's technology is characterized by adjustment costs. In order to produce i_t^J units of new durable goods, the firm must spend

$$\left(1 + S_J\left(\frac{i_t^J}{i_{t-1}^J}\right)\right) i_t^J e^{\zeta_{i_J,t}}$$

units of final good, where

$$S_J(X) = \frac{\psi_J}{2}(X-1)^2, \ \psi_J > 0, \zeta_{i_J,t} \sim AR(1).$$

Letting $q_t^J \equiv Q_t^J/P_t$, the typical capital producer seeks to maximize the value to their shareholders

$$\mathbb{E}_t\left\{\sum_{t=0}^{\infty}(\beta^p)^t \lambda_t^p \left[q_t^J i_t^J - \left(1 + S_J\left(\frac{i_t^J}{i_{t-1}^J}\right)\right) i_t^J e^{\zeta_{i_J,t}}\right]\right\}.$$

The marginal efficiency of investment shock $\zeta_{i_J,t}$ reflects an exogenous change in the efficiency with which investment goods are transformed into capital ready for use in production as in Justiniano, Primiceri, and Tambalotti (2011).

Capital Management Firms. Households acquire units of physical capital through financial intermediaries that charge a management fee, thereby capturing the role of nonbank financial intermediation. The capital management cost s_t associated with households' direct holdings of capital k_t^p is a fee collected by a continuum of measure-one firms operating under decreasing returns to scale. Each firm faces a convex cost function $z(m^p k_t^p)$, where $z(0) = 0$,

$z'(\cdot) > 0$, and $z''(\cdot) > 0$. Capital management firms maximize profits according to

$$\text{Div}_t^c = s_t^K m^p k_t^p - z(m^p k_t^p).$$

We assume a quadratic cost function

$$z(x) = \frac{\xi_s}{2}(x)^2 \qquad (7)$$

with $\xi_s > 0$.

Entrepreneurs. At the beginning of period t, entrepreneur j has net worth $N_t^e(j)$. The period $t+1$ gross nominal return on investment projects is Z_{t+1}^e. The individual entrepreneur seeks to solve the program

$$V_t^e = \max_{\widetilde{\text{Div}}_t^e, E_t^e} \left\{ \widetilde{\text{Div}}_t^e + \mathbb{E}_t \left[\beta^p \frac{\Lambda_{t+1}^p}{\Lambda_t^p} [(1 - \theta^e) N_{t+1}^e + \theta^e V_{t+1}^e] \right] \right\}$$

$$\text{s.t.} \quad \widetilde{\text{Div}}_t^e + E_t^e \leq N_t^e,$$

$$N_{t+1}^e = Z_{t+1}^e E_t^e,$$

$$\widetilde{\text{Div}}_t^e \geq 0,$$

where Λ_t^p is the Lagrange multiplier associated with patient households' budget constraint.

Nonfinancial Corporations. Investment project j receives equity $E_t^e(j)$ from entrepreneurs, together with debt $B_t^e(j)$ from banks. These funds are used to acquire $k_t^e(j)$ units of capital at price Q_t^K. The balance sheet of investment project j is thus

$$E_t^e(j) + B_t^e(j) = Q_t^K k_t^e(j).$$

The capital stock is then subject to a quality shock ω_{t+1}^e at time $t+1$, drawn from a log-normal distribution with mean $-\frac{1}{2}\exp(\zeta_{e,t})\bar{\sigma}_e^2$ and standard deviation $\exp(\zeta_{e,t})\bar{\sigma}_e$, where $\zeta_{e,t}$ follows an AR(1) process. After the realization of the quality shock, the effective capital stock is rented to intermediate goods producers at the nominal rental rate $P_{t+1}r_{t+1}^K$. The capital depreciates at rate δ^K, and the undepreciated portion is sold back to capital producers at the price Q_{t+1}^K. At the

end of period $t + 1$, the entrepreneurial firm repays its gross debt obligations at rate R_t^e. Hence, the entrepreneurial firm maximizes the expected discounted value of net profits:

$$
\mathbb{E}_t \left[\beta^p \frac{\Lambda_{t+1}^p}{\Lambda_t^p} (1 - \theta^e + \theta^e v_{t+1}^e) \max \left\{ \omega_{t+1}^e R_{t+1}^K Q_t^K k_t^e(j) \right. \right.
$$

$$
\left. \left. - R_t^e B_t^e(j); 0 \right\} \right] - v_t^e E_t^e(j)
$$

subject to banks' participation constraint, denoting

$$
R_{t+1}^K = \frac{P_{t+1} r_{t+1}^K + (1 - \delta) Q_{t+1}^K}{Q_t^K},
$$

and where v_t^e is the Lagrange multiplier associated with entrepreneurs' balance sheet constraint.

2.3 Bankers and Banks

Bankers. An individual banker starts period t with net worth N_t^b, which is invested as equity (i) in a continuum of investment projects E_t^F and (ii) a continuum of housing projects E_t^M. The period $t + 1$ aggregate gross nominal return on these projects is Z_{t+1}^b. The individual banker seeks to solve the program

$$
V_t^b = \max_{\widetilde{\mathrm{Div}}_t^b, E_t^M, E_t^F} \left\{ \widetilde{\mathrm{Div}}_t^b + \mathbb{E}_t \left[\beta^p \frac{\Lambda_{t+1}^p}{\Lambda_t^p} [(1 - \theta^b) N_{t+1}^b + \theta^b V_{t+1}^b] \right] \right\}
$$

s.t. $\widetilde{\mathrm{Div}}_t^b + E_t^M + E_t^F \leq N_t^b,$

$N_{t+1}^b = Z_{t+1}^M E_t^M + Z_{t+1}^F E_t^F,$

$\widetilde{\mathrm{Div}}_t^b \geq 0,$

where Λ_t^p is the Lagrange multiplier associated with patient households' budget constraint.

Banks. At time t, a bank of type $j \in \{M, F\}$ takes equity E_t^j from bankers and borrows D_t^j at gross rate R_t from households to extend loans B_t^j. Hence the balance sheet constraint:

$$E_t^j + D_t^j = B_t^j.$$

The return at time $t + 1$ on a well-diversified portfolio of loans is denoted R_{t+1}^j. This portfolio is subject to a performance shock ω_{t+1}^j at $t + 1$, drawn from a log-normal distribution with mean $-\frac{1}{2}\exp(\zeta_{B,t})\bar\sigma_j^2$ and standard deviation $\exp(\zeta_{B,t})\bar\sigma_j$,[3] where $\zeta_{B,t}$ is common to both bank types and follows an AR(1) process. At the end of period $t+1$, the bank pays the gross interest rate on deposits. A bank of type j thus maximizes

$$\mathbb{E}_t\left[\beta^p\frac{\Lambda_{t+1}^p}{\Lambda_t^p}(1 - \theta^b + \theta^b v_{t+1}^b)\max\left\{\omega_{t+1}^j R_{t+1}^j B_t^j - R_t D_t^j; 0\right\}\right] - v_t^b E_t^j,$$

where v_t^b is the Lagrange multiplier associated with bankers' balance sheet constraint.

Because of limited liability, shareholders' payoffs cannot be negative. Whenever $\omega_{t+1}^j R_{t+1}^j B_t^j < R_t D_t$, the bank defaults. In this event, its equity is written down to zero, and deposits are taken over by the deposit insurance agency (DIA), which reimburses an exogenous fraction κ of deposits. The DIA partially recovers these payments by seizing the failed bank's loan portfolio net of resolution costs, assumed to amount to a fraction μ^j of recovered assets.

Finally, the bank faces a regulatory capital constraint

$$E_t^j \geq \phi_t \gamma_t^j B_t^j, \tag{8}$$

which states that the capital-to-asset ratio must exceed a (possibly) time-varying level set exogenously by the prudential authority. This requirement is decomposed into two components: a broad-based risk-weighted capital requirement ϕ_t, common to all banks, and a risk weight γ_t^j, specific to each bank type. Both are assumed to be set exogenously by the prudential authority, consistent with the Basel

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[3]This parameterization ensures that $\mathbb{E}_t[\omega_{t+1}^j] = 1$.

standardized approach to risk.[4] In equilibrium, this constraint binds with equality since deposits, being partially insured, are cheaper than equity (Mendicino et al. 2020). Hence, loans can be written as $B_t^j = \frac{E_t^j}{\phi_t \gamma_t^j}$.

Macroeconomic Shocks, Banks Balance Sheets, and Capital Requirements. Capital requirements affect the transmission of macroeconomic shocks to credit through two channels. A first channel goes through the denominator of the above ratio: the higher $\phi_t \gamma_t^j$, the lower the share of loans in the balance sheet, and the lower the financial accelerator. This suggests that capital requirements may act as automatic stabilizers across the business cycle. The bank net worth is a second channel. It follows the aggregate law of motion:

$$N_t^b = [(\theta^b + \chi_b(1 - \theta^b)](Z_t^M E_{t-1}^M + Z_t^F E_{t-1}^F),$$

where θ_b is the proportion of net worth left by retiring bankers to new bankers. Z_t^i is the aggregate return on equity:

$$Z_t^i = \frac{1}{\phi_t} R_t^i \Upsilon(\bar{\omega}_t^i),$$

where $\Upsilon(\cdot)$ denotes the aggregate value of banks' idiosyncratic shocks. This function depends on $\bar{\omega}_t^i$, the threshold below which banks default. A higher capital requirement lowers this threshold, thereby increasing banks' net worth. In addition, for a given reduction in bank risk, capital requirements alter the transmission of macroeconomic shocks to banks' portfolio returns R_t^i. For instance, holding risk constant, consumption-preference or marginal-efficiency shocks affect the return on bank portfolios R_t^i more strongly than risk shocks that directly affect the default threshold $\bar{\omega}_t^i$. Changes in net worth thus result from the interplay between two opposing effects: risk mitigation and reduced loan profitability. When net

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[4]In practice, many banks use internal models where risk weights depend on estimated default probabilities. This simplification can still be justified: (i) the mapping between default probabilities and risk weights is nonlinear and would complicate the model; (ii) empirical default probabilities differ from banks' internal estimates due to portfolio selection and model optimization; and (iii) capital regulation allows supervisors to impose additional buffers or risk weights by asset class, which can be interpreted as an exogenous process.

worth remains positive, bankers reinvest it as equity to finance new loans. The relative strength of these two effects depends on the configuration of shocks hitting the economy. The remainder of the paper investigates this mechanism over the 2021–24 episode by solving and estimating the model.

2.4   Public Authorities

Government. The government levies lump-sum taxes $T_t = m^p T_t^p$ to finance the DIA and a stochastic flow of expenditures g_t. The budget is assumed to be balanced so that $T_t = T_t^{DIA} + P_t g_t$. Government expenditures follow the process $g_t = g e^{\zeta_{g,t}}$, with $\zeta_{g,t}$ following an $AR(1)$ process. We impose that in steady state $g/y = s_g$.

Deposit Insurance Agency. The DIA collects all payments from banks on the deposit market. The gross return on deposits from nondefaulting banks is recovered in full by the DIA. There is a fraction $1 - F_t^j(\bar{\omega}_t^j)$ of such deposits in the banking sector j. The remaining fraction is subject to default. In case of default, the DIA recovers the assets of the defaulting bank, net of a fraction μ^j due to recovery costs. The average default loss per unit of bank debt in sector j is thus

$$\Omega_t^j = \left(\int_0^{\bar{\omega}_t^j} f_{t+1}^j(\omega^j) d\omega^j \right) R_{t-1}$$
$$- (1 - \mu^j) \left(\int_0^{\bar{\omega}_t^j} \omega^j f_t^j(\omega^j) d\omega^j \right) R_t^j \frac{B_{t-1}^j}{D_{t-1}^j}.$$

Let us define the aggregate average default loss per unit of bank debt:

$$\Omega_t = \frac{d_{t-1}^M}{d_{t-1}} \Omega_t^M + \frac{d_{t-1}^F}{d_{t-1}} \Omega_t^F. \tag{9}$$

The DIA insures a fraction κ of deposits and then redistributes the recovered net assets to the depositors, so that

$$\tilde{R}_t = \kappa R_{t-1} + (1 - \kappa)(R_{t-1} - \Omega_t) = R_{t-1} - (1 - \kappa)\Omega_t.$$

It follows that the total cost for the DIA of insuring deposits, and hence the total amount of lump-sum taxes, is

$$T_t^{DIA} = \kappa \Omega_t d_{t-1}.$$

Monetary Policy. The central bank sets the (gross) short-term nominal interest rate R_t according to the following monetary policy rule:

$$\log\left(\frac{R_t}{R_*}\right) = \rho_R \log\left(\frac{R_{t-1}}{R_*}\right) + (1 - \rho_R)\left[a_\Pi \log\left(\frac{\Pi_t}{\Pi_*}\right)\right.$$
$$\left. + a_y \log\left(\frac{GDP_t}{GDP_{t-1}}\right)\right] + \zeta_{R,t}, \qquad (10)$$

where star values denote steady-state counterparts, ρ_R measures the degree of interest rate smoothing, a_Π measures the reaction to inflation, a_y measures the reaction to GDP, and $\zeta_{R,t}$ a white noise shock.

3.   Data and Estimation

A key contribution of this paper is to bring a medium-scale DSGE model with a rich set of financial frictions and shocks to euro-area (EA) data. Identifying which shocks are most affected by capital requirements is essential, since their impact depends on the underlying source of macroeconomic fluctuations. Estimating the model allows us to disentangle these channels and to assess the macroeconomic consequences of the prevailing prudential stance, conditional on the nature of the business cycle.

The model is estimated using quarterly euro-area data spanning 2002:Q1–2024:Q2. Although this sample is relatively short and constrained by data availability, it covers nearly the entire lifetime of the euro area.[5] Parameters determining the steady state are calibrated independently of the model's dynamic properties, while the remaining parameters are estimated. Data sources are detailed in Table 1.

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[5]Calibration targets are computed from the inception of the euro area whenever possible.

Table 1. Data Sources

Series	Source
Shadow Short-Term Interest Rate	Krippner (2013, 2015)
3-Month EURIBOR	ECB, FM, Q.U2.EUR.RT.MM.EURIBOR3MD.HSTA
Implicit GDP Price Index	Eurostat, MNA, Q.PD15.EUR.SCA.BIGQ.EA
Real GDP	Eurostat, MNA, Q.CLV15.MEUR.SCA.BIGQ.EA
Real Household Consumption	Eurostat, MNA, Q.CLV15.MEUR.SCA.P31.S14.S15.EA
Nominal Households' Investment	ECB, QSA, Q.Y.I9.W0.S1M.S1.N.D.P51G._Z._Z.XDC._T.S.V.N._T
Nominal Firms' Investment	ECB, QSA, Q.Y.I9.W0.S11.S1.N.D.P51G._Z._Z.XDC._T.S.V.N._T
Hours Worked	ECB, ENA, Q.Y.U2.W2.S1.S1._Z.EMP._Z._T._Z.HW._Z.N
EA Population (Changing Composition)	ECB, ENA, Q.N.U2.W0.S1.S1._Z.POP._Z._Z._Z.PS._Z.N
EA 20 Population (Fixed Composition)	ECB, ENA, Q.N.I9.W0.S1.S1._Z.POP._Z._Z._Z.PS._Z.N
Nominal Credit to Households	ECB, BSI, Q.U2.N.A.A20.A.1.U2.2250.Z01.E
Nominal Credit to Firms	ECB, BSI, Q.U2.N.A.A20.A.1.U2.2240.Z01.E
Real House Prices	OECD, House Prices, Q.EA.RHP
Banks' 5-Year CDS Premium	Bloomberg, Conversion into Default Probabilities (40% Recovery Rate)
Return on Equity, Banks	ECB, CBD2, Q.U2.W0.57._Z._Z.A.A.I2003._Z._Z._Z._Z._Z.PC
Price-to-Book Ratio of Banks	Datastream
General Government Final Consumption Expenditure (% GDP)	Eurostat, Government Revenue, Expenditure and Main Aggregates, A.PC-GDP.S13.P3.EA19
Nominal GDP	ECB, MNA, Q.N.U2.W2.S1.S1.B.B1GQ._Z._Z.EUR.V.N
Household Interest Rate	ECB, MIR, M.U2.B.A2C.A.R.A.2250.EUR.N
NFC Interest Rate	ECB, MIR, M.U2.B.A2A.A.R.A.2240.EUR.N
Lending for House Purchases: Up to 1 Year	ECB, BSI, M.U2.N.A.A22.F.1.U2.2250.Z01.E
Lending for House Purchases: Over 1 Year and Up to 5 Years	ECB, BSI, M.U2.N.A.A22.I.1.U2.2250.Z01.E
Lending for House Purchases: Over 5 Years	ECB, BSI, M.U2.N.A.A22.J.1.U2.2250.Z01.E
Loans to NFC: Up to 1 Year	ECB, BSI, M.U2.N.A.A20.F.1.U2.2240.Z01.E
Loans to NFC: Over 1 Year and Up to 5 Years	ECB, BSI, M.U2.N.A.A20.I.1.U2.2240.Z01.E
Loans to NFC: Over 5 Years	ECB, BSI, M.U2.N.A.A20.J.1.U2.2240.Z01.E
EURIBOR 3-Month	ECB, FM.M.U2.EUR.RT.MM.EURIBOR3MD..HSTA
German Bond 3 Years	ECB, FM.B.DE.EUR.RT.BB.DE3YT_RR.YLD
German Bond 7 Years	ECB, FM.B.DE.EUR.RT.BB.DE7YT_RR.YLD
German Bond 20 Years	ECB, FM.B.DE.EUR.RT.BB.DE20YT_RR.YLD
Bank Loans in NFC Total Debt	BDF, CFT, Q.S.I8.W0.S11.S1.N.L.LE.F401.T._Z.XDC_R_DEBT._T.S.V.N._T

We implicitly assume that the structural features of the economy remain stable throughout the two decades of data used for calibration and estimation, a strong assumption made for tractability. Moreover, since the next section focuses on a counterfactual analysis of the post-COVID episode, our main interest lies in obtaining reasonable end-of-sample estimates for the parameters and shocks. Potential misspecifications at the beginning of the sample are therefore not excessively concerning. Finally, we assume that prudential authorities do not follow any preannounced rule known to all agents, as there was no mechanical adjustment of capital requirements across euro-area countries over the sample period.

3.1 Calibrated Parameters

A first subset of parameters is set prior to estimation. Some are commonly used in the literature, while others are chosen to simultaneously match a series of steady-state moments. These parameters are presented in Table 2. Targeted moments and their theoretical counterparts are presented in Table 3.

Demographics, Preferences, and Government. The share of impatient households m_i corresponds to the share of households with debt (Finance and Network 2013). The inverse Frisch elasticity is set to 4, following Galí (2010) and Chetty et al. (2011). The labor disutility parameters φ_p and φ_i are normalized to 1, as they only affect the scale of the economy. The discount factor of patient households is set to $\beta_p = 0.997$, targeting the risk-free rate.[6] The share of final government expenditure s_g is directly set from the data to 21 percent.

Production. The markup rate is set to 20 percent, implying $\mu = 1.2$. The depreciation rate of capital is set to $\delta_K = 0.03$. The capital share in production is $\alpha = 0.3$. The survival rate of entrepreneurs θ_e is set to 0.975, as in Gertler and Kiyotaki (2010). Transfers from households to entrepreneurs are calibrated to match the NFC debt-to-GDP ratio. The standard deviation of idiosyncratic shocks affecting entrepreneurs, $\bar{\sigma}_e$, is chosen to match the observed default probability of NFCs.

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[6]See Iacoviello and Neri (2010) for a discussion of patient households' discount factor.

Table 2. Preset and Calibrated Parameters

	Parameter	Value
A. Preset Parameters		
Inverse Frisch Elasticity	η	4
Patient Disutility of Labor	φ^p	1
Impatient Disutility of Labor	φ^i	1
Bank M Bankruptcy Cost	μ_M	0.3
Bank F Bankruptcy Cost	μ_F	0.3
NFC Bankruptcy Cost	μ_e	0.3
HH Bankruptcy Cost	μ_i	0.3
Share of Insured Deposits in Bank Debt	κ	0.54
Consumption Smoothing	ψ	0.14
Productivity	A	1
Steady-State Markup	$1 - \mu$	0.2
Capital Share in Production	α	0.3
Depreciation Rate of Capital	δ_K	0.03
Survival Rate of Entrepreneurs	θ_e	0.975
Capital Requirements for Bank F	ϕ_F	0.105
B. Calibrated Parameters		
Impatient Household Discount Rate	β_i	0.982
Patient Household Discount Rate	β_p	0.997
Housing Depreciation Rate	δ_h	0.009
Patient Housing Scale Factor	ν_p	0.064
Impatient Housing Scale Factor	ν_i	0.642
Management Cost	ξ_s	0.005
Survival Rate of Bankers	θ_B	0.873
Std. Idiosyncratic Shocks, Bankers M	$\bar{\sigma}_M$	0.013
Std. Idiosyncratic Shocks, Bankers F	$\bar{\sigma}_F$	0.043
Std. Idiosyncratic Shocks, Entrepreneurs	$\bar{\sigma}_e$	0.397
Std. Idiosyncratic Shocks, HH	$\bar{\sigma}_i$	0.361
Banker's Endowment	χ_b	0.869
Entrepreneur's Endowment	χ_e	0.329
Capital Requirements for Bank M	ϕ_M	0.037

Banks. The share of insured deposits in bank debt κ is set to 0.54, following Demirgüç-Kunt, Kane, and Laeven (2015). The survival rate of bankers θ_b is used to match the price-to-book ratio of

Table 3. Calibration Targets

	Target	Model
Indebted Households Share m_i	0.44	0.44
Final Gov. Consumption Exp. s_g	0.21	0.21
Risk-Free Rate $\bar{r}$	1.34%	1.34%
Yearly Inflation Rate	1.99%	1.99%
Return on Asset Equity	8.78%	8.78%
Housing Investment as a Share of GDP	0.06	0.06
HH Loans to (Quarterly) GDP	1.98	1.97
Housing among Households Capital	0.61	0.58
NFC Loans to (Quarterly) GDP	1.67	1.66
Banks Default Rate	1.22%	1.22%
Price-to-Book Ratio μ_b	1.15	1.12
Loan to Value	37.3%	37.7%
Capital Share of Households	0.16	0.16
Spread NFC Loans	1.38	1.36
Spread Households Loans	1.05	1.05
NFC Default Rate (Untargeted)	2.5%	2.16%
HH Default Rate (Untargeted)	1%	2.28%

euro-area banks, denoted μ_b. Transfers from bankers χ_b are chosen to reproduce banks' return on assets and equity. Capital requirements are assumed to remain constant throughout the calibration period, in line with Basel III standards. Since our primary interest lies in reproducing end-of-period conditions, we set the broad-based capital requirement to $\phi = 10.5\%$. Risk weights γ^F and γ^H are set to 0.35 and 1, respectively. The volatility parameter σ_F is used to match banks' probability of default. The ratio between σ_F and σ_M, which is not observed, is set such that $\frac{PD_F}{PD_M} = \frac{\gamma^F}{\gamma^M}$, ensuring an internally consistent sectoral capital structure. Although banks granting mortgages are therefore less risky than those lending to firms, household loans are not necessarily less risky than NFC loans.

Nonfinancial Corporations and Households. As it is impossible to target both the spread and the default probability of households and NFCs at the steady state (as they depend on the same parameter), we target the spread. The resulting nontargeted default

probability remains consistent with the data (see Table 3).[7] The depreciation rate of housing capital δ_h, the discount factor of impatient households β_i, the housing utility scale factors υ_i and υ_p, the standard deviation of idiosyncratic shocks affecting households $\bar{\sigma}_i$, and the management cost ξ_s are set to jointly match: (i) housing investment as a share of GDP, (ii) the spread on household loans, (iii) housing as a share of capital held by patient households, (iv) household credit as a share of GDP, (v) the average loan-to-value ratio, and (vi) the share of capital held by households in total capital.

3.2   Estimated Parameters

The remaining parameters are estimated using 10 quarterly, calendar, and seasonally adjusted series: the GDP implicit price index, real GDP, real household consumption, the short-term interest rate, hours worked, real household investment, real nonfinancial corporations' investment, real credit to households, real credit to NFCs, and banks' default probabilities. Most of these variables are standard observables in the literature. A distinctive feature of the period under study, however, is the historically low level of nominal interest rates, suggesting that the monetary authority may have been constrained by an effective lower bound (ELB). While we do not explicitly model the ELB or unconventional monetary policy tools designed to circumvent it, we use as observable the shadow rate of Krippner (2013, 2015), i.e., the hypothetical short-term interest rate that would prevail if the ELB were not binding. This proxy enables us to analyze the role of capital requirements during the exceptional monetary tightening experienced in the euro area since 2020. When available, series correspond to a changing euro-area composition. In addition, because banks' risk shocks play a central role in assessing the macroeconomic implications of capital requirements,

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[7]We compute targeted spreads between a composite interest rate on loans and the composite risk-free rate. The composite loan rate is the weighted average of interest rates by maturity (up to one year, one to five years, and over five years). The composite risk-free rate is the weighted average of the following benchmarks: the three-month eura-area interbank offered rate, or EURIBOR (up to 1 year); the three-year German bond yield (1 to 5 years); the 7-year German bond yield (over 5 years for NFC loans); and a weighted average of the 7-year and 20-year bond yields (over 5 years for housing loans).

we construct a series of banks' expected default probabilities from CDS spreads of a sample of large euro-area banks. All quantities are normalized by total population. With the exception of the short-term interest rate and banks' probability of default, all variables are expressed in demeaned log-differences to focus on cyclical dynamics.[8] Both the short-term interest rate and banks' probability of default are expressed as deviations from their steady-state values.

The estimation follows a Bayesian approach applied to a first-order log-linearized version of the model, using the Kalman filter. Computations are performed with the Dynare toolbox (Adjemian et al. 2024). Prior and posterior distributions are reported in Table 4. As the model expresses shocks in percent of their standard deviation, the estimated standard deviations are scaled accordingly. Priors are set consistently with the literature on New Keynesian models estimated on euro-area data. For parameters related to consumption habits, adjustment costs, price indexation, and the monetary policy rule, we follow Jondeau and Sahuc (2022), whose framework similarly focuses on macrofinancial interactions in the euro area. The prior for the taste-shifter trend follows Galí, Smets, and Wouters (2012). The prior mean for price rigidity is aligned with Smets and Wouters (2003), but we impose a relatively small standard deviation to avoid overestimating rigidity during the COVID episode, which featured a sharp drop in consumption but only a mild fall in inflation. This restriction is consistent with recent empirical evidence on pre-COVID euro-area price rigidity (Gautier et al. 2024). Finally, we adopt an agnostic stance regarding shocks by assigning identical priors to all of them.

One distinctive outcome of our estimation is the relatively low degree of habit formation compared with the literature (around 0.7), implying less consumption inertia. This is partly offset by a lower estimated trend in the endogenous taste shifter relative to the variant without unemployment as an observable variable studied in Galí, Smets, and Wouters (2012): in our case, the marginal rate of substitution between labor and consumption places greater weight on

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[8]The series of investment by nonfinancial corporations display irregularities between 2015 and 2019 unrelated to macroeconomic conditions, primarily due to data for the Netherlands and Ireland. Their respective series are therefore excluded from the euro-area aggregate.

Table 4. Estimated Parameters

		Prior Distribution			Posterior Distribution	
		Dist.	Mean	Std.	Mean	Std.
A. Structural Parameters						
Endogenous Taste Shifter	ζ_J	Beta	0.5	0.2	0.0805	0.1205
Habits	ψ	Beta	0.4	0.1	0.1319	0.0423
Housing Adjustment Cost	ψ_H	Gamma	4	1	4.2464	0.8716
Capital Adjustment Cost	ψ_K	Normal	4	1	2.7013	0.5124
Price Rigidity	ξ	Beta	0.75	0.025	0.8681	0.0099
Price Indexation	ι	Beta	0.4	0.1	0.2917	0.0870
Monetary Policy Smoothing	ρ_R	Beta	0.8	0.1	0.8364	0.0146
MP Reaction to Inflation	a_Π	Normal	1.7	0.1	2.0256	0.0954
MP Reaction to GDP Growth	a_y	Normal	0.125	0.05	0.1206	0.0362
B. Shocks Standard Deviation						
Total Productivity	σ_a	Inv. Gam.	0.5	2	3.6483	0.8429
Labor Productivity	σ_z	Inv. Gam.	0.5	2	0.7786	0.0596
Markup	σ_μ	Inv. Gam.	0.5	2	23.1760	3.0251
Housing Adjustment	σ_{i_H}	Inv. Gam.	0.5	2	2.7875	0.2161
Capital Adjustment	σ_{i_K}	Inv. Gam.	0.5	2	5.0465	0.4658
Monetary Policy	σ_R	Inv. Gam.	0.5	2	0.1460	0.0129
Government Spending	σ_g	Inv. Gam.	0.5	2	2.1734	0.1672
Preference	σ_c	Inv. Gam.	0.5	2	2.4774	0.2556
NFC Risk	σ_e	Inv. Gam.	0.5	2	2.0718	0.2267
HH Risk	σ_i	Inv. Gam.	0.5	2	1.3335	0.1409
Bank Risk	σ_B	Inv. Gam.	0.5	2	4.1870	0.3169
C. Shocks Autocorrelation						
Total Productivity	ρ_a	Beta	0.5	0.2	0.8972	0.0317
Labor Productivity	ρ_z	Beta	0.5	0.2	0.9307	0.0195
Markup Shock	ρ_μ	Beta	0.5	0.2	0.0961	0.0519
Housing Adjustment Shock	ρ_{i_H}	Beta	0.5	0.2	0.6017	0.0547
Capital Adjustment Shock	ρ_{i_K}	Beta	0.5	0.2	0.7510	0.0354
Government Spending Shock	ρ_g	Beta	0.5	0.2	0.5761	0.0841
Time Preference Shock	ρ_c	Beta	0.5	0.2	0.4044	0.0930
NFC Risk Shock	ρ_e	Beta	0.5	0.2	0.9580	0.0209
HH Risk Shock	ρ_i	Beta	0.5	0.2	0.9685	0.0177
Bank Risk Shock	ρ_B	Beta	0.5	0.2	0.8970	0.0344

past consumption. Both features appear to reflect the inclusion of the COVID period. A variant estimated over the subsample ending in 2019:Q4 (although not perfectly comparable due to the nonstationarity of the short-term interest rate) yields a more conventional combination of these parameters. Adjustment costs are also somewhat lower for similar reasons but remain consistent with previous studies. Other estimated parameters are broadly standard. The monetary policy coefficients suggest that the shadow interest rate successfully captures the stance of unconventional policy at the ELB. As in Christiano, Motto, and Rostagno (2014), risk shocks—whether for households, nonfinancial corporations, or banks—are among the most persistent, together with total factor productivity and labor productivity shocks. The price markup shock displays high variance and short persistence, capturing high-frequency movements in inflation and the euro area's exposure to import price fluctuations. Other shocks, such as preference, government spending, and adjustment cost shocks, fall within intermediate ranges of persistence and volatility.

3.3   Model Evaluation

The resulting theoretical variance decomposition is reported in Table 5. A notable finding is the limited contribution of risk shocks, consistent with Pfeifer (2016). Most of the variation in macroeconomic aggregates is driven by standard sources of fluctuations—in particular, preference shocks. This partly reflects the fact that we use these shocks to match credit dynamics rather than credit spreads, in order to replicate the empirical behavior of the credit-to-GDP ratio, a key variable for macroprudential policymakers. It also reflects the estimation window, during which macroeconomic disturbances played a particularly prominent role. One might nevertheless question the relatively small contribution of bank risk shocks, despite the inclusion of the 2008–09 period in the estimation sample and the explicit use of banks' probability of default as an observable. This pattern stems from the fact that euro-area banks' default probabilities did not rise markedly in 2008, but rather in 2011, during the sovereign debt crisis. Although that episode was associated with below-trend growth, it did not exhibit the same crisis dynamics as 2008–09. In the model, therefore, risk shocks primarily capture the medium-run

Table 5. Variance Decomposition, in Percent

	σ_a	σ_z	σ_μ	σ_{i_K}	σ_{i_H}	σ_R	σ_g	σ_c	σ_e	σ_i	σ_B
GDP	4.38	3.66	6.54	15.31	1.05	4.42	8.49	56.01	0.06	0.04	0.04
Consumption	0.39	2.47	4.88	1.45	0.07	4.08	0.25	86.28	0.05	0.06	0.02
Hours Worked	4.07	4.74	6.56	13.58	1.03	3.81	8.69	56.88	0.14	0.02	0.49
Policy Rate	25.58	5.58	9.42	31.59	0.26	6.95	2.19	15.25	1.08	0.4	1.72
Inflation Rate	7.87	4.21	36.48	17.37	0.17	12.27	2.01	18.36	0.35	0.12	0.79
NFC Investment	15.14	1.36	2.82	77.96	0.04	1.27	0.05	0.47	0.86	0.02	0.01
HH Investment	5.28	6.57	1.46	14.07	68.68	0.66	0.19	1.58	0.85	0.48	0.17
NFC Credit	9.63	0.42	5.48	11.69	0.13	2.26	0.2	6.08	58.29	4.6	1.33
HH Credit	5.58	0.73	13.27	3.13	0.68	7.89	0.06	2.57	11.22	54.36	0.5
PD Banks	0.24	0.01	0.05	0.06	0	0.17	0	0.05	0.95	0.13	98.34

consequences of crises rather than their initial triggers. Overall, standard macroeconomic shocks remain the main drivers of both business and financial cycles in the estimated model.

Table 6 reports selected empirical and theoretical moments. The model replicates reasonably well the high variance observed in the data for most variables. While empirical GDP volatility exceeds model-implied volatility, the opposite holds for credit, partly because the model only features one-period debt. Empirical covariances and autocorrelations, however, deviate more substantially from their theoretical counterparts, reflecting the extraordinary nature of the COVID episode. This also suggests that the structural parameters were not excessively distorted by this period. Finally, empirical autocorrelations are qualitatively consistent with model-implied ones, except for household credit, which exhibits substantially greater persistence, partly because house prices are not included as an observable in the estimation.

4.   The Anatomy of Monetary Tightening

To assess the effects of capital requirements on the macroeconomic impact of the 2021–23 monetary tightening, we first identify the structural shocks that triggered this unprecedented episode. The 11 shocks included in the model exert distinct influences on inflation, interest rates, and default probabilities. Their joint dynamics therefore shape how capital requirements propagate through the economy, underscoring that the origin of the shock is critical.

4.1   Impulse Response Functions

Figure 2 displays the impulse response functions of the policy rate, inflation, GDP, and the three probabilities of default following macroeconomic shocks. We consider three supply shocks (total factor productivity, labor productivity, and the markup of intermediate goods producers), two demand shocks (households' preference and government spending), and one monetary policy shock. Each shock is calibrated to generate a 1 percent increase in the policy rate, in absolute value. Productivity shocks lead to a more gradual adjustment in the policy rate compared with other disturbances. Policy rate, firms' markup, and labor productivity shocks all depress

Table 6. Data and Model Moments

|	Data	Model		
		Mean	**90%**	**CI**
A. Variance				
GDP	3.53	2.61	2.07	3.09
Consumption	4.75	5.65	4.01	7.24
Hours Worked	4.93	4.95	3.92	5.89
MP Rate	5.41	4.43	2.97	5.72
Inflation	0.16	0.36	0.28	0.46
NFC Investment	12.34	20.31	14.63	26.63
HH Investment	8.21	9.43	7.6	11.58
NFC Credit	1.7	2.72	2.2	3.19
HH Credit	0.91	3.49	2.84	4.17
PD Banks	1.33	1.1	0.45	1.6
B. Covariance with GDP				
GDP	3.53	2.61	2.07	3.09
Consumption	3.87	3.11	2.14	3.92
Hours Worked	4.04	3.35	2.58	4
MP Rate	−0.14	−0.17	−0.37	0.03
Inflation	−0.29	0.08	−0.04	0.2
NFC Investment	4.87	3.47	2.55	4.44
HH Investment	4.62	0.73	0.57	0.9
NFC Credit	0.01	−0.3	−0.51	−0.09
HH Credit	0.67	0.92	0.71	1.16
PD Banks	−0.24	−0.03	−0.04	−0.02
C. First-Order Autocorrelation				
GDP	−0.2	−0.13	−0.19	−0.06
Consumption	−0.29	−0.19	−0.25	−0.12
Hours Worked	−0.28	−0.17	−0.23	−0.11
MP Rate	0.98	0.91	0.88	0.94
Inflation	0.49	0.51	0.42	0.6
NFC Investment	−0.11	0.22	0.08	0.34
HH Investment	−0.02	0.21	0.07	0.36
NFC Credit	0.67	0.49	0.45	0.53
HH Credit	0.56	0	−0.03	0.03
PD Banks	0.93	0.9	0.84	0.95

Figure 2. Impulse Response to Macroeconomic Shocks
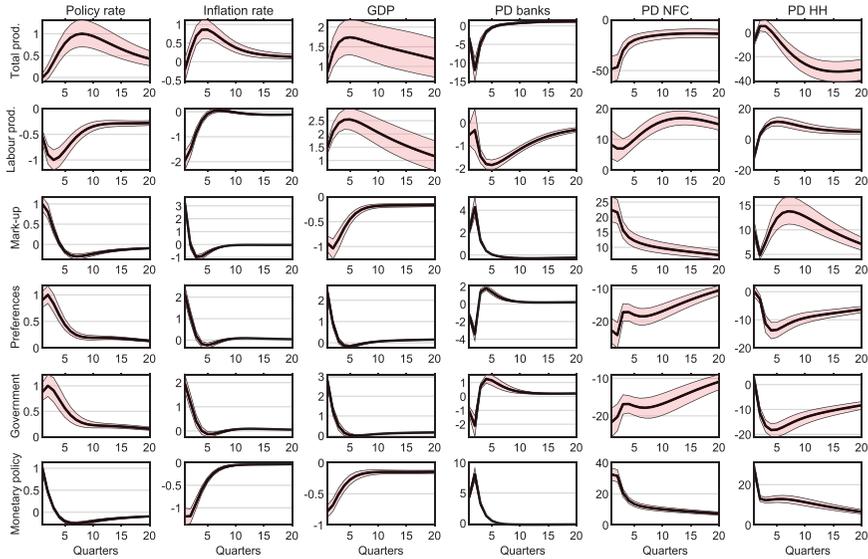
Note: All variables are expressed as deviations from their steady state: in percentage points for the policy and inflation rates, in percent for GDP, and in basis points for default probabilities. All shocks are calibrated to generate a 1 percent increase in the policy rate (in absolute value). Ninety-percent confidence intervals are based on 2,000 simulated draws from the parameter distributions.

GDP, while inflationary government spending, preference, and total productivity shocks raise it. Across all cases, banks' default probabilities respond less strongly than those of nonfinancial actors, a direct consequence of the assumption of perfect portfolio diversification. Among macroeconomic shocks, markup and monetary policy shocks are the most prone to generate financial stress. By contrast, productivity shocks display the greatest uncertainty regarding their macrofinancial impact, while uncertainty remains limited for the others.

Figure 3 presents the corresponding impulse response functions for sectoral shocks. These include three risk shocks—affecting nonfinancial corporations' capital, impatient households' housing, and banks' portfolios—along with two MEI shocks for productive capital and housing. An increase in NFC and household risk induces

Figure 3. Impulse Response to Sectoral Shocks
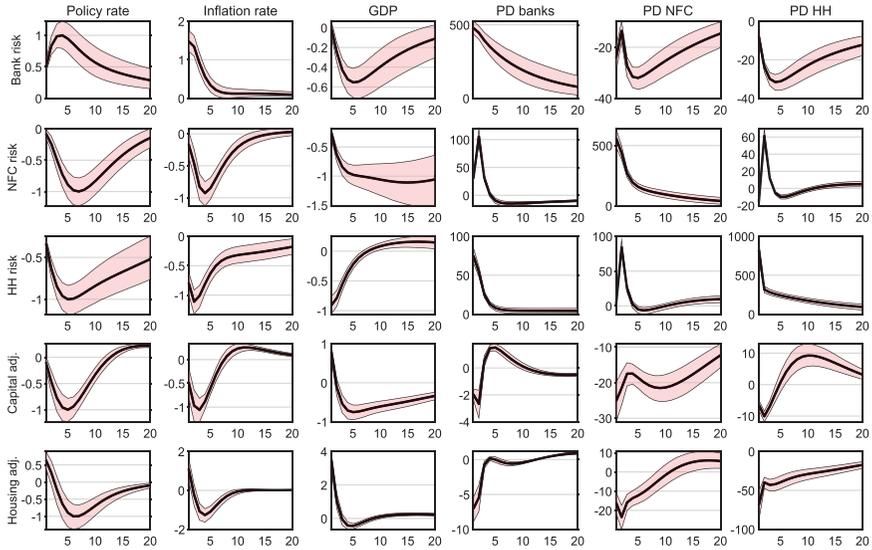
Note: All variables are expressed as deviations from their steady state: in percentage points for the policy and inflation rates, in percent for GDP, and in basis points for default probabilities. All shocks are calibrated to generate a 1 percent increase in the policy rate (in absolute value). Ninety-percent confidence intervals are based on 2,000 simulated draws from the parameter distributions.

deflationary pressures, whereas an increase in banks' risk produces inflationary pressures by fostering temporary overproduction. A reduction in capital or housing adjustment costs initially lowers GDP, as firms face greater demand, but subsequently raises it as investment adjusts more easily. This accelerates inflation and, in turn, prompts a tightening of the policy rate.

4.2   Historical Decomposition

These shocks enable one to capture the origins of the empirical variations in inflation, interest rate, and GDP. Figure 4 plots the decomposition of the policy rate, in deviation from its steady-state value. The rise of interest rates of 2006-07 is thus mainly explained by positive supply (total productivity shocks) and demand (positive preference shocks) factors. The sudden decrease of 2008 is mostly explained by a negative investment (MEI) shock, supplemented by

Figure 4. Decomposition of Short-Term Interest Rate
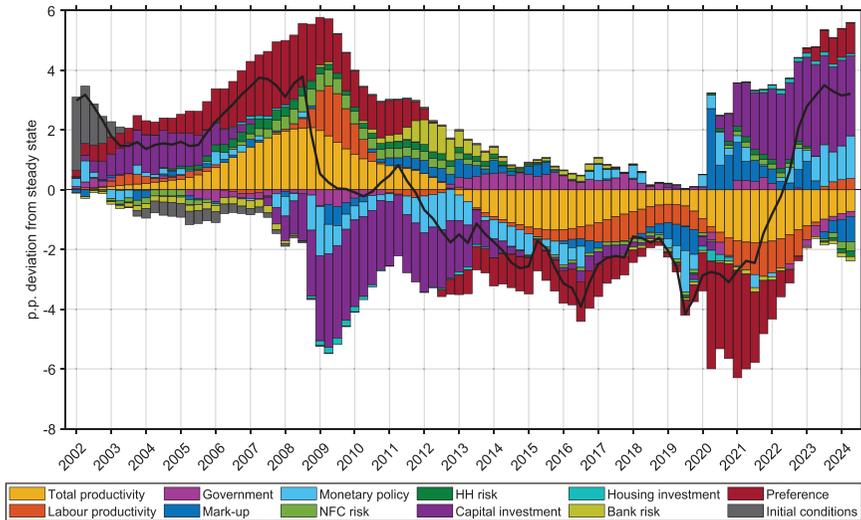
Note: Deviations from steady state in percentage points.

a particularly aggressive monetary policy. The low-rate environment that followed is then explained by a reversal in supply-side cycles, with strong and persistent negative productivity shocks, supplemented by negative preference shocks. At the beginning of this subperiod, decrease in firms' markup as well as government policy shock are the only inflationary pressures that contribute positively to GDP. Starting from 2016, total productivity begins to recover, but labor productivity and government spending firms' markup decrease, maintaining interest rates at a low level.

The COVID period set the seed of inflationary pressures, with sizable cost-push shocks countered by negative demand shocks. However, once the latter receded, inflationary pressures did not disappear. The markup shock left the stage for an increase in the marginal efficiency of investment, which contributed positively to GDP and inflation. This shock stands for sharp decrease in the relative price of tangible assets in 2021–23, as consumption prices rose more than investment prices, thus giving firms an incentive to invest and leading to overdemand in the final good market. This may capture, among others, the increase in banks' net interest rate margin and the increasing role of nonbank intermediaries during the rise

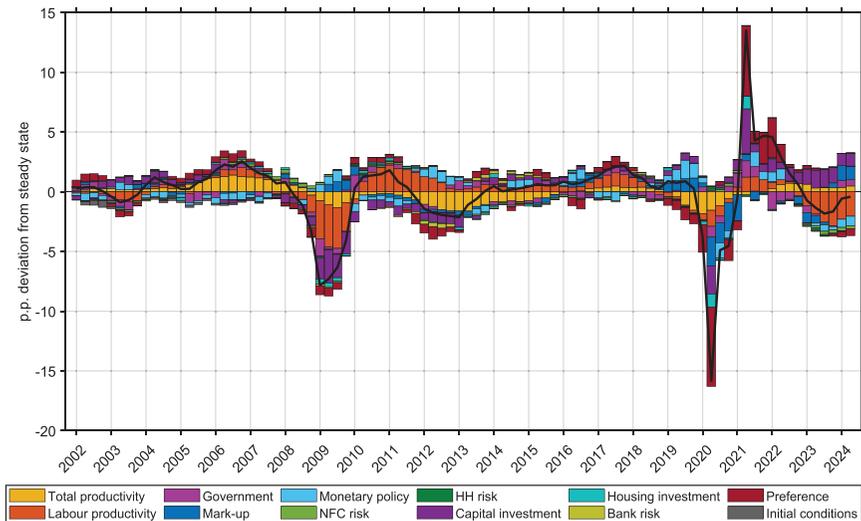**Figure 5. Decomposition of Year-on-Year Inflation Rate**
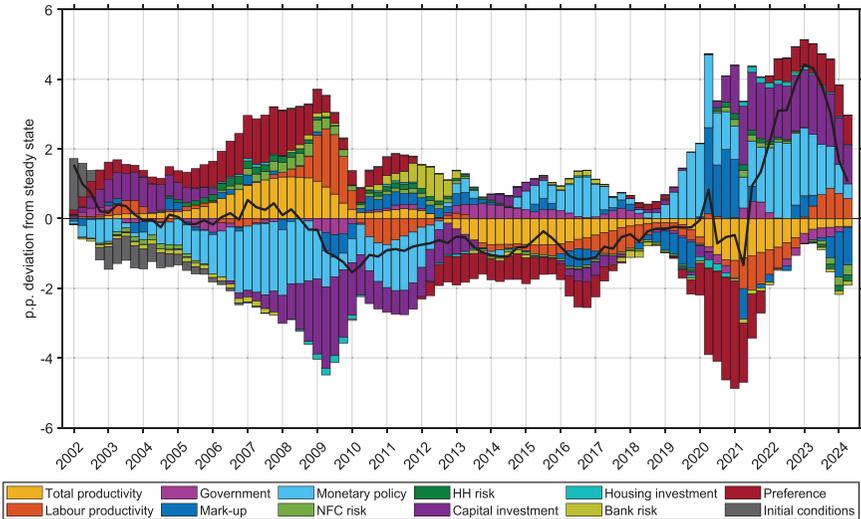
Note: Deviations from steady state in percentage points.

in interest rates, consistently with the deposit channel of monetary policy (Drechsler, Savov, and Schnabl 2017). As this shock is persistent and expansionary, it warrants a stronger reaction of monetary policy compared with a cost-push shock, which is short-lived and recessionary.

As mentioned by Licchetta and Meyermans (2022), gross fixed capital has rebounded at a significantly faster rate after COVID compared with the aftermath of the financial crisis. Public investment was more important in the post-COVID period than in the post-GFC time to support the recovery. Investment also benefited from a real cost of financing which remains relatively low at the end of our estimation period. The important contribution of the shock to the cost of investment reflects this relatively strong recovery of real investment for the period.

The decomposition of year-on-year inflation is plotted in Figure 5 and shows notably the action of monetary policy on inflation. While monetary policy appears relatively tight until 2012, expansionary shocks are the norm between 2014 and 2019 to fight below average inflation. However, once deflationary pressures disappeared after COVID, past accommodative monetary policy continued to

**Figure 6. Decomposition of Year-on-Year
GDP Growth Rate**

Note: Deviations from steady state in percentage points.

push inflation up, despite the exogenous increase in the policy stance exemplified in Figure 4. Figure 6 plots the decomposition of year-on-year GDP growth, and shows that these shocks brought down GDP growth below its average in 2023, starting from the strong post-COVID context driven by positive demand shocks.

This decomposition thus indicates that the strong rise in interest rates of 2021–23 finds its roots in mostly supply-side shocks, complemented by a positive demand shock and the lagged effect of accommodative monetary policy, with an overall ambiguous effect on GDP. We recover this combination of shocks to assess how the level of capital requirements affected their transmission in the euro area.

5. Capital Requirements and the Transmission of Monetary Tightening

5.1 Basel III and Monetary Tightening

To what extent do capital requirements affect the transmission of monetary tightening? European prudential authorities strengthened

capital regulation during the 2010s, transitioning from Basel II to Basel III. In particular, the minimum 8 percent risk-weighted assets (RWA) capital requirement under Basel II was supplemented by a 2.5 percentage point capital conservation buffer (CCoB). This new prudential environment calls for a reassessment of how monetary tightening interacts with financial stability. On the one hand, higher buffers increase banks' resilience to adverse shocks. On the other hand, by constraining credit supply in times of crisis, they may amplify those shocks. This section quantifies the impact of higher capital requirements, by 2.5 percentage points, on the transmission of the 2021–23 inflation surge and monetary tightening in the euro area, by constructing a counterfactual scenario in which capital requirements remained at 8 percent of RWA.

To assess the state of the economy, we define both an *observed* and a *counterfactual* scenario over the simulation period (2021:Q3–2024:Q2):

- The *observed scenario* is simulated using the calibrated and estimated parameters for the full sample, together with the shocks recovered for the 2021:Q3–2024:Q2 period. In this case, the capital requirement ratio is set at 10.5 percent. We assume that, in the initial steady state, the structural increase in capital requirements from Basel II (8 percent) to Basel III (10.5 percent) has been fully transmitted. Given that the reform was announced in 2012 and completed by 2019, this assumption appears reasonable.
- The *counterfactual scenario* differs only by the level of the capital requirement ratio, which is set at 8 percent, consistent with Basel II. Using the structural model, we isolate the effect of this single parameter change while holding constant the shocks estimated during the post-COVID monetary tightening episode.

Figure 7 reports the probability of default of banks under two scenarios: (i) the sum of all estimated shocks between 2021:Q3 and 2024:Q2 under Basel III regulation (black line), and (ii) the same shocks under Basel II regulation (dashed red line). Higher capital requirements under Basel III dampen the volatility of banks' probability of default. Under Basel II, the inflationary surge and

Figure 7. Probabilities of Default:
## Basel III vs. Basel II Capital Requirements
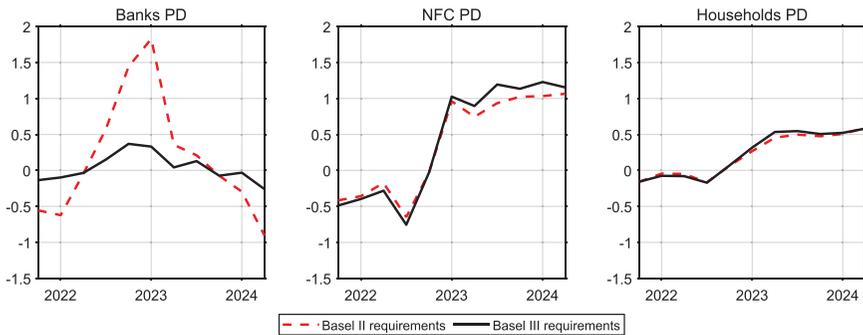
Note: The y-axis represents deviations from steady state in percentage point. The x-axis represents quarters, the first one being 2021:Q4.

subsequent monetary tightening would have raised the deviation of banks' probability of default from its long-term trend by about 100 basis points.

These results indicate that capital requirements do not need to be explicitly countercyclical to be effective. In an inflationary environment, they act as automatic stabilizers by curbing the amplitude of both expansionary and contractionary shocks. In Figure 8 and Figure 9, the black line shows the difference in macroeconomic and financial variables under Basel III relative to Basel II, while the colored bars display the contribution of each structural shock to this difference. The contribution of the bank risk shock dominates the divergence between the two regimes. As shown in Figure 4, this shock exerts a negative contribution to the evolution of the policy rate over the period considered.

Figure 8 further shows that, with Basel III, the policy rate was higher during the immediate post-COVID expansion and lower in early 2023 than it would have been under Basel II. During the post-COVID phase, higher capital requirements increased inflation, as aggregate supply was restrained by tighter credit supply and lower net worth for savers, weighing on GDP. Conversely, at the beginning of 2023, aggregate supply contracted less because credit supply remained resilient, implying higher supply relative to demand, thereby reducing inflation and the policy rate. Hence, higher

Figure 8. Impact of Basel III from 2021:Q3 to 2024:Q2—Macroeconomic Variables
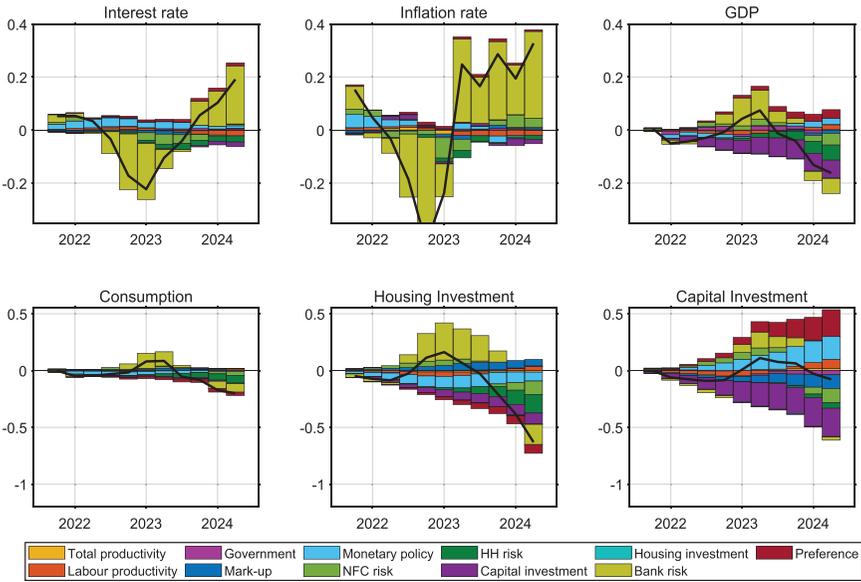
Note: The black line shows the difference between the actual and the counterfactual paths. The colored bars indicate the contribution of each shock to this overall effect. The x-axis reports quarters, with the first corresponding to 2021:Q4. All variables are expressed as deviations from their steady state in percent, except for the interest rate and inflation rate, which are in percentage points.

capital requirements smooth the cycle by moderating expansions and supporting credit during downturns.

The bank risk shock is the main contributor to the difference between the Basel II and Basel III scenarios, even though this shock remains relatively small during the simulation period. Indeed, ECB Financial Stability Reviews (European Central Bank 2023a, 2023b) describe banking risk in the euro area as contained, especially when compared with other advanced economies. This simulation suggests that the automatic stabilization role of capital requirements could be even stronger in a counterfactual scenario with larger bank risk shocks, underscoring the importance of precisely identifying the composition of shocks. For instance, the bank risk shock is almost negligible in the post-COVID period in Figure 4, while it was relatively

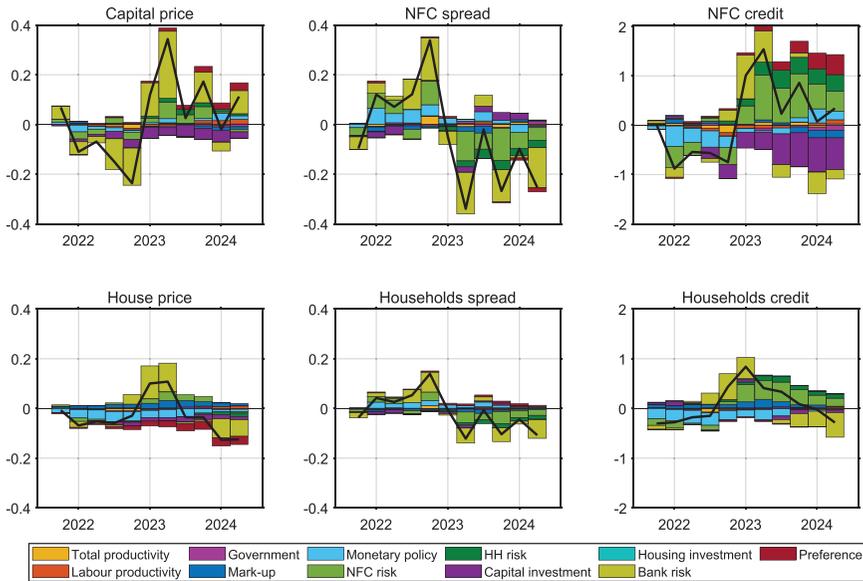## Figure 9. Impact of Basel III from 2021:Q3 to 2024:Q2—Financial Variables

Note: The black line shows the difference between the actual and the counterfactual paths. The colored bars indicate the contribution of each shock to this overall effect. The x-axis reports quarters, with the first corresponding to 2021:Q4. All variables are expressed as deviations from their steady state in percent, except for the interest rate and inflation rate, which are in percentage points.

large between 2010 and 2014. While the impact on inflation and the policy rate is mainly driven by the bank risk shock, capital requirements contributed negatively to the transmission of the MEI shock by constraining credit supply and dampening its expansionary effects. Toward the end of the period, higher capital requirements shielded the economy from the adverse effects of bank risk shocks on consumption and investment. They also appear to mitigate the negative impact of the markup shock on consumption and to stimulate capital accumulation by moderating the rise in the policy rate.

The same automatic-stabilizer mechanism applies to asset prices. Under Basel III, banks curtailed lending during the expansion but expanded it during the downturn. During the recovery phase, to meet capital requirements, banks adjusted their lending behavior

by reducing loan volumes and raising lending spreads to rebuild retained earnings, thereby sharing the cost of regulation with borrowers. Figure 9 shows that higher capital requirements implied lower capital and housing prices during the post-COVID expansion, but relatively higher asset prices when bank risk increased toward the end of the period, reflecting tighter credit supply during the recovery and looser supply during the riskier phase.

Household and NFC risk was only slightly affected by higher capital requirements. While the tighter Basel III requirements proved costly during the post-COVID recovery, they reduced households' and NFCs' leverage, thereby limiting their risk exposure over this period. Conversely, by supporting credit supply in subsequent phases of expansion, higher capital requirements implied a slightly higher probability of default for borrowers.

The quantitative effects were larger for firms than for households. During the 2022 expansion, the impact on credit supply and lending spreads was stronger for NFCs than for households because risk weights were higher for NFC exposures. In addition, the investment and firm risk shocks, which played a key role in the unfolding of the monetary tightening, directly affected firms rather than households. Yet, housing investment declined more than business investment. Investment was influenced not only by credit supply but also by demand: as patient households bore the cost of bank losses, they reduced their demand for housing. When borrowing costs rose, households cut housing investment relatively more than firms reduced their NFC investment. This effect was further amplified by another channel: capital requirements also influenced savers' demand for assets through their effect on banks' profitability.

In conclusion, the abrupt rise in interest rates could have had large macroeconomic effects through risk shocks. As discussed by Hoffmann et al. (2019), the transmission of a monetary tightening may operate through the balance sheet channel, either via banks' net worth or borrowers' leverage, with implications for consumption and investment. The potential materialization of these risks depends on which agents bear the interest rate risk. In particular, leveraged actors could have faced tighter borrowing constraints if they were imperfectly hedged against interest rate risk or held concentrated portfolios. However, our historical decompositions attribute a relatively small role to such shocks in 2023, as capital requirements

Figure 10. Impact of Basel III from 2021:Q3 to 2024:Q2—Distributive Effects
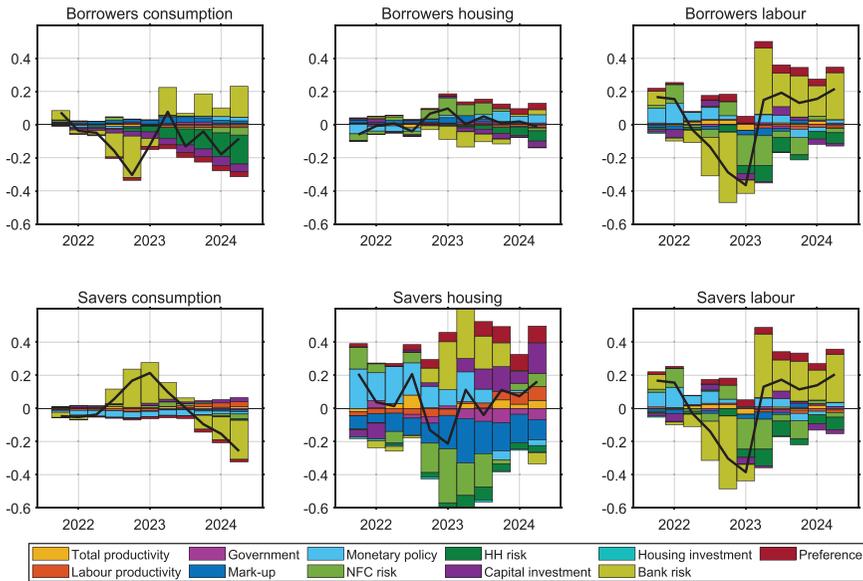
Note: The black line shows the difference between the actual and the counterfactual paths. The colored bars indicate the contribution of each shock to this overall effect. The x-axis reports quarters, with the first corresponding to 2021:Q4. All variables are expressed as deviations from their steady state in percent.

were sufficiently high to absorb a moderate risk shock. The benefits of higher capital requirements would have been even larger in the case of a stronger bank risk shock, similar to that estimated for 2011, for instance.

5.2 Redistributive Effects of Capital Requirements

As suggested in the previous subsection, the mitigating impact of capital requirements operated through both savers' net worth and borrowers' credit constraints. This implies that capital requirements had pronounced heterogeneous effects across households. Figure 10 displays the differential evolution of each household's choice variables under Basel III and Basel II. For instance, under Basel III, savers' consumption was 0.2 percentage points higher in 2023:Q1. More generally, higher capital requirements smoothed

savers' consumption, a result largely driven by the bank risk shock. When bank risk was low, capital requirements weighed on banks' profitability, reducing savers' income flows. Conversely, when bank risk materialized, the opposite occurred, boosting savers' consumption. In contrast, borrowers' consumption was temporarily constrained by capital requirements when the bank risk shock hit: higher capital buffers protected banks' owners rather than their borrowers. However, the contribution of capital requirements turned positive by the end of the period, once bank risk subsided. By strengthening banks' balance sheets, capital requirements ensured a faster recovery. Deposit insurance, financed by patient households, already helped smooth the impact of shocks, and was complemented by capital requirements, which reduced households' overall losses.

Regarding housing, capital requirements helped preserve borrowers' access to credit, with housing investment growth 0.1 percentage points higher in 2023:Q1. Interestingly, the contribution of nearly every shock was of opposite sign for savers and borrowers. For example, while capital requirements amplified the negative impact of monetary policy shocks on savers' housing, they mitigated it for borrowers. However, the quantitative effects of capital requirements on housing investment were roughly five times larger for savers than for borrowers, highlighting that their macroeconomic influence mainly operated through savers' net worth.

Finally, capital requirements had no economically significant heterogeneous effects on hours worked across households. This reflects the low short-run wealth effects in the model, implying that labor supply plays a negligible role in the adjustment process. As both households face identical labor demand, capital requirements generate no heterogeneity in employment outcomes.

These heterogeneous and redistributive effects of capital requirements help explain cross-country differences in macroprudential stances within the euro area. Countries with a larger share of borrowers have less incentive to raise capital requirements above the Basel III minimum.

5.3   Macroprudential Policies and Monetary Tightening

In recent years, several European macroprudential authorities have increased risk weights on mortgage exposures or introduced sectoral

Figure 11. Impact of Macroprudential Policies—Financial Variables
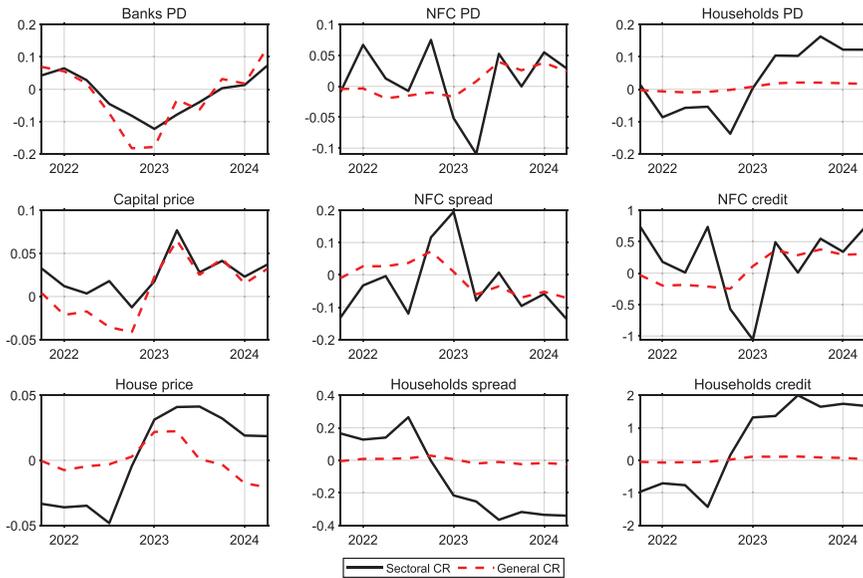
Note: All lines show the difference between the actual and the counterfactual paths. The x-axis reports quarters, with the first corresponding to 2021:Q4. All variables are expressed as deviations from their steady state in percent, except for the interest rate and the inflation rate, which are in percentage points.

buffers on housing loans.[9] In this section, we analyze the macroeconomic and financial effects of such policies. We adopt a conservative scenario in which banks' equity-to-risk-weight ratios are kept constant at their pre-crisis level throughout the entire episode. While banks are formally allowed to draw down these buffers in times of stress, past experience suggests they rarely do so, due to market stigma and the expectation that buffers will need to be rebuilt later.[10]

Figure 11 displays the response of banks' probabilities of default under two alternative policy scenarios: (i) *sectoral capital requirements*, where total capital requirements remain at their Basel III level (10.5 percent) and the authority raises the mortgage risk weight

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[9]See ESRB risk-weight measures and ESRB systemic risk buffer measures
[10]See ECB Macroprudential Bulletin.

Figure 12. Impact of Macroprudential Policies—Macroeconomic Variables

Note: All lines show the difference between the actual and the counterfactual paths. The x-axis reports quarters, with the first corresponding to 2021:Q4. All variables are expressed as deviations from their steady state in percent, except for spreads and probabilities of default, which are in percentage points.
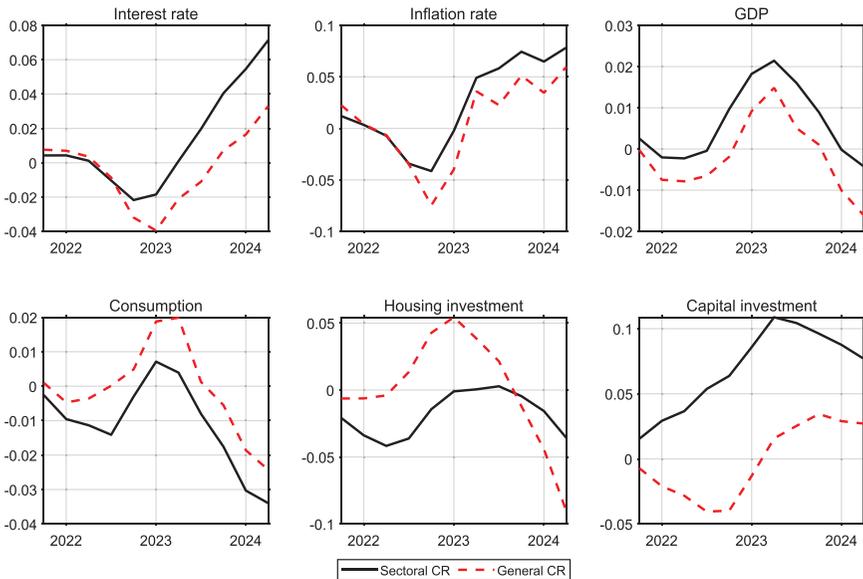
from 35 percent to 100 percent; and (ii) *general capital requirements*, where the authority instead increases the overall capital ratio from 10.5 percent to 11.5 percent. Both policies entail short-run costs but generate medium-term gains in terms of bank stability and GDP.

Sectoral capital requirements turn out to be more efficient at stabilizing GDP (see Figure 12). By offsetting distortions introduced by differential risk weights, they induce a portfolio reallocation toward NFC lending. In particular, the higher mortgage risk weights generate a substitution effect whereby banks redirect part of their lending from households to NFCs, supporting productive investment. Overall, this policy reduces the GDP cost of tighter capital requirements during the post-COVID investment catch-up.

Under the alternative scenario (ii) with higher general capital requirements (red dashed line), the cost–benefit balance is less

favorable. This outcome reflects the contribution of capital requirements to capital investment dynamics in the wake of the post-COVID recovery. Compared with a sectoral tightening, the general capital requirement has a smaller negative effect on consumption and housing investment but dampens NFC investment more severely. This result illustrates how higher capital requirements can affect housing and productive investment asymmetrically, given the composition of estimated shocks. Nonetheless, this option remains attractive in terms of financial stability, as it delivers lower volatility in financial variables and could therefore be preferred by households, whose consumption and housing investment are less affected.

6. Conclusion

This paper develops a New Keynesian model with a rich set of financial frictions and structural shocks to assess the role of capital requirements in business cycle dynamics, specifically during the 2021–24 monetary tightening episode. We show that while banks' capital requirements limited post-COVID growth, they successfully prevented the materialization of risks when the ECB raised short-term interest rates. By smoothing the response of banks' net worth to macroeconomic conditions, capital requirements acted as automatic stabilizers and reduced the likelihood of a hard landing during the tightening cycle. Overall, they proved complementary to monetary policy. Hence, even in a period of unprecedented monetary tightening, capital requirements do not need to be countercyclical to be effective. Their impact, however, is heterogeneous across savers and borrowers, and thus across euro-area member states, leaving room for cross-country heterogeneity in the design of macroprudential policies.

That said, while capital requirements helped prevent a hard landing by shifting interest rate risk toward banks, they are not sufficient on their own to ensure financial stability. By enhancing banks' resilience, such policies may, up to a point, encourage greater indebtedness among private agents. Other macroprudential tools, such as borrower-based measures, can therefore play a complementary role by ensuring sound financing conditions and appropriate leverage levels before the onset of a monetary tightening episode.

Appendix. Equilibrium Conditions

To simplify the exposition, we redefine a number of variables:

$$b_t^e \leftarrow m^e b_t^e,$$
$$k_t^e \leftarrow m^e k_t^e,$$
$$n_t^e \leftarrow m^e n_t^e,$$
$$n_t^b \leftarrow m^b n_t^b.$$

We let Φ denote the cumulative distribution function (CDF) of the $\mathcal{N}(0,1)$ distribution. The threshold value of idiosyncratic shock above which an entity defaults is denoted $\bar{\omega}_t^j$, where $j \in \{e, i, F, M\}$.

We also express capital requirements as a leverage ratio combining the broad base capital requirement as well as sector-specific risk weights:

$$f_t^F = \phi_t \gamma_t^F$$

$$f_t^M = \phi_t \gamma_t^M.$$

Intermediary and final good producer:

$$w_t = s_t e^{\zeta_{a,t}} (1 - \alpha) e^{\zeta_{z,t}} \left(\frac{k_{t-1}}{e^{\zeta_{z,t}} \ell_t} \right)^{\alpha} \tag{A.1}$$

$$r_t^K = s_t e^{\zeta_{a,t}} \alpha \left(\frac{k_{t-1}}{e^{\zeta_{z,t}} \ell_t} \right)^{\alpha-1} \tag{A.2}$$

$$\bar{P}_t^{\star} = \frac{K_{1,t}}{K_{2,t}} \tag{A.3}$$

$$K_{1,t} = \mu_t y_t s_t + (\beta^p \xi) \mathbb{E}_t \left[\frac{\lambda_{t+1}^p}{\lambda_t^p} \left(\frac{(\Pi_*)^{1-\iota} (\Pi_t)^{\iota}}{\Pi_{t+1}} \right)^{\frac{\mu_t}{1-\mu_t}} K_{1,t+1} \right] \tag{A.4}$$

$$K_{2,t} = y_t + (\beta^p \xi) \mathbb{E}_t \left[\frac{\lambda_{t+1}^p}{\lambda_t^p} \left(\frac{(\Pi_*)^{1-\iota} (\Pi_t)^{\iota}}{\Pi_{t+1}} \right)^{\frac{1}{1-\mu_t}} K_{2,t+1} \right] \tag{A.5}$$

$$1 = (1 - \xi)(\bar{P}_t^{\star})^{\frac{1}{1-\mu_t}} + \xi \left[\frac{(\Pi_*)^{1-\iota} (\Pi_{t-1})^{\iota}}{\Pi_t} \right]^{\frac{1}{1-\mu_t}} \tag{A.6}$$

$$\Upsilon_t^{\frac{\mu_t}{1-\mu_t}} y_t = e^{\zeta_{a,t}}(k_{t-1})^\alpha (e^{\zeta_{z,t}}\ell_t)^{1-\alpha} \tag{A.7}$$

$$\Upsilon_t^{\frac{\mu_t}{1-\mu_t}} = (1-\xi)(\bar{P}_t^\star)^{\frac{\mu_t}{1-\mu_t}} + \xi\left(\frac{(\Pi_*)^{1-\iota}(\Pi_{t-1})^\iota}{\Pi_t}\right)^{\frac{\mu_t}{1-\mu_t}}\Upsilon_{t-1}^{\frac{\mu_t}{1-\mu_t}} \tag{A.8}$$

Capital production:

$$q_t^K = e^{\zeta_{i_K,t}}\left(1 + \frac{\psi_K}{2}\left(\frac{i_t^K}{i_{t-1}^K} - 1\right)^2 + \psi_K\left(\frac{i_t^K}{i_{t-1}^K} - 1\right)\frac{i_t^K}{i_{t-1}^K}\right)$$
$$- \beta^p \mathbb{E}_t\left[e^{\zeta_{i_K,t+1}}\frac{\lambda_{t+1}^p}{\lambda_t^p}\psi_K\left(\frac{i_{t+1}^K}{i_t^K} - 1\right)\left(\frac{i_{t+1}^K}{i_t^K}\right)^2\right] \tag{A.9}$$

$$k_t = (1-\delta^K)k_{t-1} + i_t^K \tag{A.10}$$

Housing production:

$$q_t^H = e^{\zeta_{i_H,t}}\left(1 + \frac{\psi_H}{2}\left(\frac{i_t^H}{i_{t-1}^H} - 1\right)^2 + \psi_H\left(\frac{i_t^H}{i_{t-1}^H} - 1\right)\frac{i_t^H}{i_{t-1}^H}\right)$$
$$- \beta^p \mathbb{E}_t\left[e^{\zeta_{i_H,t+1}}\frac{\lambda_{t+1}^p}{\lambda_t^p}\psi_H\left(\frac{i_{t+1}^H}{i_t^H} - 1\right)\left(\frac{i_{t+1}^H}{i_t^H}\right)^2\right] \tag{A.11}$$

$$h_t = (1-\delta^H)h_{t-1} + i_t^H \tag{A.12}$$

Patient households:

$$\lambda_t^p = \frac{e^{\zeta_{c,t}}}{c_t^p - \psi c_{t-1}^p} \tag{A.13}$$

$$e^{\zeta_{c,t}}\varphi^p J_t^p(\ell_t^p)^\eta = w_t \tag{A.14}$$

$$J_t^p = (J_{t-1}^p)^{1-\zeta_J}[(c_t^p - \psi c_{t-1}^p)]^{\zeta_J} \tag{A.15}$$

$$\lambda_t^p = \beta^p \mathbb{E}_t\left[\lambda_{t+1}^p\frac{\tilde{R}_{t+1}}{\Pi_{t+1}}\right] \tag{A.16}$$

$$\lambda_t^p(q_t^K + \xi_s m^p k_t^p) = \beta^p \mathbb{E}_t\left[\lambda_{t+1}^p[r_{t+1}^K + (1-\delta^K)q_{t+1}^K]\right] \tag{A.17}$$

$$\lambda_t^p q_t^H = e^{\zeta_{c,t}} \upsilon^p \frac{1}{h_t^p} + \beta^p (1 - \delta^H) \lambda_{t+1}^p q_{t+1}^H \tag{A.18}$$

Bankers and banks:

$$v_t^b = \beta^p \mathbb{E}_t \left[\frac{\lambda_{t+1}^p}{\lambda_t^p} (1 - \theta^b + \theta^b v_{t+1}^b) \frac{Z_{t+1}^M}{\Pi_{t+1}} \right] \tag{A.19}$$

$$v_t^b = \beta^p \mathbb{E}_t \left[\frac{\lambda_{t+1}^p}{\lambda_t^p} (1 - \theta^b + \theta^b v_{t+1}^b) \frac{Z_{t+1}^F}{\Pi_{t+1}} \right] \tag{A.20}$$

$$\bar{\omega}_t^M = (1 - f_{t-1}^M) \frac{R_{t-1}}{R_t^M} \tag{A.21}$$

$$\bar{\omega}_t^F = (1 - f_{t-1}^F) \frac{R_{t-1}}{R_t^F} \tag{A.22}$$

$$Z_t^M = \frac{(1 - \Gamma_t^M) R_t^M}{f_{t-1}^M} \tag{A.23}$$

$$Z_t^F = \frac{(1 - \Gamma_t^F) R_t^F}{f_{t-1}^F} \tag{A.24}$$

$$n_t^b = [\theta^b + \chi^b (1 - \theta^b)] \left(\frac{Z_t^M}{\Pi_t} f_{t-1}^M m^i b_{t-1}^i + \frac{Z_t^F}{\Pi_t} f_{t-1}^F b_{t-1}^e \right) \tag{A.25}$$

$$n_t^b = f_t^M m^i b_t^i + f_t^F b_t^e \tag{A.26}$$

Entrepreneurs and investment firms:

$$v_t^e = \mathbb{E}_t \left[\beta^p \frac{\lambda_{t+1}^p}{\lambda_t^p} (1 - \theta^e + \theta^e v_{t+1}^e) \frac{Z_{t+1}^e}{\Pi_{t+1}} \right] \tag{A.27}$$

$$x_t^e = \frac{R_t^e b_t^e}{q_t^K k_t^e} \tag{A.28}$$

$$\bar{\omega}_t^e = \frac{x_{t-1}^e}{R_t^K} \tag{A.29}$$

$$R_t^K = \Pi_t \frac{r_t^K + (1 - \delta)q_t^K}{q_{t-1}^K} \tag{A.30}$$

$$R_t^F = (\Gamma_t^e - \mu^e G_t^e)R_t^K \frac{q_{t-1}^K k_{t-1}^e}{b_{t-1}^e} \tag{A.31}$$

$$Z_t^e = (1 - \Gamma_t^e)R_t^K \frac{q_{t-1}^K k_{t-1}^e}{n_{t-1}^e} \tag{A.32}$$

$$\mathbb{E}_t \left[\beta^p \frac{\lambda_{t+1}^p}{\lambda_t^p} \frac{1}{\Pi_{t+1}} \left((1 - \theta^e + \theta^e v_{t+1}^e)\Gamma_{t+1}^{e\prime} \right. \right.$$

$$\left. \left. - \xi_t^e (1 - \theta^b + \theta^b v_{t+1}^b)(1 - \Gamma_{t+1}^F)(\Gamma_{t+1}^{e\prime} - \mu^e G_{t+1}^{e\prime}) \right) \right] = 0 \quad \text{(A.33)}$$

$$\mathbb{E}_t \left[\beta^p \frac{\lambda_{t+1}^p}{\lambda_t^p} \left((1 - \theta^e + \theta^e v_{t+1}^e)(1 - \Gamma_{t+1}^e) \right. \right.$$

$$\left. \left. + \xi_t^e(1 - \theta^b + \theta^b v_{t+1}^b)(1 - \Gamma_{t+1}^F)(\Gamma_{t+1}^e - \mu^e G_{t+1}^e) \right) \frac{R_{t+1}^K}{\Pi_{t+1}} \right] - \xi_t^e f_t^F v_t^b = 0$$

$$\tag{A.34}$$

$$n_t^e = [\theta^e + \chi^e(1 - \theta^e)](1 - \Gamma_t^e)(r_t^K + (1 - \delta)q_t^K)k_{t-1}^e, \tag{A.35}$$

$$n_t^e + b_t^e = q_t^K k_t^e \tag{A.36}$$

Impatient households:

$$R_t^M = (\Gamma_t^i - \mu^i G_t^i)\frac{R_t^H q_{t-1}^H h_{t-1}^i}{b_{t-1}^i} \tag{A.37}$$

$$c_t^i + q_t^H h_t^i = w_t \ell_t^i + b_t^i + (1 - \Gamma_t^i)(1 - \delta^H)q_t^H h_{t-1}^i \tag{A.38}$$

$$R_t^H = \Pi_t \frac{(1 - \delta^H)q_t^H}{q_{t-1}^H} \tag{A.39}$$

$$x_t^i = \frac{R_t^i b_t^i}{q_t^H h_t^i} \tag{A.40}$$

$$\bar{\omega}_t^i = \frac{x_{t-1}^i}{R_t^H} \tag{A.41}$$

$$\lambda_t^i = \frac{e^{\zeta_{c,t}}}{c_t^i - \psi c_{t-1}^i} \tag{A.42}$$

$$w_t = e^{\zeta_{c,t}} \varphi^i J_t^i (\ell_t^i)^\eta \tag{A.43}$$

$$J_t^i = (J_{t-1}^i)^{1-\zeta_J} [(c_t^i - \psi c_{t-1}^i)]^{\zeta_J} \tag{A.44}$$

$$\beta^i \mathbb{E}_t \left[\lambda_{t+1}^i \frac{\Gamma_{t+1}^{i\prime}}{\Pi_{t+1}} \right] = \xi_t^i \beta^p \mathbb{E}_t \left[\frac{\lambda_{t+1}^p}{\lambda_t^p} (1 - \theta^b + \theta^b v_{t+s+1}^b) \right.$$

$$\times (1 - \Gamma_{t+1}^M) \frac{\Gamma_{t+1}^{i\prime} - \mu^i G_{t+1}^{i\prime}}{\Pi_{t+1}} \Bigg] \tag{A.45}$$

$$\lambda_t^i = \xi_t^i f_t^M v_t^b \tag{A.46}$$

$$\lambda_t^i q_t^H = e^{\zeta_{c,t}} v^i \frac{1}{h_t^i} + \beta^i \mathbb{E}_t \left[\lambda_{t+1}^i (1 - \Gamma_{t+1}^i)(1 - \delta^H) q_{t+1}^H \right]$$

$$+ \beta^p \xi_t^i \mathbb{E}_t \left[\frac{\lambda_{t+1}^p}{\lambda_t^p} (1 - \theta^b + \theta^b v_{t+s+1}^b)(1 - \Gamma_{t+1}^M) \right.$$

$$\times (\Gamma_{t+1}^i - \mu^i G_{t+1}^i)(1 - \delta^H) q_{t+1}^H \Bigg] \tag{A.47}$$

Market clearing:

$$k_t = k_t^e + m^p k_t^p \tag{A.48}$$

$$h_t = m^p h_t^p + m^i h_t^i \tag{A.49}$$

$$c_t = m^p c_t^p + m^i c_t^i \tag{A.50}$$

$$\ell_t = m^p \ell_t^p + m^i \ell_t^i \tag{A.51}$$

$$y_t = c_t + e^{\zeta_{i_K,t}} \left(1 + \frac{\psi_K}{2} \left(\frac{i_t^K}{i_{t-1}^K} - 1 \right)^2 \right) i_t^K$$

$$+ e^{\zeta_{i_H,t}} \left(1 + \frac{\psi_H}{2} \left(\frac{i_t^H}{i_{t-1}^H} - 1 \right)^2 \right) i_t^H + s_g y_* e^{\zeta_{g,t}}$$

$$+ \mu^i G_t^i (1 - \delta^H) q_t^H m^i h_{t-1}^i + \mu^e G_t^e (r_t^K + (1 - \delta) q_t^K) k_{t-1}^e$$

$$+ \mu^M G_t^M \frac{R_t^M}{\Pi_t} m^i b_{t-1}^i + \mu^F G_t^F \frac{R_t^F}{\Pi_t} b_{t-1}^e + \frac{\xi_s}{2} (m^p k_t^p)^2 \tag{A.52}$$

Deposit insurance:

$$\tilde{R}_t = R_{t-1} - (1 - \kappa)\Omega_t \tag{A.53}$$

$$\Omega_t d_{t-1} = (\bar{\omega}_t^M - \Gamma_t^M + \mu^M G_t^M) R_t^M m^i b_{t-1}^i$$
$$+ (\bar{\omega}_t^F - \Gamma_t^F + \mu^F G_t^F) R_t^F b_{t-1}^e \tag{A.54}$$

$$n_t^b + d_t = b_t^e + m^i b_t^i \tag{A.55}$$

Monetary authority:

$$\log\left(\frac{R_t}{R_*}\right) = \rho_R \log\left(\frac{R_{t-1}}{R_*}\right)$$
$$+ (1 - \rho_R)\left[a_\Pi \log\left(\frac{\Pi_t}{\Pi_*}\right) + a_y \log\left(\frac{GDP_t}{GDP_{t-1}}\right)\right] + \zeta_{R,t} \tag{A.56}$$

Exogenous processes:

$$\zeta_{a,t} = \rho_a \zeta_{a,t-1} + \frac{\sigma_a}{100}\epsilon_{a,t}, \tag{A.57}$$

$$\zeta_{z,t} = \rho_z \zeta_{z,t-1} + \frac{\sigma_z}{100}\epsilon_{z,t}, \tag{A.58}$$

$$\zeta_{i_K,t} = \rho_{i_K} \zeta_{i_K,t-1} + \frac{\sigma_{i_K}}{100}\epsilon_{i_K,t}, \tag{A.59}$$

$$\zeta_{i_H,t} = \rho_{i_H} \zeta_{i_H,t-1} + \frac{\sigma_{i_H}}{100}\epsilon_{i_H,t}, \tag{A.60}$$

$$\zeta_{e,t} = \rho_e \zeta_{e,t-1} + \frac{\sigma_e}{100}\epsilon_{e,t}, \tag{A.61}$$

$$\zeta_{i,t} = \rho_i \zeta_{i,t-1} + \frac{\sigma_i}{100}\epsilon_{i,t}, \tag{A.62}$$

$$\zeta_{B,t} = \rho_B \zeta_{B,t-1} + \frac{\sigma_B}{100}\epsilon_{B,t}, \tag{A.63}$$

$$\zeta_{c,t} = \rho_c \zeta_{c,t-1} + \frac{\sigma_c}{100}\epsilon_{c,t}, \tag{A.64}$$

$$\zeta_{\mu,t} = \rho_\mu \zeta_{\mu,t-1} + \frac{\sigma_\mu}{100}\epsilon_{\mu,t}, \tag{A.65}$$

$$\zeta_{g,t} = \rho_g \zeta_{g,t-1} + \frac{\sigma_g}{100}\epsilon_{g,t}, \tag{A.66}$$

$$\zeta_{R,t} = \frac{\sigma_R}{100}\epsilon_{R,t}, \tag{A.67}$$

Auxiliary variables:

$$\Gamma_t^F = G_t^F + \bar{\omega}_t^F \left[1 - \Phi \left(\frac{\log(\bar{\omega}_t^F) + \frac{1}{2}(\sigma_F e^{\zeta_{B,t}})^2}{\sigma_F e^{\zeta_{B,t}}} \right) \right] \tag{A.68}$$

$$G_t^F = \Phi \left(\frac{\log(\bar{\omega}_t^F) - \frac{1}{2}(\sigma_F e^{\zeta_{B,t}})^2}{\sigma_F e^{\zeta_{B,t}}} \right) \tag{A.69}$$

$$\Gamma_t^M = G_t^M + \bar{\omega}_t^M \left[1 - \Phi \left(\frac{\log(\bar{\omega}_t^M) + \frac{1}{2}(\sigma_M e^{\zeta_{B,t}})^2}{\sigma_M e^{\zeta_{B,t}}} \right) \right] \tag{A.70}$$

$$G_t^M = \Phi \left(\frac{\log(\bar{\omega}_t^M) - \frac{1}{2}(\sigma_M e^{\zeta_{B,t}})^2}{\sigma_M e^{\zeta_{B,t}}} \right) \tag{A.71}$$

$$\Gamma_t^e = G_t^e + \bar{\omega}_t^e \left[1 - \Phi \left(\frac{\log(\bar{\omega}_t^e) + \frac{1}{2}(\sigma_e e^{\zeta_{e,t}})^2}{\sigma_e e^{\zeta_{e,t}}} \right) \right] \tag{A.72}$$

$$G_t^e = \Phi \left(\frac{\log(\bar{\omega}_t^e) - \frac{1}{2}(\sigma_e e^{\zeta_{e,t}})^2}{\sigma_e e^{\zeta_{e,t}}} \right) \tag{A.73}$$

$$\Gamma_t^{e\prime} = 1 - \Phi \left(\frac{\log(\bar{\omega}_t^e) + \frac{1}{2}(\sigma_e e^{\zeta_{e,t}})^2}{\sigma_e e^{\zeta_{e,t}}} \right) \tag{A.74}$$

$$G_t^{e\prime} = \frac{1}{\sigma_e e^{\zeta_{e,t}}} \varphi \left(\frac{\log(\bar{\omega}_t^e) + \frac{1}{2}(\sigma_e e^{\zeta_{e,t}})^2}{\sigma_e e^{\zeta_{e,t}}} \right) \tag{A.75}$$

$$\Gamma_t^i = G_t^i + \bar{\omega}_t^i \left[1 - \Phi \left(\frac{\log(\bar{\omega}_t^i) + \frac{1}{2}(\sigma_i e^{\zeta_{i,t}})^2}{\sigma_i e^{\zeta_{i,t}}} \right) \right], \tag{A.76}$$

$$G_t^i = \Phi \left(\frac{\log(\bar{\omega}_t^i) - \frac{1}{2}(\sigma_i e^{\zeta_{i,t}})^2}{\sigma_i e^{\zeta_{i,t}}} \right) \tag{A.77}$$

$$\Gamma_t^{i\prime} = 1 - \Phi \left(\frac{\log(\bar{\omega}_t^i) + \frac{1}{2}(\sigma_i e^{\zeta_{i,t}})^2}{\sigma_i e^{\zeta_{i,t}}} \right) \tag{A.78}$$

$$G_t^{i\prime} = \frac{1}{\sigma_i \mathrm{e}^{\zeta_{i,t}}} \varphi \left(\frac{\log(\bar{\omega}_t^i) + \frac{1}{2}(\sigma_i \mathrm{e}^{\zeta_{i,t}})^2}{\sigma_i \mathrm{e}^{\zeta_{i,t}}} \right) \tag{A.79}$$

$$S_t^b = \beta^p \frac{\lambda_t^p}{\lambda_{t-1}^p}(1 - \theta^b + \theta^b v_t^b) \tag{A.80}$$

$$S_t^e = \beta^p \frac{\lambda_t^p}{\lambda_{t-1}^p}(1 - \theta^e + \theta^e v_t^e). \tag{A.81}$$

$$GDP_t = m^i c_t^i + m^p c_t^p + \mathrm{e}^{\zeta_{i_K,t}} \left(1 + \frac{\psi_K}{2} \left(\frac{i_t^K}{i_{t-1}^K} - 1 \right)^2 \right) i_t^K$$

$$+ \mathrm{e}^{\zeta_{i_H,t}} \left(1 + \frac{\psi_H}{2} \left(\frac{i_t^H}{i_{t-1}^H} - 1 \right)^2 \right) i_t^H + s_g y_* \mathrm{e}^{\zeta_{g,t}} \tag{A.82}$$

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Rightsizing Bank Capital: The Role of Macrofinancial Structure*

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We employ a macroeconomic cost-benefit approach to determine the appropriate tier 1 capital ratio for the banking systems of advanced economies. The macroeconomic costs of higher capital ratios are quantified using structural and semi-structural models of the Irish economy, while the macroeconomic benefits are derived using probabilistic models of financial crises and assumptions about the persistence of resulting output losses. We then examine the role of certain macrofinancial characteristics in determining the optimal level of bank capital. Incorporating these characteristics, the "rightsized" level of capital lies in a range of 12.5 to 19 percent.

JEL Codes: E5, G01, G17, G28, R39.

1. Introduction

Given their importance in the economy, banks face a number of requirements on the quantity and quality of their funding structure. Large losses in the banking system can have considerable spillover consequences for the real economy, which cannot be fully internalized by individual banks when mitigating their own risk profile. In addition, banks benefit from both explicit and implicit deposit insurance. Since capital represents the first line of defense in terms of loss

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absorption, banks are required to hold minimum levels of capital in line with existing regulations, regardless of the contribution of debt to their funding structure. In addition, they must fund themselves via tranches of capital to cater to specifically targeted balance-sheet-related risks, as well as systemic risk related to the broader environment or the systemic importance of a particular institution.

O'Brien and Wosser (2022) find that economies that are smaller, more open to trade and financial flows, more dependent on foreign direct investment (FDI), and that have more concentrated banking systems tend to have relatively higher systemic banking crisis probabilities, suffer larger systemic banking crisis-related costs, and exhibit relatively more adverse gross domestic product (GDP) growth tail risk through the financial cycle. In this paper, we examine the implications for appropriate levels of capital in the banking system of countries which display these structural characteristics. Specifically, we examine the influence of macrofinancial structural characteristics on the appropriate range of tier 1 capital[1] during periods when cyclical systemic risks are neither elevated nor subdued, including as necessary any additional bank capital needed to mitigate the effect of such structure-related systemic risks. This issue has been largely neglected in the existing literature.

Several studies have attempted to establish an appropriate capital range for particular banking systems based on the macroeconomic cost-benefit methodology that we follow in this paper (see Table 1). In the post–Global Financial Crisis (GFC) era, the Basel Committee on Banking Supervision (BCBS) study finds that the "optimal" tier 1 capital ratio range lies in the interval of 10 to 15 percent for advanced economies (see BCBS 2010).[2] However, as the approach has been refined and applied in other settings, the range found in subsequent studies is often somewhat higher.

From a methodological perspective, our approach is most similar to that of Brooke et al. (2015), who in turn follow Miles, Yang, and

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[1] The tier 1 capital ratio is the ratio of a bank's core tier 1 capital, that is, its equity capital and disclosed reserves, to its total risk-weighted assets. Risk-weighted assets comprise approximately 60 to 70 percent of total assets (see Firestone, Lorenc, and Ranish 2019, p. 218).

[2] In an update to their paper (Birn et al. 2020), the BCBS acknowledges subsequent studies and concludes that optimal capital levels are likely to be higher than originally estimated.

Table 1. Estimates of Optimal Capital in Previous Studies

Study	Country	MM Offset	Optimal Bank Capital
Admati and Hellwig (2014)	—	Holds	20–30% tier 1 capital ratio
Barth and Miller (2018)	U.S.	Does not fully hold	Leverage ratio of 19% (equates to a tier 1 capital ratio of 25%)
BCBS (2010)	OECD	Holds	10–15% tier 1 capital ratio
Brooke et al. (2015)	U.K.	Does not fully hold	10–14% tier 1 capital ratio, 15–19% if resolution ineffective
Clerc et al. (2015)	Euro Area	No reference (does not hold)	Circa 10.5% tier 1 capital ratio
Cline (2016)	Ind. Countries	Does not fully hold	12–14% CET1 to RWA
Collard et al. (2017)	U.S.	Does not hold	10–14% tier 1 capital ratio
Dagher et al. (2016) (IMF)	Ind. Countries	0–75%	15–23% tier 1 capital ratio
Firestone, Lorenc, and Ranish (2019)	U.S.	Does not fully hold	13–26% tier 1 capital ratio
Junge and Kugler (2013)	Switzerland	Does not fully hold	13–17% tier 1 ratio for global systemically important banks (G-SIBs)
Miles, Yang, and Marcheggiano (2013)	U.K.	Does not fully hold (45% offset used)	16–20% CET1 to RWA
Schroth and Moyen (2017)	None	No reference	12.75–15.75% tier 1 ratio
Kragh-Sorensen (2012)	Norway	Does not fully hold	13–23% CET1 to RWA
Almenberg et al. (2017)	Sweden	Holds	10–17% CET1 to RWA

Note: The MM offset captures the extent to which a bank's weighted average cost of capital is invariant to changes in its capital structure in accordance with Modigliani and Miller (1958). RWA refers to risk-weighted assets.

Marcheggiano (2013), although we depart from their paper in some aspects of our modeling framework and in our focus on the role of macrofinancial structural characteristics. In addition, we employ two structural macroeconomic models of a small open economy (Ireland) to estimate the output-related costs of higher capital. Depending on the assumed effectiveness of the resolution regime for banks that are failing or likely to fail, Brooke et al. (2015) establish an optimal tier 1 capital range of 10–19 percent for the U.K. Abstracting from the potential benefits of the resolution regime, Miles, Yang, and Marcheggiano (2013) similarly find that much higher levels of capital than those deemed optimal by the original BCBS (2010) study were appropriate for the U.K., up to as much as 20 percent.

An important determinant of the macroeconomic cost of higher capital requirements in the literature is the extent to which the Modigliani and Miller (1958) theorem regarding the irrelevance of the capital structure to the weighted average cost of capital is expected to hold empirically for banks. Higher capital requirements can reduce economic activity if they raise banks' funding costs and, consequently, lead to higher interest rates for firms and households. Studies that have examined the macroeconomic impact of raising capital requirements typically assume that equity is more costly than debt financing, and that the increase in funding costs associated with higher capital requirements is partially or fully passed through to borrowers (BCBS 2010). However, the change in banks' weighted average cost of capital due to higher capital targets hinges on the value of the Modigliani-Miller "offset" that is applied. This offset determines the degree to which lower levels of leverage, by reducing the risk of bank failure, will also reduce banks' cost of equity and debt (Birn et al. 2020). Higher values of the offset will accordingly reduce the sensitivity of banks' funding costs to changes in the debt-equity composition of their liabilities.

Firestone, Lorenc, and Ranish (2019) consider the U.S. economy and estimate the optimal tier 1 capital ratio to be between 13 and 25 percent. In their analysis, the Modigliani-Miller offset does not fully hold, which has the effect of raising the optimal capital levels somewhat and goes some way toward explaining their relatively higher upper bound. In one of the few papers to specifically consider a smaller economy, Almenberg et al. (2017) determine the appropriate capital range for Sweden. They estimate that the optimal tier 1

capital ratio falls within a slightly different range (10–24 percent with Modigliani-Miller offset set to zero). However, this paper does not consider the specific contribution that the macrofinancial structural characteristics of Sweden contributes to their findings.

Barth and Miller (2018) examine the costs and benefits from raising the leverage ratio from 4 to 15 percent.[3] They find that, based on their benchmark specification, the optimal leverage ratio is 19 percent (equating to a tier 1 capital ratio of circa 25 percent). At those levels of capital, banks are able to absorb high losses and almost completely shield the sovereign from having to recapitalize the banking system following crisis onset.

Of particular relevance is the study conducted by Cline (2016) who, similar to this paper, examines optimal capital across a range of countries, including Ireland. Our optimal capital range (12.5 to 19 percent) is aligned with his (12 to 14 percent).[4] While the range for optimal capital ratios that we estimate is wider, this is likely attributable to our more structural approach, which tries to identify the independent and joint role of individual macrofinancial characteristics in determining these optimal levels of capital.

In line with the previous literature, we examine the resulting macroeconomic costs and benefits associated with requiring banks to raise additional capital. Following a similar methodology to the papers discussed above, we find that during periods when systemic risk is at median levels, the net marginal benefit of higher capital is zero when the tier 1 capital ratio is 16 percent. Below this point, the benefits of higher capital still outweigh the costs, whereas above this point the opposite holds. The results require a range of assumptions on key modeling parameters, such as the value of the Modigliani-Miller offset applied, the duration of crises, and the discount factor applied to future GDP losses related to systemic banking crises. Based on these assumptions, we derive a range of appropriate tier

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[3] Defined as total capital divided by total exposures (i.e., inclusive of off-balance-sheet items). The leverage ratio can be converted to a tier 1 capital ratio via the application of a risk-weighted asset scaling factor. Our sample's median risk-weighted assets to total assets ratio is 60 percent. Assuming this condition holds in our generalized "benchmark" country, a tier 1 ratio of 16 percent then equates to a leverage ratio of 9.7 percent.

[4] Under the same assumptions of median risk-weighted assets to total assets of 60 percent, this equates to an optimal leverage ratio range of 7.2 to 12 percent.

1 capital ratios for normal risk environments between 12.5 to 19 percent with a benchmark level that is centered around 16 percent.

It is important to note, however, that our analysis does not address ancillary factors such as changes in the resolution framework or in approaches to risk weighting, which may influence both the steady-state and transition costs or benefits of particular capital levels. In terms of transition costs, the short-run impact of shifting to stronger capital regulations could also be significant. For example, the Macroeconomic Assessment Group (MAG 2010) finds that a 1 percentage point (pp) increase in capital ratios leads to a temporary negative deviation of GDP from its baseline of between 0.1 and 0.26 percent, with a concomitant 15 to 17 basis point increase in lending spreads. Similarly, Dorich and Zhang (2010) find that a 1 percentage point increase in capital ratios, implemented over four years, generates a fall in Canadian GDP of 0.26 percentage points eight years after implementation. In the case of Spain, Gerba and Mencia (2017) find that a 1 percentage point increase in capital leads to a drop in bank credit to firms and households by 1.1 and 1.4 percentage points, respectively, after four quarters, lowering GDP by close to 0.3 percentage points. More recently, Mendicino et al. (2020) find, using the three-dimensional model of the euro area, that higher capital requirements can carry considerable short-term costs, leading to a decline of GDP by up to 0.34 percent. Consequently, they argue that changes in required capital requirements should be implemented gradually across the euro area.

In terms of one of the main focal points of this paper, we find that net benefits of up to 3.5 percentage points of additional tier 1 capital accrue when macrofinancial structural characteristics are taken into account. This additional capital holds over the range derived from various modeling parameter assumptions mentioned above. While we consider the independent and joint impact of a number of structural macrofinancial characteristics, our results highlight the particularly important role played by country size, trade and financial openness, and FDI exposure in determining optimal capital buffers for a given country. Accordingly, countries that are smaller, more open to trade and financial flows, or have a high dependency on FDI should maintain slightly higher levels of tier 1 capital to mitigate the concomitant higher levels of systemic risk within their financial systems.

Finally, a key advantage of our analytical approach is that our results for the optimal capital ratio are readily generalizable to other countries. In particular, as we use a panel of OECD (Organisation for Economic Co-operation and Development) countries to estimate the marginal benefits of higher capital for given macrofinancial characteristics, these estimates provide an international benchmark which can be used to inform the rightsizing of capital levels across countries. On the marginal cost side, while our estimates are Irish-specific, they are consistent with the literature on the impact of higher capital ratios on steady-state output levels.

Moreover, there are aspects of our empirical approach that can provide insights for policymakers in other countries in terms of the strength of the different mechanisms through which capital-based macroprudential policy is transmitted to the real economy. We also highlight how using two macroeconomic models that feature detailed banking sectors, but that are methodologically quite different, can be used to enhance the overall robustness of the cost estimates. Alternatively, given the assumption that the marginal macroeconomic cost of higher capital is constant, policymakers could also combine local estimates of these costs with our results for marginal benefits to derive an optimal capital range for their banking system.

The remainder of the paper is structured as follows. Section 2 outlines our methodology for estimating the macroeconomic costs and benefits of additional capital. Section 3 presents our benchmark estimate of optimal capital and then quantifies the role of macrofinancial structural characteristics in shifting this optimal level. Section 4 addresses the robustness of our results and Section 5 concludes.

2.   Estimating the Costs and Benefits of Higher Capital

We adopt and modify the "top-down" optimal capital approach set out in the existing literature. This methodology determines the marginal macroeconomic costs and benefits, in GDP terms, that are associated with additional bank capital. In this framework the marginal benefit of higher capital relates to the reduction in the probability of a systemic banking crisis as capital levels increase. The lower probability of a crisis in turn reduces the potential GDP losses that arise when systemic banking crises emerge. The marginal costs of

additional capital relate to the potential for higher capital requirements to increase bank lending rates, and consequently to damp consumption, investment, and aggregate output growth.

Combining the marginal benefit with the marginal cost yields the net marginal benefit of additional bank capital:

$$NetMargBen = (\Delta CrisisProb * CrisisCost) - \Delta CapitalCost, \quad (1)$$

which remains positive up until the point at which the costs associated with a given level of capital exceed the benefits. The level of capital achieved at that point is the estimate of the appropriate level of capital for a given banking system.

In order to address our main research question—the role of macrofinancial structural characteristics in determining appropriate levels of bank capital—we focus primarily on how these factors can influence the marginal benefit component of Equation (1). Specifically, we examine how these characteristics can influence the probability of systemic banking crises and thus their expected cost in output terms. Our approach to estimating marginal costs employs structural and semi-structural models of the Irish economy, which could be considered the prototypical small, open advanced economy. Accordingly, the key aspects of our modeling framework can be adapted to examine optimal capital regulation in other small, open economies.

2.1   Marginal Benefits of Higher Capital

The first step in our analytical approach is to estimate systemic banking crisis probabilities for each country over time. Following O'Brien and Wosser (2018), we use a pooled logit model that estimates systemic banking crisis probabilities for 27 OECD countries.[5] Crisis probabilities are determined over a forecasting horizon of up to two years, conditional on a set of contemporaneous indicators found in the literature to have robust predictive properties, which we augment with the level of tier 1 bank capital in each country. The

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[5] The logit model has become the de facto standard in the literature. See Demirgüç-Kunt and Detragiache (1997), Davis and Karim (2008), Eichler and Sobański (2012), and Lo Duca and Peltonen (2013).

model estimates the following regression specification using biannual data from 1980 to 2021:

$$Log\left(\frac{Pr(Crisis_{it}|Z_{it})}{Pr(NoCrisis_{it}|Z_{it)})}\right) = \alpha + \beta Z_{it} + \epsilon_{it}. \qquad (2)$$

The dependent variable is a binary variable that takes a value of one in crisis periods and zero otherwise. To determine crisis and non-crisis periods in our sample we use data from Lo Duca et al. (2017) for European countries and Laeven and Valencia (2013) for non-European countries. Based on the definitions in Laeven and Valencia (2013) and Lo Duca et al. (2017), systemic banking crises are those that result in the failure of one or more banks, exhibit some degree of bank-to-bank contagion, require particular government-backed support programs for the banking sector, and result in spillovers from banking system losses to the real economy. In the benchmark O'Brien and Wosser (2018), vector Z_{it} comprises eight leading indicator variables: (i) the first-difference of the short-term real interest rate, (ii) the credit-to-GDP ratio, (iii) a house price index and (iv) its deviation from its long-run trend, (v) losses on equity markets, (vi) unemployment rate, (vii) a financial conditions index, and (viii) the extent of household leverage relative to GDP. To this specification we add the tier 1 capital ratio in the banking system for each country in our sample. All variables are lagged by one period. The list of our sample countries is provided in Table 2, while variable definitions, data sources, and summary statistics are shown in Table 3.

Our data are pooled across all countries, with standard errors clustered by country. We do not use a fixed-effects model, so that countries which never experienced a banking crisis may be included during model estimation. Following this, we add dummy variables capturing structural characteristics to the model, allowing for the potential role of macrofinancial structural characteristics to be identified.

To estimate the marginal effect of higher capital on crisis probability, we hold the remaining explanatory variables at their sample median levels to reflect time periods when systemic risk levels are neither elevated nor subdued. We then estimate crisis probabilities for each percentage point increment of the tier 1 capital ratio over a range from 5 to 30 percent. The fitted crisis probabilities across this

Table 2. Countries, Crises, and Macrofinancial Structure

Country	Crisis Years Start	Crisis Years End	Source	Small Country	Fin. Open	Trade Open	CBS (R.E.)	CBS (WB)	CBS (Mkt. Sect.)	FDI Dep. Country
Argentina	1980:Q1	1980:Q4	LV (2013)							
	1989:Q1	1989:Q4	LV (2013)							
Australia	—	—	LV (2013)		X					
Austria	2007:Q4	2014:Q1	ECB (2016)			X	X	X		
Belgium	2007:Q4	Ongoing	ECB (2016)		X	X		X	X	X
Brazil	1990:Q1	1990:Q4	LV (2013)							
	1994:Q1	1994:Q4	LV (2013)							
Canada	—	—	LV (2013)				X			
China	1998:Q1	1998:Q4	LV (2013)							
Denmark	1987:Q1	1995:Q1	ECB (2016)	X	X		X			
	2008:Q1	2013:Q4								
Finland	1991:Q3	1996:Q4	ECB (2016)	X	X			X	X	
France	1991:Q2	1995:Q1	ECB (2016)		X				X	
	2008:Q2	2009:Q4								
Germany	2001:Q1	2003:Q4	ECB (2016)		X					
	2007:Q3	2013:Q2								
Greece	2010:Q2	Ongoing	ECB (2016)	X						
Hungary	1991:Q1	1995:Q4	ECB (2016)	X		X				X
	2008:Q3	2010:Q3								
Ireland	2008:Q3	2013:Q4	ECB (2016)	X	X	X	X	X	X	
Italy	1991:Q3	1997:Q4	ECB (2016)		X	X	X	X	X	X
	2011:Q3	2013:Q4								

(*continued*)

Table 2. (Continued)

Country	Crisis Years Start	Crisis Years End	Source	Small Country	Fin. Open	Trade Open	CBS (R.E.)	CBS (WB)	CBS (Mkt. Sect.)	FDI Dep. Country
Japan	1997:Q3	1997:Q4	LV (2013)		X	X		X		X
Luxembourg	2008:Q1	2010:Q4	ECB (2016)	X	X	X		X		
Netherlands	2008:Q1	2013:Q2	ECB (2016)		X	X	X	X	X	
New Zealand	—	—	LV (2013)	X				X		
Norway	1991:Q1	1991:Q4	LV (2013)	X				X		
Poland	1981:Q1	1994:Q4	ECB (2016)			X				
Portugal	1983:Q1	1985:Q1	ECB (2016)	X	X		X		X	X
	2008:Q4	Ongoing								
Spain	1980:Q1	1985:Q3	ECB (2016)		X	X	X			X
	2009:Q1	2013:Q4								
Sweden	1991:Q1	1997:Q2	ECB (2016)		X	X	X	X		X
	2008:Q3	2010:Q4								
Switzerland	2008:Q1	2010:Q4	LV (2013)		X	X				X
United Kingdom	1991:Q3	1994:Q1	ECB (2016)		X					X
	2007:Q3	2010:Q1								
United States	1988:Q1	1988:Q4	LV (2013)				X			
	2007:Q4	2011:Q4								

Note: This table presents information identifying the name and number of countries in the panel. The abbreviations LV (2013) and ECB (2016) refer to the Laeven and Valencia (2013) and the Lo Duca et al. (2017) crises databases, respectively. Crisis start and end dates are based on the ECB crisis data set as documented in Lo Duca et al. (2017) and on that of Laeven and Valencia (2013) for non-EU countries. Countries are designated as small if they fall into the lower median of countries in the underlying EWS database based on sample average rankings of a country's contribution to world GDP. Trade openness measures exports plus imports to GDP ratio. Financial openness measures the upper median of countries based upon the ratio of external claims of the banking system (inward and outward) relative to GDP. FDI dependency measures the ratio of foreign direct investment to GDP according to a CIA World Factbook survey (2018). "CBS" refers to different measures of concentration in the banking system. World Bank (WB) concentration measures the proportion of total banking system assets held by the largest three retail banks in a country. Bank concentration by market segment measures market segment concentration by NACE code (based on Herfindahl-Hirschmann methodology; see ECB statistical data warehouse). Concentration by real estate (R.E.) measures the proportion of bank assets that are real estate related with underlying bank balance sheet source data provided by Bloomberg and aggregated at the country level.

Table 3. Variable Description and Summary Statistics

Variable Name	Summary Statistics				Description	Obs.	Countries	Coverage	Source
	Mean	S.D.	Min.	Max					
Real Short-Term Interest Rates	0.053	0.058	−0.01	0.53	Real 3m money mkt rate	3,560	27	1980:Q1–2021:Q2	OECD
Losses Only S&P 500 Index	−0.014	0.04	−0.26	0.00	S&P losses only in a quarter	4,676	27	1980:Q1–2021:Q2	Yahoo Finance Historical Data
% Deviation of House Price Index from Trend	−0.91	0.11	−0.48	2.38	Trend fitted using Hamilton (4,8) filter	3,550	17	1981:Q4–2021:Q2	BIS—Long Property Series
% Deviation of Household Credit Growth from Trend	0.036	5.63	−100.45	30.22	Trend fitted using Hamilton (4,8) filter	2,780	27	1981:Q2–2021:Q2	BIS—Total Credit Statistics
% Deviation of Unemployment Rate from Trend	−.06	1.4	−10.00	6.73	Trend fitted using Hamilton (4,8) filter	3,228	25	1980:Q4–2021:Q2	OECD
Credit-to-GDP Ratio	135.48	64.63	9.4	455.3	Total credit extended to GDP	4,249	27	1980:Q1–2018:Q3	BIS—Total Credit Statistics
Financial Stability Index	0.12	0.10	0.00	0.84	Country-level index of financial stress (CLIFS)	2,750	17	2000:Q1–2021:Q2	ECB—Statistical Data Warehouse
House Price Index	155.75	101.52	21.29	564.96	House Price Index (1995=100)	3,727	17	1980:Q1–2021:Q2	BIS—Long Property Series

Table 3. (Continued)

Variable Name	Summary Statistics				Description	Obs.	Countries	Coverage	Source
	Mean	S.D.	Min.	Max					
GDP World Share	2.40	4.07	0.42	22.27	Contribution to world GDP share	4,202	27	1980:Q1–2021:Q2	IMF—IFS Database
Trade Openness	75.14	54.35	11.54	423.99	Ratio of exports plus imports as a percentage of GDP	3,816	27	1980:H1–2021:H1	IMF—IFS Database
Financial Openness	10.65	47.17	0.01	466.33	External claims inward and outward as a percentage of GDP	2,348	27	1980:H1–2021:H1	IMF—IFS Database
FDI Dependency	49.58	62.27	0.58	391.11	Stock of FDI to GDP ratio	1,225	27	1980:H1–2021:H1	IMF—IFS Database
Tier 1 Capital Ratio	0.11	.04	.01	.25	Tier 1 capital as a proportion of risk-weighted assets	1,450	15	2000:H1–2020:H2	Bloomberg
Bank Concentration I	66.47	20.02	20.19	100.00	Share of total banking assets held by three largest banks	2,252	26	2000:H1–2020:H2	World Bank
Bank Concentration II	2,318.01	520.43	1,365.41	3,588.03	HHI Index of concentration	682	11	2000:H1–2020:H2	BIS
Bank Concentration III	53.39	11.28	21.87	74.27	Share of R/E exposure of banking sys.	744	11	2000:H1–2020:H2	Bloomberg

Note: This table presents information on the variables in the panel. The EWS panel is held at quarterly frequency whereas bank balance sheet data are only available. EWS data are collapsed according to the frequency available for analysis. The bank crisis data are taken from the ECB's crisis database (Lo Duca et al. 2017) for EU countries and from Laeven and Valencia (2013) for non-EU countries.

Table 4. Crisis Probability and Tier 1 Capital

	(1)
Constant	0.489
	(3.473)
Real Short-Term Int. Rates	−141.558***
	(35.074)
Losses Only S&P 500	−8.352**
	(3.960)
House Prices (%d)	0.846
	(4.429)
Unemployment (%d)	−0.121
	(0.139)
Household Credit Growth (%d)	0.159
	(0.136)
Credit-to-GDP Ratio	0.005
	(0.005)
Fin. Stability Index	−13.821**
	(5.483)
House Price Index	0.001
	(0.016)
Tier 1 Capital Ratio	−54.561***
	(9.051)
Observations	1,021
Pseudo R^2	0.348

Note: This table shows the effects of including tier 1 capital in the baseline EWS panel logit model with random effects. The dependent variable is a crisis dummy variable that takes a value of one in the quarter in which a systemic banking crisis begins, and is zero otherwise. Variables denoted by (%d) represent the deviation of the variable from its underlying trend. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.

range allow the marginal contribution of each additional 1 percentage point of tier 1 capital to be estimated. Fitted systemic banking crisis probabilities are determined according to the following equation:

$$Pr\left(Crisis_{it} = \frac{e^{Z_{it}\beta}}{1 + e^{Z_{it}\beta.}}\right).$$ (3)

An example of the regression output from one of the underlying logit models is presented in Table 4. In this model, tier 1 capital is negative and statistically significant at the 1 percent level, indicating that the given level of tier 1 capital reduces the likelihood

of a systemic banking crisis emerging in the subsequent two years when "normal" or median risk conditions prevail. However, there are diminishing marginal benefits as tier 1 capital increases, which suggests that there is an optimal level beyond which the costs of additional capital requirements outweigh the benefits.

This finding that tier 1 capital has a negative and statistically significant effect on crisis likelihood is robust to alternative model specifications. Table 5 presents the results of a robustness test for the inclusion of tier 1 capital in the logit model using the algorithm outlined in Young and Holsteen (2017). This procedure examines all possible combinations of the variables in the logit model together with the tier 1 ratio. In total, 254 models are considered. In all cases, the coefficient on tier 1 capital is negative and significant. The lower panel of the table shows the effect that the exclusion of each of the control variables has on the coefficient on tier 1 capital. For example, in all models that exclude real short-term interest rates, the coefficient on tier 1 capital is 5.4 percent larger than its mean value when all variables are included. Overall, we interpret these results as providing strong evidence of a systematic negative correlation between bank capitalization and crisis likelihood.

From Equation (1), there are two components to the calculation of the marginal benefits of capital comprising the probability of systemic crises and the expected cost of crises. In our analysis we use a common measure of the cost of crises derived from the crisis episodes in our sample. In particular, we estimate costs as the difference between actual GDP in the five years following the onset of the crisis and a pre-crisis linear projection of GDP over the same period, and express this difference as a percentage of the projected values.[6] The results suggest that, on average, crises reduce GDP by 7.17 percent relative to pre-crisis trend. This is in line with prior studies, as shown in Table 6.

The final elements to consider when estimating the marginal benefit of higher bank capital are (i) the permanence or transience of the shock to GDP arising from crises, (ii) if the crisis costs are transitory, how long do they persist, and (iii) the appropriate discount rate to be used to evaluate the present value of losses.

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[6] Calculated using an exponentially weighted moving average of the GDP series up to the quarter where the crisis is deemed to have commenced.

Table 5. Logit Model Robustness and Tier 1 Capital

Model Robustness: Tier 1 Capital			
Dependent Var.	Prob. Sys. Crisis		
Robust Var.	Tier 1 Capital		
Control Variables	8		
No. Models	254		
No. Observations	1,023		
Model Robustness Statistics		**Significance Testing (%)**	
Mean Coefficient	−0.346	Sign Stability	100
Sampling Std. Error	0.113	Significance Rate	100
Modeling Std. Error	0.024	Positive	0
Total Std. Error	0.116	Positive and Significant	0
		Negative	100
		Negative and Significant	100
Model Influence			
Marg. Effect of Variable		**%Δ from Mean Coeff.**	
Unemployment (%d)	0.025	7.3	
Real Short-Term Rate	−0.019	5.4	
Credit-to-GDP Ratio	−0.016	4.7	
House Price Index	−0.010	2.9	
Losses Only S&P 500	−0.008	2.3	
Fin. Stability Index	−0.007	2.0	
HH Credit Growth (%d)	−0.006	1.6	
House Prices (%d)	0.001	−0.1	
Constant	−0.326		
R-Squared	0.643		

Note: This table presents robustness results related to the inclusion of tier 1 capital in the benchmark EWS logit model using the Young and Holsteen (2017) algorithm. The dependent variable is a crisis dummy variable that takes a value of one in the quarter in which a systemic crisis begins, and is zero otherwise. The remaining variables are as defined in Table 2. All possible combinations of these variables that include tier 1 capital are examined (254 models).

If the GDP loss from a systemic banking crisis is permanent, the present value (PV) of the loss can be calculated using the formula for a perpetuity, with the PV of the loss (C = 7.17 percent) determined via the discount factor r according to

$$PV(Crisis_{it}) = \frac{C}{r}. \qquad (4)$$

Table 6. Prior Studies of Crises and Output Loss

Study	Peak Loss (% GDP)	Long-Run Impact (% GDP)
Barrell et al. (2010)	6	3
Cecchetti, Kohler, and Upper (2009)	9	—
Cerra and Saxena (2008)	8	7
IMF (2009)	10	10
BCBS (2010)	9	6
Romer and Romer (2015)	4	3
Brooke et al. (2015)	5	4

In contrast, if the costs of crises are assumed to be transitory, then the duration over which they persist t will also be incorporated in the computation of losses (again with C = 7.17 percent):

$$PV(Crisis_{it}) = C \left(\frac{1 - (1+r)^{-t}}{r} \right). \tag{5}$$

Overall, our estimate of the marginal benefit of higher bank capital is the reduction in crisis probability at each level of the tier 1 capital ratio multiplied by the expected crisis cost as calculated above.

2.2 Marginal Costs of Higher Capital

Imposing additional capital requirements on the banking sector may raise banks' funding costs and ultimately lead to higher interest rates on lending to firms and households. The macroeconomic cost of higher capital is the lower growth in consumption, investment, and GDP that results from the increase in interest rates relative to the scenario in which capital requirements remain unchanged. To illustrate how such capital shocks are transmitted to the economy and to quantify their macrofinancial impact, we use two detailed macroeconomic models of the Irish economy—COSMO and Eire-Mod.

The transmission mechanism of an increase in capital requirements to the real economy is broadly similar in both models. There are several channels through which banks can raise their risk-weighted capital ratios: through retained earnings, via deleveraging,

by shifting the risk profile of their lending portfolios, or by issuing new equity. Both COSMO and EireMod assume that banks generate higher capital ratios through raising retained earnings. This assumption is consistent with the "pecking order theory" (see Myers and Majluf 1984) according to which banks prefer to exhaust internal funds first due to having to pay a premium on external finance. It is also consistent with other studies that use macroeconomic models to assess the costs of higher capital requirements (BCBS 2010) and with the empirical evidence on the behavior of banks' capital ratios since the Global Financial Crisis (Cohen and Scatigna 2016). Deleveraging does occur endogenously in COSMO and EireMod as households and firms demand less credit in response to higher lending rates.

To quantify the impact of higher capital requirements, we simulate a scenario in both COSMO and EireMod in which banks are required to increase their capital ratios by 1 percentage point. Following the literature on optimal levels of capital, our analysis focuses on the long-run or "steady-state" impact of higher requirements and abstracts from transition costs.[7]

2.3   COSMO

COSMO is a medium-scale estimated semi-structural model of the Irish economy. At its core it comprises three sectors: a traded sector that depends on world demand and Ireland's export prices relative to competitors; a nontraded sector that is primarily driven by domestic economic conditions; and a government sector that grows in line with the rest of the economy in the absence of exogenous policy changes.[8]

The model incorporates a wide range of linkages between the central bank, retail banks, households, and firms. A key feature of the model is that it includes several borrower- and lender-based macroprudential instruments. The central bank can set limits on loan-to-income (LTI) and loan-to-value (LTV) ratios on household

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[7] If banks are required to increase capital ratios relatively quickly, they may choose to adjust loan volumes rather than interest rates. This may generate substantial short-run economic costs (Bridges et al. 2014; Aiyar, Calomiris, and Wieladek 2016).

[8] See Bergin et al. (2017), Conefrey, O'Reilly, and Walsh (2018), and McInerney (2020) for details on different aspects of COSMO.

Figure 1. Macrofinancial and Macroprudential Linkages in COSMO
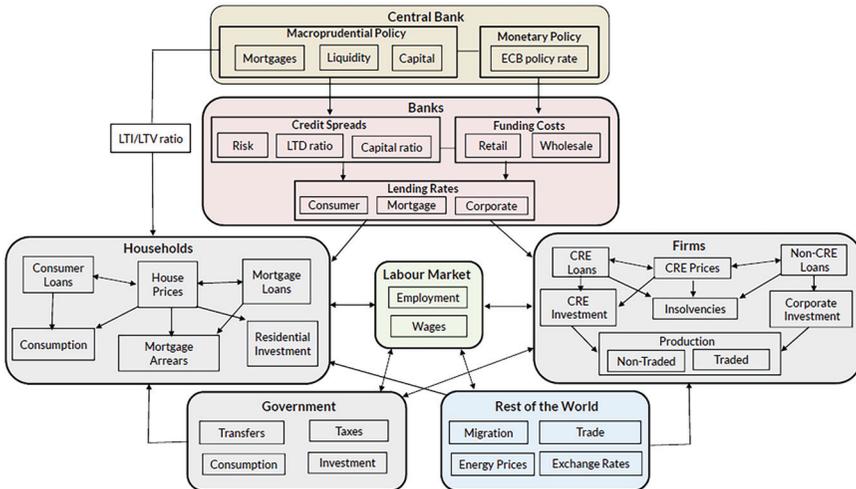
Source: Authors' own schematic representation of the COSMO model.

mortgage borrowing. Given the focus of our study, it can also impose additional capital requirements or buffers on banks by raising their target capital ratio. These macroprudential and macrofinancial linkages are illustrated in Figure 1, where the transmission paths of macroprudential and monetary shocks are represented by the solid arrows.

COSMO assumes a monopolistically competitive banking sector in which banks set lending rates as a variable spread over deposit and wholesale funding costs. These lending rates form supply curves for the respective types of credit in the model: mortgages, consumer credit, commercial real estate (CRE) lending, and other (non-CRE) corporate credit. Lending spreads are a function of policy and risk factors, and it is through the spread that lender-based macroprudential instruments operate. When the central bank raises capital requirements, banks respond by raising lending spreads so as to generate the necessary increase in retained earnings to meet the new target capital ratio.

Higher lending rates increase the user cost of capital for firms and households and reduce the demand for all types of credit. The

**Table 7. Impact of a 1 pp Increase in
Banks' Capital Ratio in COSMO**

Variable	Long-Run Impact (%)
Lending Rates (bps)	+11
Credit	−0.61
Total Investment	−0.28
Residential Investment	−0.64
CRE Investment	−0.51
House Prices	−0.42
Consumption	−0.06
GDP	−0.05
"Nontraded" Output	−0.12
Total Employment	−0.06

Note: Estimates are percent deviations from baseline except for lending rates, which are basis point deviations.

contraction in credit depresses house prices. This reduces household consumption through the housing wealth effect and residential investment due to the fall in the profitability of housing construction. The combination of higher mortgage rates and lower house prices pushes up the rate of household mortgage arrears. As lending to households is now riskier, banks raise lending spreads on loans to this sector.

Similarly, higher borrowing costs reduce corporate investment while the fall in CRE prices reduces investment in CRE. The fall in CRE prices reduces the value of collateral used for corporate borrowing, leading to a fall in both CRE and non-CRE corporate lending. Lower collateral values also affect firms' ability to roll over existing credit lines and obtain working capital. This increases the rate of corporate insolvency, which—as a driver of the risk component of the corporate lending rate—further raises firms' user cost of capital. The cumulative fall in investment leads to lower capital stocks and accordingly reduces the productive capacity of each sector in the economy in the long run.

To assess the macroeconomic cost of higher capital requirements, we simulate a 1 percentage point increase in banks' capital ratios in COSMO. The impact on key variables is reported in Table 7. To generate the retained earnings necessary to meet the new target for the capital ratio, banks raise the weighted average lending rate by 11

basis points (bps) relative to the baseline scenario in which capital requirements do not change.[9] The increase in the cost of borrowing reduces the demand for credit, with the weighted average stock of credit falling by 0.6 percent.[10]

The increase in lending rates raises the user cost of capital for both firms and households. In response, total investment falls by approximately 0.3 percent. CRE and residential investment, which are more interest rate-sensitive than other types of investment, fall by 0.5 percent and 0.6 percent, respectively. The increase in the user cost of housing capital reduces the demand for housing, leading to a fall in house prices relative to baseline of 0.4 percent. Household consumption falls by 0.06 percent due to the negative wealth effect arising from lower house prices.

Overall, the long-run macroeconomic impact of a 1 percentage point increase in capital requirements in COSMO is to reduce GDP by 0.05 percent and employment by 0.06 percent. However, the impact on the more bank-dependent, domestically oriented sectors of the economy is larger, with the output of the nontraded sector falling by 0.12 percent relative to the baseline.[11]

2.4   EireMod

EireMod is a dynamic stochastic general equilibrium (DSGE) model of the Irish economy. At its core it comprises two sectors: a tradable-good sector, which consists of firms producing consumption and investment goods for the domestic market and a tradable goods sector producing export goods. The tradable goods sector uses intermediate imported goods as input and employs foreign capital as a factor of production. The core structure of the model has been extended by Lozej, Onorante, and Rannenberg (2023) to include a realistic

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[9] The weighted average rise in lending rates comprises an increase of 10, 11, and 19 bps in corporate, mortgage, and consumer lending rates, respectively.

[10] This comprises a fall of 0.5, 0.4, 0.7, and 0.8 percent in the stock of mortgage, (non-CRE) corporate, CRE, and consumer credit, respectively.

[11] The traded, nontraded, and government sectors in COSMO are defined using the Irish Central Statistics Office's (CSO) Supply and Use Input-Output tables. The nontraded sector includes those sectors in which less than 50 percent of total final uses is exported and those sectors in which less than 50 percent of total final uses is used as government consumption.

financial sector, so that credit is intermediated by banks subject to a minimum capital requirement.

In the model, an implicit government guarantee on deposits creates an incentive for banks to increase leverage. As discussed below, this creates a break with the Modigliani-Miller proposition. As banks face a trade-off between increasing their leverage and incurring regulatory penalties if a shock hits their balance sheet, they optimally set their capital ratio above the regulatory minimum. All else equal, a marginal increase in the capital requirement forces the bank to deleverage, decreasing the bank's profitability. Monopolistically competitive banks respond to the decline in profitability by increasing the lending rate. In the long run, the lending rate will increase enough to keep the return on equity unaltered.

The model features a central role of the banking system in credit intermediation, by assuming that at each point in time, a constant share of both productive capital and the housing stock is intermediated through bank loans. An increase in the lending rate will therefore directly affect investment in productive capital and the demand for housing, which, in turn, affect investment in the construction sector. In the long run, capital will be lower, limiting production possibilities in the economy. Overall, the long-run macroeconomic impact of a 1 percentage point increase in capital requirements in EireMod is to increase average lending rates by 10 basis points and to reduce GDP by about 0.04 percent.[12]

2.5   The Modigliani-Miller Offset

The Modigliani-Miller theorem (Modigliani and Miller 1958) comprises two propositions. The first states that in a perfectly competitive and frictionless economy the value of a firm is independent of how it is financed, while the second postulates that, given that the first proposition holds, the cost of equity for a leveraged firm increases linearly with the debt-to-equity ratio. The implication of the theorem is that the relative returns on debt and equity adjust in response to a change in the capital structure so that the weighted average cost of capital (WACC) remains constant. For example, an

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[12] A more detailed decomposition of these results is available from the authors.

Table 8. Estimates of the Modigliani-Miller Offset

Study	Sample	Offset (%)
Toader (2015)	European Banks	42
ECB (2011)	International Banks	41–73
Yang and Tsatsaronis (2012)	International Banks	10
Junge and Kugler (2013)	Swiss Banks	36
Miles, Yang, and Marcheggiano (2013)	U.K. Banks	45–90
Brooke et al. (2015)	U.K. Banks	53
Kashyap, Stein, and Hanson (2010)	U.S. Banks	36–64
Cline (2015)	U.S. Banks	45
Clark, Jones, and Malmquist (2018)	U.S. Banks	25–100
Barth and Miller (2018)	U.S. Banks	0

increase in capital (reduction in leverage) reduces the volatility of the return on equity and therefore lowers its required return.

However, there are two main distortions that prevent the Modigliani-Miller theorem from holding empirically in relation to banks. The first is the tax treatment of debt—banks' interest payments on debt can be used to reduce their tax liabilities. The second relates to the implicit or explicit public guarantees on bank debt, mainly deposits. This acts as a subsidy to banks that reduces the cost of debt relative to equity, which does not enjoy such guarantees.

Accordingly, the key question from an empirical perspective is whether the required return on equity falls as the volatility of the return falls due to higher capital ratios (or lower leverage). The most common approach to testing the Modigliani-Miller theorem uses the Hamada (1972) framework that combines the theorem with the capital asset pricing model (CAPM). Essentially, this involves estimating the relationship between a bank's leverage and its equity beta.[13] Assuming that the beta of a bank's debt is zero, this gives a relationship between the beta (or riskiness) of a bank's assets and its leverage (Miles, Yang, and Marcheggiano 2013).[14]

As Table 8 shows, the empirical evidence on the Modigliani-Miller theorem is mixed. The estimated values for the offset from the

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[13] A bank's equity beta measures the covariance between the return on the bank's equity and that of the overall market.

[14] Assuming a debt beta of zero implies that debt has bank-specific default risk but no systematic market risk.

Table 9. Impact of a 1 pp Increase in Banks' Capital Ratio

Study	Country	Lending Rates (bps)	GDP (%)	Offset (%)
COSMO	Ireland	11	−0.05	0
EireMod	Ireland	10	−0.04	0
Mikkelsen and Pedersen (2017)	Denmark	10	−0.2	0
BCBS (2010)	OECD	9 to 19	−0.02 to −0.35	0
Almenberg et al. (2017)	Sweden	16	−0.09	0
Brooke et al. (2015)	U.K.	5 to 10	−0.01 to −0.05	50 to 0
Cline (2016)	U.S.	6	−0.08	50
Federal Reserve Bank of Minneapolis (2017)	U.S.	5.7	−0.06	50
Firestone, Lorenc, and Ranish (2019)	U.S.	3.4 to 6.9	−0.04 to −0.08	50 to 0

literature range from zero to a full offset, with a median value of close to 50 percent. There is some evidence that the offset is close to full for large or too-big-to-fail banks but significantly lower for small- and medium-sized banks (Clark, Jones, and Malmquist 2018) and some evidence that it is time-varying (Kashyap, Stein, and Hanson 2010).

Given the considerable heterogeneity in estimates of the offset, together with the absence of specific estimates for Irish banks, it is not clear which value for the offset should be applied to the increase in lending rates. The median estimate for the offset from Table 8 is close to 50 percent. However, in many studies that examine the macroeconomic impact of higher capital requirements, the rate at which the increase in lending rate is "offset" by a fall in the required return on equity is simply assumed. As our baseline, we assume that the offset is zero, but we consider alternative values in Section 3.1. Moreover, it is important to note that, as both COSMO and EireMod are linear models, any value for the offset can be applied ex post by scaling the fall in output due to higher capital requirements by that value.

2.6   Comparing Cost Estimates with Other Studies

Table 9 compares the impact of a 1 percentage point increase on lending rates and GDP in COSMO and EireMod with estimates for

other countries. Similar to our approach, some of these studies such as BCBS (2010) and Mikkelsen and Pedersen (2017) use macroeconomic models that include a banking sector to quantify the impact of higher capital requirements on both lending rates and GDP and which allow for feedback from the real economy to the banking sector. The remaining studies broadly adopt a two-step approach. They first use a basic loan pricing model and information on the relative cost of debt and equity to calculate how lending spreads may increase in response to higher capital requirements. They then feed this information into either a simple production function as an increase in the cost of capital (Brooke et al. 2015; Cline 2016) or as an increase in bond spreads facing nonfinancial firms in a macro model (Almenberg et al. 2017; Federal Reserve Bank of Minneapolis 2017; Firestone, Lorenc, and Ranish 2019).

All of the approaches yield broadly similar results to those from COSMO and EireMod in terms of the long-run increase in lending spreads and fall in output relative to a baseline. The study by the Basel Committee on Banking Supervision (BCBS 2010) is perhaps the most comprehensive, as it covers 13 countries and uses a variety of models. It finds that a 1 percentage point increase in capital requirements raises lending rates by between 9 and 19 basis points and reduces output relative to baseline between 0.02 and 0.35 percent of GDP. However, our results are closest to those of the Bank of England (Brooke et al. 2015). They find that a similar increase in capital requirements raises lending rates by between 5 and 10 basis points and reduces output relative to baseline by between 0.01 and 0.05 percent, depending on the value of the Modigliani-Miller offset applied. As the results from COSMO and EireMod assume the Modigliani-Miller offset is zero, they closely match the upper bound in Brooke et al. (2015).

The similarity of our cost estimates to those from other studies reflects a consistency in the approach to modeling these costs across countries. The models employed by these studies have similar transmission mechanisms from the shock to capital to the increase in lending rates and through to the reduction in the interest rate-sensitive components of aggregate demand. In particular, in the case of those models that explicitly incorporate a banking sector, the primary channel through which banks achieve the higher capital target is by accumulated retained earnings from raising lending rates. In

this respect, our framework for quantifying the macroeconomic cost of increasing capital requirements can be readily applied to other countries.

While our cost estimates are consistent with the literature, there are two potential caveats to these estimates that should be mentioned relating to the use of macroeconomic models of the Irish economy to generate these estimates. First, the models' equations are estimated or calibrated over a sample period that includes episodes of severe macrofinancial and macrofiscal volatility in the aftermath of the 2007–08 financial crisis. Isolating and quantifying the economic impact of higher capital requirements is therefore complicated by the concurrent shocks to banks' balance sheets, financial market liquidity, and sovereign creditworthiness that buffeted the real economy and banking system over that period. In addition, the introduction of comprehensive macroprudential regulations over the last decade in Ireland has significantly changed how banks respond to real and financial shocks. These factors can therefore complicate the identification of capital shocks when using Irish data.

Second, the outsized presence of multinational enterprises (MNEs) in the Irish economy distorts the relationship between conventionally used measures of aggregate output, such as GDP, and macroeconomic conditions in the domestic economy. The activities of MNEs in Ireland are outward-focused and have limited spillovers to the local economy. Moreover, as they are not typically dependent on domestic banks for financing, investment by MNEs in their Irish operations is generally insensitive to any increase in retail lending rates arising from higher capital requirements for Irish banks (Desai, Foley, and Hines 2004; Lawless, O'Connell, and O'Toole 2014). These factors result in a relatively low (semi-) elasticity of aggregate output (GDP) with respect to interest rates in the macroeconomic models we use, and explain why our estimates of the macroeconomic impact of capital shocks are at the lower bound of the literature. However, our analysis does also highlight how when we focus on the impact of shocks to bank capital on the output of domestically focused sectors, our results are close to the mean found in the literature. These additional results can therefore provide useful information for interpreting our estimates relative to those found in studies of similar sized economies.

Figure 2. Benchmark Rightsized Tier 1 Capital Ratio
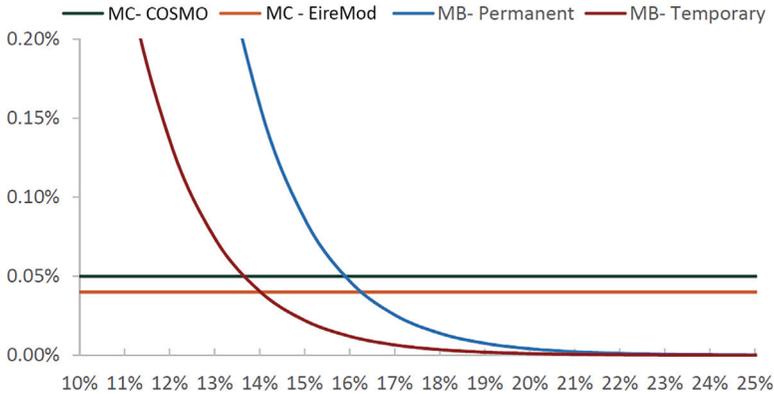
Note: The figure plots the marginal benefits of additional tier 1 capital when systemic banking crises have temporary (MB-Temporary) or permanent (MB-Permanent) effects, and the marginal costs of additional capital as simulated by a DSGE (MC-EireMod) and semi-structural (MC-COSMO) model. The marginal benefits relate to a risk environment in which EWS variables are at their median.

3.   Rightsizing Tier 1 Capital Ratios

3.1   Benchmark Model

Using the estimates discussed above, we plot the resulting marginal benefit and marginal cost curves consistent with given levels of tier 1 capital in Figure 2. We show the marginal benefits curves for the cases in which systemic crises are assumed to have either permanent or temporary effects. In the latter scenario, the economic impact of a crisis is assumed to dissipate after five years. The slope of these curves capture the extent to which the marginal gain in terms of lower crisis likelihood from additional capital diminishes as the tier 1 capital ratio increases. The point at which the marginal cost and benefit curves intersect corresponds to the level of capital beyond which net benefits of higher capital become negative, and thus this level can be interpreted as the "optimal" or "rightsized" level for the economy.

Figure 2 clearly illustrates how assumptions regarding the nature of economic scarring effects from financial crises can significantly

influence the optimal capital ratio. If the policymaker assumes that crises have a transitory effect on the economy only, the appropriate level of capital for an economy is approximately 14 percent. In contrast, if these effects are assumed to be permanent, the appropriate level of capital rises to 16 percent. From a macroprudential and risk management perspective, policymakers would likely adopt a conservative approach to the calibration of capital buffers and thus we adopt the latter as our "benchmark" model of optimal capital. This represents the baseline case against which alternative parameterizations of the marginal benefit and marginal cost curves can be compared. This benchmark model includes all eight early warning system (EWS) variables, set to their median values, and the tier 1 capital ratio. It assumes that crises reduce GDP by 7.17 percent relative to the pre-crisis trend and these output losses are discounted using a discount rate of 3 percent. Finally, it assumes that banks' weighted average cost of capital rises in proportion to the increase in capital so that the Modigliani-Miller offset is zero.

To highlight how the appropriate tier 1 capital ratio varies according to particular calibrations of the model, we consider alternative values for each of the key input parameters. A summary of alternative model calibrations is presented in panel A of Table 12. For example, assuming crises negatively affect GDP growth over a 10-year horizon results in an optimal tier 1 capital ratio of 13.5 percent (Scenario 2). Table 12 also shows the impact that different values of the Modigliani-Miller offset has on the optimal level. Setting the offset to a value of 50 percent, as some studies have assumed, results in a 1 percentage point increase in the appropriate capital level (Scenario 5). While the relatively small incremental increase in optimal capital that results from a halving of the macroeconomic costs of capital may seem surprising, it is important to note that the slope of the marginal benefit at that point mainly determines this change. As discussed above, the change in the slope of the marginal benefit curve is primarily a function of how the probability of experiencing a systemic crisis falls as the tier 1 capital ratio of the banking system increases. Thus, if the marginal benefit curve is relatively steep at the benchmark, this indicates that small changes in capital levels have a relatively large effect on mitigating the likelihood of lost output, or the expected output loss, due to a crisis. Accordingly, a given change in the marginal cost of higher capital will

result in a smaller increase in optimal capital than if the marginal benefit curve were flatter.

Overall, this sensitivity analysis suggests that, based on plausible alternative parameterizations of the marginal cost and marginal benefit curves, optimal tier 1 capital levels can range between 12.5 and 19 percent, with our benchmark or baseline calibration indicating a level of 16 percent. Having established this benchmark estimate for an appropriate tier 1 capital ratio for advanced economies, we now focus on the role that macrofinancial structural characteristics may play in influencing that ratio.

3.2   The Role of Macrofinancial Characteristics

Our choice of structural characteristics is informed by O'Brien and Wosser (2022), who find that economic size, the extent of trade and financial openness, the dependency on inward foreign direct investment (FDI), and the degree of market and sectoral exposure concentration in the banking system are important structural factors determining systemic risk. We now employ the same set of variables in our framework to assess how they affect the optimal or rightsized level of capital for the economy. The definitions of these variables, along with data sources and summary statistics, are reported in Table 3.

We first consider the role played by macrofinancial structural variables in amplifying or mitigating financial crisis likelihood. To classify an economy as having a particular macrofinancial structure, we construct dummy variables that indicate whether the economy is the top or bottom tertile of the cross-country distribution of the variable. For example, a country is categorized as being "small" if its contribution to global GDP is in the bottom tertile of countries in our sample. In the case of trade openness, we classify a country as being "trade open" if its ratio of exports and imports to GDP is in the top tertile across countries. In terms of financial openness, we focus on a de facto measure of financial globalization as captured by the ratio of inward and outward external claims to the total assets of the country's banking system. A country is thus defined as being "financially open" if this ratio is in the top tertile in our sample.

We measure bank concentration using three variants: (i) a market exposures concentration index (based on a Herfindahl-Hirschmann

Index (HHI) of market-sector exposures), (ii) the share of total banking system assets held by the three largest banks in a country, and (iii) the extent to which a banking system has exposures to real estate in particular. Our final structural variable measures the extent to which the country may be FDI dependent as indicated by the ratio of the stock of FDI to GDP.

The results of including these macrofinancial variables in our benchmark model with tier 1 capital are presented in columns 1–7 in Table 10, with the results relating to the structural dummy variables shown in the bottom panel. We find that only the small (at the 10 percent level) trade and financial openness variables have an independent effect on crisis likelihood for a given level of tier 1 capital. While not shown here, it is worth noting that the FDI dependency variable and two of the banking concentration measures are statistically significant if the capital variable is excluded or if these variables are included in continuous rather than discrete (dummy variable) form.[15] Thus, these variables may be systematically associated with higher probabilities of crises, but either these risks are offset by higher levels of capital or the direct relationship is essentially linear.

We now examine the interactions between the dummy variables given that countries in our sample may exhibit multiple macrofinancial structural characteristics concurrently. For example, countries may be small and highly open to trade, or they may be financially open and also have concentrated banking systems. To assess how combinations of different characteristics may amplify or mitigate the effect of each characteristic on systemic risk, we include the interaction of different combinations of macrofinancial variables in the benchmark logit model. The results of these regressions are reported in columns 8–10 in Table 10, where only statistically significant interactions are reported for expository reasons. We find that being a small country tends to amplify the impact of other macrofinancial characteristics on systemic risk. In particular, systemic risk tends to be higher in countries that are both small and also open to trade, financially open, and dependent on FDI.

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[15] These results are available on request from the authors.

Table 10. Crisis Probability and Macrofinancial Structure

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Constant	−0.635	0.622	−1.195	2.023	1.438	1.724	1.784	−1.780	−2.542	1.447
	(1.987)	(1.987)	(1.748)	(4.003)	(2.774)	(3.900)	(3.790)	(2.562)	(2.818)	(4.063)
Real Short-Term Int. Rates	303.889***	226.663***	277.919***	270.206***	258.736***	271.202***	279.548***	277.553***	282.989***	276.429***
	(116.285)	(75.315)	(94.199)	(98.968)	(85.719)	(96.705)	(83.620)	(92.790)	(99.256)	(105.146)
Losses Only S&P 500	−30.031**	−26.460***	−25.493***	−26.979**	−25.468***	−25.919**	−27.576***	−28.456***	−26.357***	−28.586***
	(11.976)	(10.005)	(9.100)	(10.757)	(9.191)	(10.204)	(10.161)	(10.395)	(9.560)	(11.000)
House Prices (%d)	9.947**	12.838***	12.333***	10.659***	8.931*	9.701***	8.143*	13.935***	12.463***	11.459***
	(4.333)	(4.295)	(4.106)	(3.258)	(4.765)	(3.102)	(4.664)	(4.515)	(4.359)	(2.998)
Unemployment (%d)	−0.374*	−0.521**	−0.586*	−0.391*	−0.302	−0.325*	−0.272	−0.430***	−0.424***	−0.319**
	(0.205)	(0.217)	(0.312)	(0.231)	(0.214)	(0.179)	(0.182)	(0.130)	(0.164)	(0.135)
HH Credit Growth (%d)	0.272**	0.234**	0.270**	0.229**	0.221***	0.234**	0.229**	0.248**	0.281**	0.234**
	(0.133)	(0.096)	(0.117)	(0.090)	(0.086)	(0.097)	(0.102)	(0.118)	(0.139)	(0.106)
Credit-to-GDP Ratio	0.004	−0.009	−0.009	−0.007	−0.001	−0.002	0.008	−0.001	0.003	−0.002
	(0.007)	(0.009)	(0.010)	(0.012)	(0.010)	(0.009)	(0.022)	(0.010)	(0.010)	(0.009)
Fin. Stability Index	−19.943**	−19.146**	−17.468**	−16.426***	−14.970**	−15.444***	−15.356***	−16.596***	−15.595***	−16.269***
	(8.852)	(7.577)	(7.033)	(6.140)	(6.567)	(5.586)	(5.325)	(5.781)	(5.532)	(5.959)
House Price Index	−0.002	−0.001	0.016	−0.013	−0.015	−0.013	−0.025	0.009	0.017	−0.013
	(0.015)	(0.013)	(0.015)	(0.033)	(0.022)	(0.031)	(0.024)	(0.018)	(0.021)	(0.033)
Tier 1 Capital Ratio	−55.914***	−55.315***	−61.195***	−50.983***	−49.889***	−54.288***	−51.821***	−59.001***	−67.710***	−53.461***
	(17.973)	(12.227)	(16.540)	(12.106)	(11.909)	(12.660)	(11.204)	(16.685)	(21.902)	(12.774)

Table 10. (Continued)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Small Country	2.098*									
	(1.280)									
Trade Openness		3.339***								
		(1.023)								
Fin. Openness			3.646***							
			(1.401)							
FDI Dependent				2.438						
				(1.691)						
CBS I: HHI					0.747					
					(1.762)					
CBS II: Three-Bank Share						1.606				
						(1.476)				
CBS III: Real Estate							−0.698			
							(2.567)			
Small*TradeOpen								4.122***		
								(1.194)		
Small*Fin.Open									3.900***	
									(1.417)	
Small*FDI										3.198***
										(1.065)
Observations	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021
Pseudo R²	0.381	0.403	0.403	0.374	0.359	0.366	0.358	0.431	0.419	0.393

Note: This table shows the effects of including macrofinancial structural characteristic variables in the EWS panel logit model with random effects. The dependent variable is a crisis dummy variable that takes a value of one in the quarter in which a systemic banking crisis begins, and is zero otherwise. Variables denoted by (%d) represent the deviation of the variable from its underlying trend. "CBS" refers to the different measures of concentrated banking systems. All variables are lagged by one period. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.

The marginal effects of these macrofinancial characteristics on the probability of experiencing a systemic financial crisis are presented in Table 11. We find that, conditional on the early warning indicators in the benchmark model, the marginal effect of being a small country is statistically significant (at the 10 percent level) and increases the probability of experiencing a crisis by 0.7 percentage points. Countries that are classified as "trade open" or "financially open" are over 1 percentage point more likely to experience crises. Focusing on the statistically significant interaction terms, crisis probabilities are 1.2 percentage points higher in countries that are both small and trade open, and 1.1 percentage points higher in countries that are both small and financially open. Finally, we find that the marginal effect of being small and FDI dependent has a similar impact on crisis likelihood (1.1 percentage point increase) as being small and either trade or financially open.

To quantify how optimal capital varies in countries with these types of macrofinancial structure, we first compute the marginal benefits of additional tier 1 capital incorporating the impact of these macrofinancial characteristics on the likelihood of financial crises. Figure 3 illustrates how the optimal level of capital changes for countries that are small and those that are trade open when crises are assumed to have either permanent or temporary effects on output. The marginal benefit curves from the benchmark models that exclude structural characteristics are shown for comparison. The top panel of Figure 3 shows that for small countries, the optimal level of capital increases by 1 percentage point relative to the benchmark in both scenarios for crisis-related output losses. The bottom panel of Figure 3 shows the impact of being "trade open" on the optimal level of capital. While small countries are typically also those that are most open to trade, we find that the impact of the latter on the appropriate level of capital is 50 basis points higher than the former in our baseline case that assumes that crises have permanent effects on output. However, in the case that the effects of financial crises are transitory, the small country and trade open characteristics have a similar impact on optimal levels of capital.[16]

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[16] It is important to note that the relative scale of the marginal effects associated with structural variables, vis-à-vis each other, does not necessarily translate

Table 11. Marginal Effects of Macrofinancial Characteristics on Crisis Probabilities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Small Country	0.007* (0.004)									
Trade Openness		0.010*** (0.004)								
Fin. Openness			0.011** (0.005)							
CBS I: HHI				0.003 (0.004)						
CBS II: Three-Bank Share					0.005 (0.007)					
CBS III: Real Estate						0.002 (0.004)				
FDI Dependent							0.008 (0.006)			
Small*TradeOpen								0.012*** (0.003)		
Small*Fin.Open									0.011*** (0.004)	
Small*FDI										0.011*** (0.002)
Observations	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021

Note: This table shows the marginal effects of macrofinancial structural characteristics variables on crisis likelihood. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.

Figure 3. Impact of Structural Characteristics on Rightsized Capital Ratios
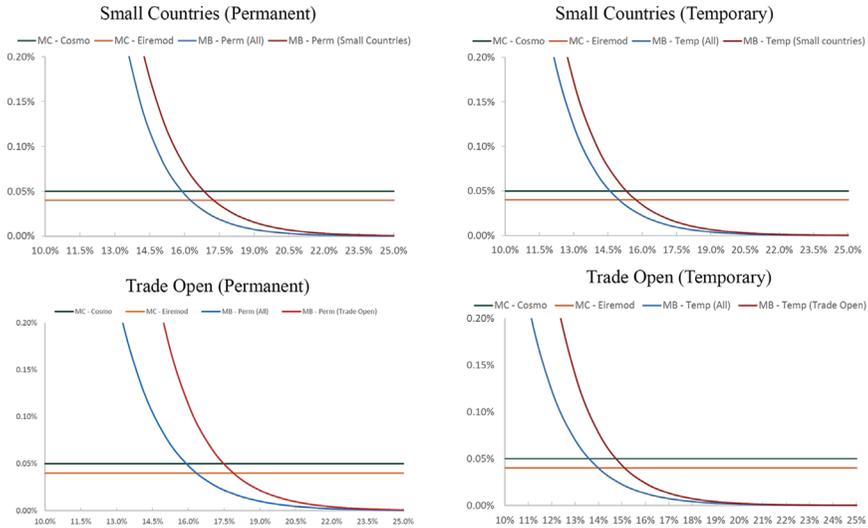
Note: Impact of the "small country" and "trade open" characteristics on optimal capital ratios when systemic crises are assumed to have either permanent or temporary effects. The marginal benefit curves for all countries are plotted for comparison.

The loadings on the benchmark capital ratio that are attributable to each of the other macrofinancial characteristics are shown in panel B of Table 12. To keep the presentation tractable, we focus on the case where financial crises have permanent effects on output. For completeness, we also include the loadings based on individual characteristics, including those for FDI dependency and banking concentrations. As these coefficients are not statistically significant, any inference based on their values is subject to the associated caveats.

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into a similar scale of optimal capital adjustments. The inclusion of various structural variables in regressions is associated with variation in the coefficients of the other EWS variables, depending upon which structural variable (or combination thereof) is included. Thus the trajectory of the marginal benefit curve, and its intersection point with the marginal cost curve, is altered, depending upon the structural variable involved. Whereas the optimal capital point is influenced by the marginal effect of the structural variable upon crisis probability, fitted values for the latter are also affected by the variation in the other coefficients.

However, the point estimates may be indicative of the magnitude of capital loadings that could be appropriate in countries that exhibit these characteristics. In these cases, the additional capital that is appropriate given higher levels of systemic risk ranges from 1 percentage point in countries with banking systems that are highly concentrated in either the share of assets held by the largest three or in their exposure to the real estate sector, to 2 percentage points in countries that are FDI dependent.

Table 12 shows that the largest increase in optimal capital relative to the benchmark comes from being both small and dependent on FDI, with an additional 3.5 percentage points of tier 1 capital required to mitigate the systemic risks associated with these characteristics. In countries that are small and open to trade, or small and financially open, additional capital of approximately 1.25 to 1.5 percentage points above the benchmark level may be appropriate. To our knowledge, these are the first estimates of how macrofinancial characteristics can independently or jointly raise the level of tier 1 capital that is optimal for a country's banking system.

In summary, the results in Table 12 show that estimates of appropriate levels of the tier 1 capital ratio in the banking system of advanced economies when cyclical systemic risk is at its median level can, depending on the particular calibration, range from 12.5 to 19 percent with a benchmark estimate of 16 percent. However, when various structural macrofinancial characteristics are considered, that range and benchmark could be up to 3.5 percentage points higher. From a financial stability perspective, therefore, our analysis suggests that it may be prudent for macroprudential authorities in countries that aim to incorporate systemic risk factors in their calibration of required capital buffers to also consider the structural macrofinancial dimension to these risks.

3.3   Capital Ratios, Risk Weights, and Cyclical Risks

While our framework is primarily designed to assess appropriate capital ratios in the steady state, policymakers would also likely require an analytical assessment of how rightsized levels of capital vary due to risk weights and to cyclical risks. In terms of the former, we can derive the implicit average risk weights applied to bank

Table 12. Model Calibration and Effect of Economic Structure on Optimal Capital

| A. Sensitivity of Benchmark Tier 1 Ratio of 15% to Alternative Parameterization						
Parameterization Scenario	MM Offset (%)	Discount Factor	Perm. Crisis Effects	Temp. Crisis Effects	Duration (Years)	Optimal T1 Capital (%)
Benchmark	0	3	Y	N	—	16.00
Scenario 1	0	3	N	Y	5	12.50
Scenario 2	0	3	N	Y	10	13.50
Scenario 3	25	3	Y	N	—	16.50
Scenario 4	75	3	Y	N	—	18.00
Scenario 5	50	3	Y	N	—	17.00
Scenario 6	50	3	N	Y	5	13.75
Scenario 7	50	3	N	Y	10	14.75
Scenario 8	50	5	Y	N	—	16.25
Scenario 9	50	5	N	Y	5	13.75
Scenario 10	50	5	N	Y	10	14.50
Scenario 11	50	1	Y	N	—	19.00
Scenario 12	50	1	N	Y	5	14.00
Scenario 13	50	1	N	Y	10	15.00

Table 12. (Continued)

B. Impact of Structural Characteristics Loadings on Benchmark Tier 1 Ratio of 16%

Structural Variable	Definition	ΔOptimal Ratio (pp)
Small Economy	Based on contribution of bottom tertile of countries in sample to world GDP	+1.00
Trade Openness	Countries in top tertile of share of exports plus imports in GDP	+1.50
Financial Openness	Countries with ratio of banking system external claims to GDP in top tertile	+1.00
FDI Dependent[†]	Countries with ratio of FDI to GDP in top tertile	+2.00
CBS I[†]	Countries in top tertile of shares of total banking system assets held by three largest retail banks	+1.00
CBS II[†]	Countries in top tertile of concentrated market-sector exposures measured by HHI	+1.25
CBS III[†]	Countries in top tertile of concentrated real estate market exposures	+1.00
Small and Trade Open	Based on cohort of countries that are both small and trade open	+1.25
Small and Fin. Open	Based on cohort of countries that are both small and financially open	+1.50
Small and FDI Dependent	Based on cohort of countries that are both small and FDI dependent	+3.50

Note: EWS variables in the benchmark scenario are set at their sample median. "CBS" refers to the different measures of a concentrated banking system. [†] denotes variables with coefficient point estimates that are not statistically significant in the structural dummy variable regressions.

Figure 4. Impact of Risk-Weighted Assets
## on Structural Capital Delta
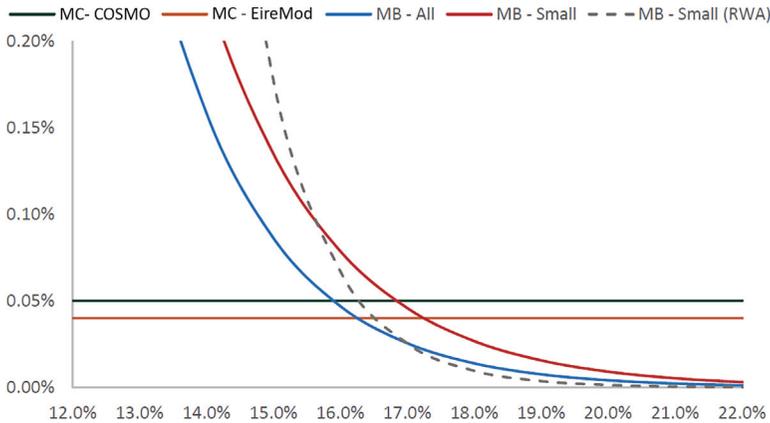
Note: The figure plots the marginal benefits of additional tier 1 capital for all countries, for small countries, and for small countries incorporating risk weights. The marginal benefit curves assume that systemic banking crises have permanent effects on output.

assets by country and over time.[17] This allows us to examine the capital implications implied by higher risk weights, in addition to the capital implications of different structural macrofinancial characteristics considered above. For exposition purposes, we focus only on the "small" structural characteristic in the case that crises have permanent effects on output. Figure 4 illustrates how the incorporation of risk weights changes both the slope and position of the marginal benefit curve. Importantly, it shows that, although higher risk weights reduce the structure-related capital gap, they do not eliminate it.

In terms of cyclical risks, our analysis has focused on appropriate levels of capital when risks are held at median levels. To address the issue of how rightsized capital ratios change when risks are elevated, we evaluate the marginal benefits of additional capital when each leading crisis indicator is at a "stressed" level. Note that as the macroeconomic models we use to estimate the marginal costs of

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[17] For example, where tier 1 capital to total assets are reported alongside tier 1 capital to risk-weighted asset ratios such as in BCBS (2010), the risk-weighted assets and the average risk weights may be determined. See also footnote 1.

**Figure 5. Rightsized Capital in
an Elevated Risk Environment**
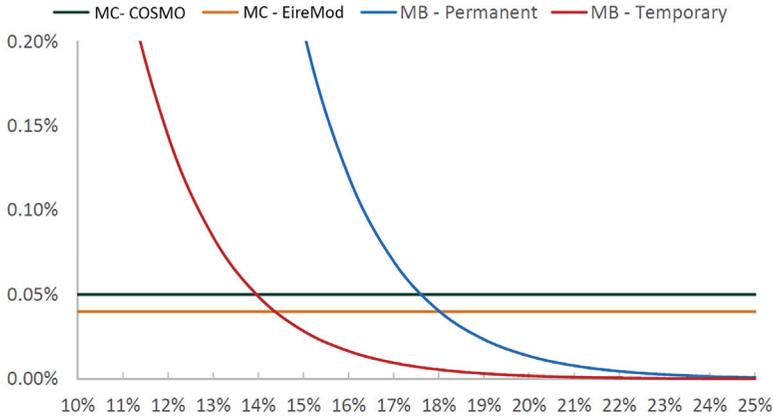
Note: The figure plots the marginal benefits of additional tier 1 capital when
EWS variables are at their 75th percentile for cases in which banking crises have
temporary (MB-Temporary) and permanent (MB-Permanent) effects. The marginal costs of additional capital are simulated using a DSGE (MC-EireMod) and
semi-structural (MC-COSMO) model and relate to average macroeconomic costs
over the cycle.

additional capital are linear, these costs do not vary over the cycle.
To keep the discussion concise, we focus on the benchmark capital
models and thus abstract from the impact of macrofinancial structure. Figure 5 illustrates how the rightsized level of capital changes
when all early warning indicators reflect a stressed value represented
by the 75th percentile. We find that the rightsized levels increase
by approximately 2 percentage points to 18 percent when systemic
crises have permanently harmful effects, and by 1 percentage point
to circa 14.5 when crises are assumed to have temporary effects on
output. With the caveat that our framework is more suitable for
assessing long-run capital requirements, these results suggest that
accounting for an elevated risk environment can materially affect
the calibration of appropriate macroprudential buffers.

4.   Robustness Checks

We assess the robustness of our results across several dimensions. To
ensure that our results are not driven by a single crisis episode or

country, we drop each crisis observation sequentially and reestimate the logistic model. These changes in the composition of our sample do not affect our results. We also estimate the model over different time periods and similarly find that our primary findings are broadly unchanged.

More fundamentally, we adjust the classification scheme for defining dummy variable according to each macrofinancial structural characteristic. Instead of assigning a particular characteristic to a country depending on whether they are above or below the top or bottom tertile value of the macrofinancial variable, we consider different thresholds such as quartiles and quintiles. We do find that some results are sensitive to these changes. The reclassification mainly affects bank concentration indicators with the coefficients on the HHI and market-sector exposure variables changing sign when the thresholds change.

As O'Brien and Wosser (2022) show however, when these structural characteristics are included in the estimation in continuous instead of discrete form, they are shown to be positively and significantly correlated with higher crisis likelihood. Moreover, when the dummy variables are more narrowly defined based on quartiles or quintiles, it becomes more difficult to distinguish between country cohorts sharing multiple characteristics, and thus the underlying structural characteristic become more difficult to identify. Accordingly, we argue that, while a more granular classification would be preferable a priori, our approach based on classifying countries according to whether they are above or below the top or bottom tertile of a particular variable is apposite given the relatively small number of country-financial crisis episodes that is available.

5.   Conclusions

The analysis in this paper suggests that when the prevailing systemic risk environment is neither elevated nor subdued, the appropriate tier 1 capital range for the banking systems of advanced economies can plausibly lie in a range between 12.5 and 19 percent, with our benchmark specification indicating an optimal value of approximately 16 percent.

Additionally, we show that a country's macrofinancial structural characteristics can materially influence the appropriate level of capital by an additional 3.5 percentage points. The characteristics we find to be most important in determining steady-state capital ratios include whether a country is "small" in terms of its contribution to global GDP, the extent to which it is "open" to trade and capital flows, and the degree to which it is FDI dependent.

The range we identify is relatively broad but is consistent with prior literature, especially with those studies that use panel data similar to that used here. Our results, particularly in terms of the marginal benefits of higher capital for given macrofinancial characteristics, could therefore help inform the calibration of optimal capital ratios across different banking systems. Further, the analytical framework we outline in this paper is sufficiently flexible to allow policymakers to derive a country-specific range for appropriate levels of bank capital by combining local estimates of the marginal macroeconomic costs of higher capital requirements, which are assumed to be constant, with our results for the marginal benefits (which are nonlinear).

To further narrow the optimal capital range, additional analysis is warranted. On a country-by-country basis, a bottom-up approach toward "rightsizing" banking system capital should also be considered given that prior research has shown that the results achieved in top-down studies, such as we have adopted, can yield results indicating a higher capital range than suggested by a bottom-up approach. However, our results do point to the relevant additional capital that macroprudential policymakers could consider when framing an approach to capital buffers in small open advanced economies.

While our finding that the assessment of appropriate levels of capital should incorporate structure-related factors is novel, it should be noted that these recommendations relate to a "long-run" perspective and refer specifically to normal or median systemic risk levels. In particular, the transitional costs associated with shifting to higher levels of capital could be relatively large depending on how the introduction of additional capital requirements is sequenced. When making specific policy decisions regarding the calibration of these ratios, macroprudential authorities would also need to evaluate the

impact of prevailing economic and systemic risk conditions, as well as any associated transition costs to the steady state (or normal times), on their rightsized level.

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