Bank Capital in the Short and in the Long Run*

Caterina Mendicino† Kalin Nikolov‡ Javier Suarez§ Dominik Supera¶

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Abstract

How far should capital requirements be raised in order to ensure a strong and resilient banking system without imposing undue costs on the real economy? Capital requirement increases make banks safer and are beneficial in the long run but also entail transition costs because their imposition reduces credit supply and aggregate demand on impact. In the baseline scenario of a quantitative macro-banking model, 25% of the long-run welfare gains are lost due to transitional costs. The strength of monetary policy accommodation and the degree of bank riskiness are key determinants of the trade-off between the short-run costs and long-run benefits from changes in capital requirements.

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†European Central Bank - Directorate General Research - Monetary Policy Research.
‡European Central Bank - Directorate General Research - Financial Research.
§CEMFI and CEPR.
¶Wharton School, University of Pennsylvania.

1. Introduction

The recent financial crisis revealed the importance of banks and their prudential regulation, giving impetus to the reinforcement of capital requirements (Basel III) and boosting research on the macroeconomic implications of bank capital regulation. In the long run, higher capital requirements improve bank resilience and mitigate the misallocation of resources resulting from excessive bank leverage and risk taking. In the short run, however, a rise in capital requirements may have a contractionary impact on credit supply and aggregate economic activity. The short-run costs from increasing banks' capitalization have been largely neglected by the existing literature, which has so far focused on the effects of higher capital requirements on the long-run allocation of the economy and social welfare.

In this paper, we assess the positive and normative implications of changing capital requirements taking into account the trade-off between their short- and long-run effects. We focus on a number of hitherto unexplored questions. How important are these transitional effects? What factors determine the overall balance between the transitional costs and the long-run benefits of raising capital requirements? What is the optimal level of capital requirements once transitional effects are factored in?

We build a quantitative macro-banking model featuring both financial and nominal frictions. Banks intermediate funds between saving households and borrowing firms. Firms and banks can default on their debts and their net worth is key in reducing the deadweight losses associated with default risk, as in the financial accelerator literature (e.g. Bernanke, Gertler and Gilchrist, 1999). The model also features nominal price rigidities, nominal debt, and a monetary authority that follows a standard Taylor-type interest rate rule.

The key bank-related friction in the model is that bank depositors do not price individual bank default risk at the margin but on the basis of their expectations about the potential losses associated with the risk of failure of an average bank.[1] This friction provides banks with an incentive to lever up excessively and not properly price the risk associated with their loans, providing a prima facie case for regulatory capital requirements, as in Kareken and Wallace (1978). Increasing capital requirements limits bank risk taking and default risk and leads to lower bank debt funding costs. However, given that the availability of bank equity is limited by the net worth of bank owners, increasing capital requirements may also reduce the supply of bank credit while bank equity is adjusting to its new steady state level.

The size of the short-term costs of increasing capital requirements depends crucially on the degree of monetary policy accommodation. In the calibrated model – which reproduces salient features of the euro area (EA) economy and assumes a standard Taylor rule – transitional costs offset 25% of the welfare gains from the long-run optimal increase in capital requirements. If monetary policy is constrained in

[1] Formally this is equivalent to assuming that individual bank leverage is unobservable to bank depositors, which could be justified by the fact that their dispersion and/or lack of sophistication make them unwilling and/or unable to monitor the banks (Dewatripont and Tirole, 1993).

its ability to be accommodative, for example because of an effective lower bound (ELB), the transitional costs reduce the long-run welfare gains by up to 40% .

When monetary policy is conducted optimally in response to the increase in bank capital requirements, it reduces the real interest rate beyond what prescribed by the Taylor rule and further than what is needed to stabilize inflation. Output declines much less over the transition path albeit at the cost of an increase in inflation. This reduces the transitional costs to 17% of the long-term welfare gains without completely eliminating the trade-off between the short and long-run effects of capital requirements. Intuitively, monetary policy cannot directly offset the short term tightening in the supply of credit but can soften the economy's adjustment to it.

The balance between long-run gains and transitional costs is also affected by bank risk. Under heightened uncertainty about the returns on the banks' loan portfolio, higher capital requirements are more beneficial in the long run and less costly in the short run: the larger long-run benefits are factored in by the forward looking households who increase consumption, mitigating the drop in demand over the transition. Thus, when the degree of bank fragility is high, capital requirement increases are most beneficial, which is consistent with microprudential logic.

The optimal capital requirements are lower once transitional costs are taken into account. The logic behind this result is similar to that behind the optimality of deviating from the Golden Rule in the neoclassical growth model. Indeed, impatient agents care about the costs incurred during the transition. Thus, the optimal increase in capital requirements depends on the factors that determine the size of the transitional costs. In particular, the optimal increase in capital requirement is larger when the transition cost declines, e.g. due to a more accommodative monetary policy, a more gradually increase or higher risk in the banking sector.

Our paper is complementary to the literature that quantifies the long-run effects of changes in capital requirements.[2] Van Den Heuvel (2008) focuses on the long-run cost of capital requirements in a model where deposits provide liquidity services to their holders. Begenau (2019) contrasts this cost with the benefits of decreasing some reduced-form costs of bank default in a dynamic setup. Martinez-Miera and Suarez (2014) discuss optimal long-run capital requirements in a setup in which they reduce banks' systemic risk taking. Clerc et al. (2015), Mendicino et al. (2018) and Elenev et al. (2018) analyze the long-run impact of capital requirements in DSGE frameworks which explicitly account for the financial stability gains associated with the reduction in bank default.

From a methodological stand point this paper shares with some of the previous work the explicit modeling of bank default risk and combines it with elements such as nominal debt, price rigidities, monetary policy, and the analysis of transitions between steady states. These additional features, which are not present in any of the aforementioned papers, allow us to obtain the two most distinctive findings

[2]More broadly, our work fits in the macroeconomic literature that stresses the role of bank frictions, including Gertler and Kiyotaki (2010), Gertler and Karadi (2011), Brunnermeier and Sannikov (2014) and Christiano and Ikeda (2016).

of this paper: (i) that the transitional impact of regulatory measures matters for the overall welfare assessment and (ii) that the trade-off between short-run costs and long-run benefits depends on the response of monetary policy.

Our work is connected to the literature on the interaction between monetary and macroprudential policy in stabilizing fluctuations (e.g. De Paoli and Paustian, 2013; Kiley and Sim, 2017; Lambertini et al. 2013; Leduc and Natal, 2016; Collard et al., 2017; Carrillo et al. 2017; Gersbach el al., 2018; Ferrero et al., 2018; Van der Ghote, 2018). Differently from these studies, we focus on the interaction of policies during the transition to higher capital requirements in a framework where the capital requirements reduce bank default.

Our work is also related to the literature showing that fiscal multipliers are much larger at the ELB of nominal interest rates (e.g. Christiano, Eichenbaum and Rebelo, 2011; Erceg and Linde, 2014; and Eggertson, Ferrero and Raffo, 2014). Our results confirm that the short term impact of any policy that changes aggregate demand (be it fiscal or macroprudential) depends very much on how monetary policy reacts.

The paper is structured as follows. Section 2 and 3 present the model and the calibration to EA data. Section 4 and 5 investigate the long-run and transitional effects of higher capital requirements. Section 6 discusses optimal capital requirements. Section 7 concludes.

2. Model Economy

We consider an economy populated by a dynasty of saving households that provide consumption insurance to three types of members: workers, entrepreneurs, and bankers, of measures x_j, with $j = w, e, b$, respectively. Workers supply labor and transfer their wage income to the household. Entrepreneurs and bankers use their scarce net worth to provide equity financing to, respectively, entrepreneurial firms and banks and transfer their accumulated earnings back to the dynasty. Firms' debt financing takes the form of (non contingent) bank loans. Banks finance their loans to firms by raising equity from bankers and (non contingent) deposits from households. Entrepreneurial firms and banks operate under limited liability and default when the value of their assets falls below their debt obligations. Default entails asset repossession costs and borrowers' net worth plays a key role in reducing these costs.

A fraction κ of bank deposits is insured by a deposit insurance scheme (DIS) funded with lump sum taxes. The remaining fraction $1-\kappa$ is uninsured and depositors price it on the basis of their expectations about the potential losses associated with the risk of failure of an average bank. Thus, the pricing of deposits is not a function of the leverage and risk taking choices of each individual bank, which are assumed to be unobservable to small and dispersed depositors as in, e.g. Dewatripont and Tirole, 1993.[3]

[3] In addition, deposit taking differs from standard corporate debt issuance in that it does not carry explicit covenants that constrain the banks from taking further deposits. The implications of unobservable leverage are similar to those of the

This key friction implies that the risk of bank default is not priced at the margin and banks have incentives to lever up excessively and to underprice the risk involved in bank loans, which provides a rationale for capital requirements.[4]

The next subsections describe the main ingredients in detail.[5]

2.1 Default Risk

The debt issued by firms and banks is risky due to the existence of idiosyncratic return shocks $\omega_{j,t+1}$ ($j \in \{b, f\}$) which multiplicatively affect the gross return of their assets. These shocks are independently distributed and follow a log-normal distribution with a mean of one and standard deviation of σ_j, identical across borrowers of the same class. For each class of borrower, we denote by $F_j(\omega_{i,t+1})$ the distribution function of $\omega_{j,t+1}$ and by $\overline{\omega}_{j,t+1}$ the threshold realization below which a borrower of class j defaults, so the probability of default of such borrower is $F_j(\overline{\omega}_{i,t+1})$.

As in Bernanke, Gertler and Gilchrist (1999), the share of total assets owned by borrowers of class j which end up in default is defined as

$$G_j\left(\overline{\omega}_{i,t+1}\right) = \int_0^{\overline{\omega}_{j,t+1}} \omega_{j,t+1} dF_j\left(\omega_{j,t+1}\right), \tag{1}$$

and the expected gross share of asset value that goes to the lender as

$$\Gamma_j(\overline{\omega}_{j,t+1}) = \mathbb{E}[\min\{\omega_{j,t+1}, \overline{\omega}_{j,t+1}\}] = G_j\left(\overline{\omega}_{j,t+1}\right) + \overline{\omega}_{j,t+1}(1 - F_j\left(\overline{\omega}_{j,t+1}\right)). \tag{2}$$

Assuming a proportional asset repossession cost μ_j, the expected net share of assets that goes to the lender is $\Gamma_j(\overline{\omega}_{j,t+1}) - \mu_j G_j\left(\overline{\omega}_{j,t+1}\right)$. The expected share of assets accrued to the borrowers is $\mathbb{E}[\max\{\omega_{j,t+1} - \overline{\omega}_{j,t+1}, 0\}] = 1 - \Gamma_j(\overline{\omega}_{j,t+1})$.

2.2 Households

The dynasty of households solves

$$\max_{\{C_{t+\tau}, L_{t+\tau}, K_{s,t+\tau}, D_{t+\tau}, B_{t+\tau}\}_{\tau=0,1,2,\ldots}} \mathbb{E}\left[\sum_{\tau=0}^{\infty} \beta^{t+\tau}\left[\log\left(C_{t+\tau}\right) - \frac{\varphi}{1+\eta}\left(L_{t+\tau}\right)^{1+\eta}\right]\right] \tag{3}$$

subject to:

$$\begin{aligned} & P_t C_t + \left(Q_t + P_t s_t\right) K_{s,t} + D_t + B_t \\ & \leq \left[P_t r_{k,t} + (1-\delta)\, Q_t\right] K_{s,t-1} + W_t L_t + \widetilde{R}_t^d D_{t-1} + R_{t-1} B_{t-1} + P_t T_{s,t} + P_t \Pi_t + P_t \Xi_t \end{aligned} \tag{4}$$

unobservable risk taking decisions modelled in Martinez-Miera and Suarez (2014) or Christiano and Ikeda (2016).

[4]We focus on capital requirements because of their relevance in the micro and macroprudential regulation of banks. In theory, deposit insurance premia explicitly contingent on bank leverage might be a more natural way to address banks' excessive leverage incentives. However, in practice, deposit insurance premia are risk-insensitive (Pennacchi, 2006) and the burden of controlling bank leverage falls on capital regulation.

[5]See Online Appendix for the market clearing conditions and some variable definitions.

where C_t denotes consumption and L_t hours worked in the consumption good producing sector. Parameter φ measures the disutility of labor, and η is the inverse of the Frisch elasticity of labor supply. P_t is the nominal price of the consumption good and W_t is the nominal wage rate. Households can directly hold, subject to a per unit management cost s_t, physical capital $K_{s,t}$ with nominal price Q_t, depreciation rate δ, and rental rate $r_{k,t}$.

Holdings B_{t-1} of the risk free asset (which is in zero net supply) pay the gross short-term nominal interest rate R_{t-1} at t. The gross return obtained on the deposit portfolio D_{t-1} is $\widetilde{R}_t^d = R_{t-1}^d - (1-\kappa)\Omega_t$, where R_{t-1}^d is the promised gross deposit rate (that the fraction κ of insured deposits always pay) and Ω_t is the average per unit loss rate (relative to the promised repayment) experienced on the fraction of uninsured deposits. For $\kappa < 1$, making (the bundle of insured and uninsured) bank debt attractive to savers will require a contractual gross interest rate R_{t-1}^d higher than the free rate R_{t-1}. Finally, $T_{s,t}$ is a lump-sum tax used by the DIS to ex-post balance its budget, Π_t are the aggregate net transfers from entrepreneurs and bankers to the household, and Ξ_t the profits from capital management firms.

2.3 Entrepreneurs and Bankers

In each period, after receiving the returns of their previous period investments, some entrepreneurs ($\varrho = e$) and bankers ($\varrho = b$) become workers (with probability $1 - \theta_\varrho$) and some workers become either entrepreneurs or bankers (producing the entry of a mass $(1-\theta_\varrho)\, x_\varrho$ of new agents of class ϱ). Thus, the population of each of these classes of agents remains constant at size x_ϱ, while their aggregate accumulated net worth is prevented to grow excessively.[6] The new agents of class ϱ receive an endowment of total net worth $\iota_{\varrho,t}$, from the patient dynasty. Surviving and new entrepreneurs and bankers can use their net worth to provide equity financing to entrepreneurial firms and banks, respectively, or to pay dividends to the household.

2.3.1 Individual Entrepreneurs

The problem of the representative entrepreneur can be written as

$$V_{e,t} = \max_{A_t, dv_{e,t}} \left\{ dv_{e,t} + \mathbb{E}\frac{\Lambda_{t+1}}{\pi_{t+1}} \left[(1-\theta_e)\, N_{e,t+1} + \theta_e V_{e,t+1} \right] \right\} \tag{5}$$

subject to $A_t + dv_{e,t} = N_{e,t}$, where

$$N_{e,t+1} = \int_0^\infty \rho_{f,t+1}(\omega) dF_f(\omega)\, A_t, \tag{6}$$

and $dv_{e,t} \geq 0$; $\Lambda_{t+1} = C_t / C_{t+1}$ is the household's real stochastic discount factor, $\pi_{t+1} = P_{t+1}/P_t$ is the inflation rate, $N_{e,t}$ is the nominal value of the entrepreneur's net worth, A_t is the net worth symmetrically

[6] This guarantees that entrepreneurs and bankers do not stop investing all their net worth in the equity of firms and banks, respectively (see, e.g. Gertler and Kiyotaki, 2010).

invested in the continuum of entrepreneurial firms further described below, $dv_{e,t} \geq 0$ is the dividend paid to the household, and $\rho_{f,t}(\omega)$ is the nominal return on the equity invested in a firm with return shock ω.

As in Gertler and Kiyotaki (2010), guessing that the value function is linear in net worth, we can write (5) as

$$v_{e,t}N_{e,t} = \max_{A_t, dv_{e,t}} \left[dv_{e,t} + \mathbb{E}\frac{\Lambda_{t+1}}{\pi_{t+1}} \left(1 - \theta_e + \theta_e v_{e,t+1}\right) N_{e,t+1} \right]. \tag{7}$$

Insofar as the shadow value of one unit of entrepreneurial equity satisfies $v_{e,t} > 1$ (which we verify to hold true), entrepreneurs only pay a final dividend when they retire. Finally, (7) allows us to define entrepreneurs' stochastic discount factor as $\Lambda_{e,t+1} = \Lambda_{t+1} \left(1 - \theta_e + \theta_e v_{e,t+1}\right)$.

2.3.2 Entrepreneurial Firms

The representative entrepreneurial firm, which operates across two consecutive dates, takes equity A_t from entrepreneurs and borrows $B_{f,t}$ from banks at nominal interest rate R_t^b to buy physical capital $K_{f,t}$ from capital producers at t. In the next period, the firm rents the available effective units of capital, $\omega_{f,t+1}K_{f,t}$, where $\omega_{f,t+1}$ is the firm-idiosyncratic return shock, to capital users, sells back the depreciated capital to capital producers, and pays out its terminal net worth to entrepreneurs. The representative entrepreneurial firm maximizes the net present value of the equity taken from entrepreneurs by solving

$$\max_{A_t, B_{f,t}, R_t^b, K_{f,t}} \mathbb{E}\left\{ \Lambda_{e,t+1}(1 - \Gamma_f\left(\overline{\omega}_{f,t+1}\right)) \left[r_{k,t+1} + (1-\delta)\frac{Q_{t+1}}{P_{t+1}} \right] \right\} K_{f,t} - v_{e,t}A_t,$$

where the equity A_t is valued at its equilibrium opportunity cost $v_{e,t}$, subject to the budget constraint $Q_tK_{f,t} = B_{f,t} + A_t$, and the participation constraint of the bank

$$\mathbb{E}\left[\frac{\Lambda_{b,t+1}}{\pi_{t+1}} (1 - \Gamma_b\left(\overline{\omega}_{b,t+1}\right)) \widetilde{R}_{t+1}^b B_{f,t} \right] \geq v_{b,t}\phi_t B_{f,t}, \tag{8}$$

where

$$\widetilde{R}_{t+1}^b B_{f,t} = \left(\Gamma_f\left(\overline{\omega}_{f,t+1}\right) - \mu_f G_f\left(\overline{\omega}_{f,t+1}\right)\right)\left(P_{t+1}r_{k,t+1} + (1-\delta)\,Q_{t+1}\right)K_{f,t}. \tag{9}$$

Constraint (8) reflects the competitive pricing of bank loans for different choices of firm leverage. It imposes that the loan rate R_t^b must be such that the expected, properly discounted payoffs that the loans provide to bankers are large enough to compensate them for the opportunity cost of the equity contributed to such loans, $v_{b,t}\phi_t B_{f,t}$, where $v_{b,t}$ is the shadow value of one unit of bankers' wealth and ϕ_t is the (binding) capital requirement faced by the bank. The term $\Lambda_{b,t+1}$ is bankers' stochastic discount factor, $1 - \Gamma_{b,t+1}(\overline{\omega}_{b,t+1})$ accounts for the fact that bankers obtain levered returns from the loan portfolio, and $\overline{\omega}_{b,t+1}$ is the threshold of the idiosyncratic bank return shock below which the bank defaults.[7]

Equation (9) describes the payoff that the bank receives from its portfolio of loans, which takes into account that the firm defaults when its asset value, $\omega_{f,t+1}((1-\delta)Q_{t+1} + P_{t+1}r_{k,t+1})K_{f,t}$, is insufficient

[7] When solving this problem, the entrepreneurial firm takes $\overline{\omega}_{b,t+1}$ as given, since the impact of an infinitesimal marginal loan on bank solvency is negligible. Instead, the firm internalizes the impact of its decision on its own default threshold $\overline{\omega}_{f,t+1}$.

to pay its debt obligations $R_t^b B_{f,t}$. It also reflects the proportional cost μ_f incurred by the bank when repossessing the physical capital if the firm defaults. Firms' default threshold is:

$$\overline{\omega}_{f,t} = \frac{R_{t-1}^b B_{f,t-1}}{\left(\left(1-\delta\right) Q_t + P_t r_{k,t}\right) K_{f,t-1}} = \frac{R_{t-1}^b \frac{B_{f,t-1}}{P_{t-1}}}{\left(\left(1-\delta\right) \frac{Q_t}{P_t} + r_{k,t}\right) K_{f,t-1}} \frac{1}{\pi_t} \tag{10}$$

2.3.3 Individual Bankers

Bankers' problem is formally symmetric to that of entrepreneurs, with the key difference that bankers invest their net worth $N_{b,t}$ into the measure one of banks. Hence, to save on space, we will skip the detailed expression of their decision problem. Variables such as $V_{\varrho,t}$, $dv_{\varrho,t}$, $v_{\varrho,t}$, and $\Lambda_{\varrho,t+1}$ with $\varrho = b$ represent for bankers exactly the same as their counterparts with $\varrho = e$ for entrepreneurs. Bankers' diversified nominal equity investment in the continuum of banks is denoted E_t (and plays the same role in their problem as A_t in entrepreneurs' problem). The nominal return of a well diversified portfolio of bank equity is denoted by $\rho_{b,t+1} = \int_0^\infty \rho_{b,t+1}\left(\omega\right) dF_b\left(\omega\right)$ and plays a role equivalent to $\rho_{e,t+1}$ in entrepreneurs' problem.

2.3.4 Banks

The representative bank issues equity $E_{b,t}$ among bankers and nominal deposits D_t that promise a gross interest rate R_t^d among households, and uses these funds to provide a continuum of identical loans of total size $B_{f,t}$. This loan portfolio has a terminal value of $\omega_{b,t+1}\widetilde{R}_{t+1}^b$, where $\omega_{b,t+1}$ is the bank-idiosyncratic asset return shock and $\widetilde{R}_{t+1}^b$ denotes the realized gross return on a well diversified portfolio of loans.[8] The bank operates across two consecutive dates and gives back its terminal net worth, if positive, to the bankers. If a bank's terminal net worth is negative, it defaults. The DIS then takes the returns $(1-\mu_b)\omega_{b,t+1}\widetilde{R}_{t+1}^b B_{f,t}$ where μ_b is a proportional repossession cost, pays the fraction κ of insured deposits in full, and pays a fraction $1-\kappa$ of the repossessed returns to the holders of uninsured deposits.

The representative bank maximizes the net present value of bankers' equity stake

$$NPV_{b,t} = \mathbb{E}\left(\frac{\Lambda_{b,t+1}}{\pi_{t+1}} \max\left\{\omega_{b,t+1}\widetilde{R}_{t+1}^b B_{f,t} - R_t^d D_t, 0\right\}\right) - v_{b,t}E_{b,t}, \tag{11}$$

where the equity $E_{b,t}$ is valued at its equilibrium opportunity cost $v_{b,t}$, and the max operator reflects shareholders' limited liability as explained above. The bank is subject to the balance sheet constraint, $B_{f,t} = E_{b,t} + D_t$, and the regulatory capital constraint $E_{b,t} \geq \phi_t B_{f,t}$, where ϕ_t is the capital requirement on entrepreneurial loans. For a binding capital requirement then $B_{f,t} = E_{b,t}/\phi_t$, $D_t = (1-\phi_t)E_{b,t}/\phi_t$ and the bank's default threshold as $\overline{\omega}_{b,t+1} = \left(1-\phi_t\right) R_t^d / \widetilde{R}_{t+1}^b$.[9]

[8]This layer of idiosyncratic uncertainty is an important driver of bank default and is intended to capture limits to diversification of borrowers' risk (e.g. regional or sectoral specialization or large exposures) or shocks stemming from (unmodeled) sources of banks' cost or revenue.

[9]Since partially insured deposits are "cheaper" than equity financing, equilibrium the capital requirement is binding.

With prior definitions, the bank's net worth at $t+1$ can be written as

$$\omega_{b,t+1}\widetilde{R}^b_{t+1}B_{f,t} - R^d_t D_t = \left[\omega_{b,t+1}\widetilde{R}^b_{t+1} - R^d_t(1-\phi_t)\right] B_{f,t} = \left(\omega_{b,t+1} - \overline{\omega}_{b,t+1}\right)\widetilde{R}^b_{t+1}\frac{E_{b,t}}{\phi_t},$$

which, using (2), allows us to rewrite the bank's objective function as

$$NPV_{b,t} = \left\{\mathbb{E}\frac{\Lambda_{b,t+1}}{\pi_{t+1}}\left[1-\Gamma_b(\overline{\omega}_{b,t+1})\right]\left(\widetilde{R}^b_{t+1}/\phi_t\right) - v_{b,t}\right\} E_{b,t}. \tag{12}$$

This expression is linear in the bank's scale as measured by $E_{b,t}$ and implies that the bank is willing to invest in loans with gross returns described by $\widetilde{R}^b_{t+1}$ insofar as

$$\mathbb{E}\frac{\Lambda_{b,t+1}}{\pi_{t+1}}\left[1-\Gamma_b(\overline{\omega}_{b,t+1})\right]\widetilde{R}^b_{t+1} \geq \phi_t v_{b,t}. \tag{13}$$

This explains the form of the participation constraint (8) in the entrepreneurial firms' problem. This constraint will hold with equality since it is not in the firms' interest to pay more for its loans than strictly needed. Finally, we can write the aggregate nominal return on bank equity as $\rho_{b,t+1} = \left[1-\Gamma_b(\overline{\omega}_{j,t+1})\right]\widetilde{R}^b_{t+1}\phi_t$.

2.3.5 Laws of Motion of Net Worth

The evolution of active entrepreneurs' and bankers' nominal aggregate net worth can be described as:[10]

$$N_{e,t} = \theta_e \rho_{f,t} A_{t-1} + \iota_{e,t}, \tag{14}$$

$$N_{b,t} = \theta_b \rho_{b,t} E_{b,t-1} + \iota_{b,t}, \tag{15}$$

where $\rho_{f,t} = \int_0^\infty \rho_{f,t}(\omega) dF_{f,t}(\omega)$ is the return on a well-diversified unit portfolio of equity investments in entrepreneurial firms. As for the endowments $\iota_{e,t}$ and $\iota_{b,t}$ received by the new entrepreneurs and bankers, we assume them to be a proportion χ_e and χ_b of the net worth of corresponding retiring agents.

2.4 Consumption Goods Production Sector

We assume a continuum $i \in [0,1]$ of monopolistically competitive firms that produce a differentiated intermediate good $y_t(i)$ by combining labor $l_t(i)$ and capital $k_t(i)$ using a constant-returns-to-scale technology:

$$y_t(i) = l_t(i)^{1-\alpha} k_{t-1}(i)^{\alpha}, \tag{16}$$

where α is the share of capital in production. Intermediate good firms are owned by the household dynasty and distribute profits or losses back to it. The intermediate output is then purchased by the perfectly competitive firms that produce the final consumption good Y_t according to a CES technology.

We assume sticky prices at the intermediate production sector according to the standard Calvo setup. Prices are set for contractual periods of random length. Each contract expires with probability $1-\xi$ per period. When the contract expires, the intermediate producer i sets the new price $\widetilde{p}_t(i)$ to maximize the present discounted value of future real profits over the validity of the contract.

[10] To save on notation, we also use $N_{\varrho,t+1}$ to denote the aggregate net worth of agents of class ϱ, while in (6) $N_{e,t+1}$ denoted the net worth of an individual continuing entrepreneur.

2.5 Capital Production

Producers of capital combine investment, I_t, with the previous stock of capital, K_{t-1}, in order to produce new capital which can be sold at nominal price Q_t. Capital producers face adjustment costs as in Jermann (1998), $S\left(\frac{I_t}{K_{t-1}}\right) = \frac{a_1}{1-\frac{1}{\psi_K}}\left(\frac{I_t}{K_{t-1}}\right)^{1-\frac{1}{\psi_K}} + a_2$, where a_1 and a_2 are chosen to guarantee that, in the steady state, the investment-to-capital ratio is equal to the depreciation rate and $S'\left(I_t/K_{t-1}\right)$ equals one. The law of motion of the capital stock can be written as

$$K_t = (1-\delta) K_{t-1} + S\left(\frac{I_t}{K_{t-1}}\right) K_{t-1}, \tag{17}$$

where δ is the depreciation rate of capital.

2.6 Capital Management Firms

A measure-one continuum of competitive firms operating with decreasing returns to scale manage the capital directly held by households in exchange for a fee s_t per unit of capital. These firms have a quadratic cost function, $z\left(K_{s,t}\right) = \frac{\varsigma}{2} K_{s,t}^2$, with $\varsigma > 0$. Their profit maximization implies $s_t = \varsigma K_{s,t}$.

2.7 Policy Authorities

The monetary authority sets the one-period short-term nominal interest rate R_t according to a Taylor-type policy rule:

$$R_t = R_{t-1}^{\rho_R}\left[\bar{R}\left(\frac{\pi_t}{\bar{\pi}}\right)^{\alpha_\pi}\left(\frac{GDP_t}{GDP_{t-1}}\right)^{\alpha_{GDP}}\right]^{1-\rho_R} \tag{18}$$

where ρ_R is the interest rate smoothing parameter, α_π and α_{GDP} determine the responses of the interest rate to GDP growth and inflation deviations from the target $\bar{\pi}$, respectively. $\bar{R}$ denotes the steady state level of the nominal interest rate.[11]

The macroprudential authority sets the capital level requirement, ϕ, and the speed of implementation of the change in the requirement from its initial level.

3. Mapping the Model to the Data

The model is calibrated using EA macroeconomic, banking and financial data for the period 2001:1-2016:4. Time is in quarters. We first set a number of parameters to values commonly used in the literature and then calibrate the remaining parameters simultaneously so as to match key steady state targets.[12]

Pre-set parameters. Following convention, we set the Frisch elasticity of labor supply, η, equal to one, the capital-share parameter of the production function, α, equal to 0.30, and the depreciation rate of

[11] To avoid the counterintuitive impact of the resource costs of default on the measurement of output, we define $GDP_t = C_t + I_t$.

[12] The Online Appendix describes the data series and sources in detail.

physical capital, δ, equal to 0.03 (Table 1). The labor disutility parameter, φ, which only affects the scale of the economy, is normalized to one. The average net markup of intermediate firms, θ, is 20% and the Calvo parameter, ξ, is 0.75 in line with values used in the literature. The bankruptcy cost parameters, μ_f and μ_b, are set equal to a common value of 0.30 for both banks and entrepreneurial firms.[13] Regarding the monetary policy rule, we choose a degree of interest rate inertia, ρ_R, of 0.75, a moderate reaction to the output growth, α_{GDP}, of 0.1, and a reaction to inflation, α_π, of 1.5. We calibrate ψ_K in the adjustment cost function of capital producing firms as in Mendicino et al. (2018).[14] θ_e is set equal to 0.975 as in Gertler and Kiyotaki (2010).

Parameters set with steady state targets. Although the second stage parameters are set jointly, some parameters can be linked to specific targets. The steady state inflation parameter, $\overline{\pi}$, and the discount factor, β, directly pin down the inflation target of 1.77% per annum and the yearly risk free rate of 2.32%. The capital requirement level, ϕ, is set to the reference capital requirement of 8% that characterized Basel I and II.[15] The share of insured deposits in bank debt κ is set to 0.54 in line with the evidence by Demirgüç-Kunt, Kane, and Laeven (2015) for EA countries.

The new entrepreneurs' endowment parameter, χ_e, helps to match the ratio of bank loans to non-financial corporations (NFC loans) over GDP. The new bankers' endowment parameter, χ_b, is used to make the steady state bank expected return on equity, ρ_b, equal to the average cost of equity of EA banks.[16] The parameter of the capital management cost function, ς, is set to match the share of physical capital directly held by savers in the model with an estimate, based on EA flow of funds data, of the proportion of assets of the NFC sector whose financing is not supported by banks. In addition, the survival rate of bankers, θ_b, is used so that the shadow value of bank equity, υ_b, matches the average price-to-book ratio of banks.

We set the standard deviation of the two idiosyncratic shocks, σ_f and σ_b, to match simultaneously the average probability of default of NFCs, the spread between the NFC loan rate and the risk free rate, and the average probability of bank default. As shown in Table 2, we match very closely the eleven targets.

[13]Similar values for μ are used, among others, in Carlstrom and Fuerst (1997), which refers to the evidence in Alderson and Betker (1995) where estimated liquidation costs are as high as 36% of asset value. In Andrade and Kaplan (1998), the estimated financial distress costs for highly levered publicly traded US corporations falls in the range from 10% to 23%. Our choice of 30% is consistent with the large foreclosure, reorganization and liquidation costs found in Djankov et al. (2008).

[14]Calibrating the parameter ψ_K would require the matching of second order moments, i.e. moments that require the specification of the stochastic structure of the model. Since the analysis in this paper abstract from aggregate shocks, we borrow from the calibration in Mendicino et al. (2018) a value for the parameter which is in the middle of the range of values used in the literature.

[15]Basel II featured a total regulatory capital requirement equal to 8% of "risk weighted assets". Thus calibrating ϕ to 8% implies assuming that the loans in the model carry a full risk-weight, as it is the case for loans to unrated corporations under the standardized approach of Basel II and III.

[16]For estimates of the cost of equity faced by euro area banks, see Box 1 at: https://www.ecb.europa.eu/pub/pdf/other/eb201601_article01.en.pdf

4. Long-run Effects of Higher Capital Requirements

We use our quantitative model as a laboratory to explore the real and welfare effects of increases in capital requirements. To build some intuition, we assess the long-run (steady state) effects of setting a time-invariant capital requirement, $\phi_t = \phi$, at levels above the 8% of the baseline calibration; see Figure 1. In the long run, higher capital requirements affect bank funding costs in two partially off-setting ways, producing a non-monotonic effect on the weighted average cost of bank funding. On the one hand, they lower bank defaults and, thus, the cost of bank debt funding. On the other hand, they increase the share of more expensive equity funding, explaining the shape of the average real bank funding cost. Such cost gets transmitted to the cost of borrowing and, through it, to economic activity. When the probability of bank default is high, the first force dominates and credit supply actually expands and, with it, investment and GDP. However, once the probability of bank failure becomes sufficiently close to zero, tighter capital requirements raise the cost of credit and reduce investment and GDP. In contrast, the cost of deposit insurance to taxpayers falls monotonically with ϕ since the reduction in bank leverage unambiguously reduces the probability of bank failure and the costs to the DIS.

The bottom right panel of Figure 1 displays the long-run welfare implications of different capital requirement levels. Household welfare is defined in a recursive form, i.e. $V_t = U(C_t, L_t) + \beta E_t V_{t+1}$. Welfare gains are measured in consumption-equivalent terms with respect to the situation with $\phi = 0.08$. The hump shape in the welfare gains reflects the changing nature of the mentioned trade-offs as capital requirements rise. The capital requirement that maximizes households' long-run welfare is 1.38 pp higher than the calibrated level. This requirement significantly reduces the probability of bank default and, thus, the deposit spread and the social cost of bank default relative to the 8% benchmark. Beyond that point, long-run welfare decreases with ϕ because it tightens the supply of credit excessively.

5. The Transition to Higher Capital Requirements

In this section, we examine the transition to higher capital requirements. We do so by solving non-linearly the equations that describe the perfect foresight equilibrium produced in a number of experiments structured as follows:[17]

In period $t = 1$, we start the economy at the deterministic steady state associated with the initial capital requirement, ϕ_1. For periods $t = 2, 3, 4, ...$ we compute the response of the economy to a (from that point onwards) anticipated gradual increase in ϕ_t up to the new time-invariant long-run level $\bar{\phi}$, with $\phi_t = \lambda\bar{\phi} + (1 - \lambda)\phi_{t-1}$, where $\lambda \in (0, 1]$ is a partial adjustment parameter that shapes the speed of implementation of the increase in the long-run requirement. In the description of the results, the

[17] We solve the system of non-linear equations given by the set of first order conditions and market clearing conditions of the model using the Newton-Raphson algorithm.

implementation horizon (denoted by T) refers to the period at which 99% of the adjustment in ϕ_t is completed.

5.1 The Baseline Experiment

Our baseline experiment explores the effects of a 2.5pp (up to the Basel III level) increase in the capital requirement with an implementation horizon of 8 quarters ($T = 8$). The monetary authority follows a standard Taylor rule. As shown by the solid lines in Figure 2, the immediate fall in bank default risk is accompanied by a reduction in credit supply on impact. Lending spreads rise and lending volumes decline. This depresses investment on impact, before gradually recovering, mainly in response to the accumulation of net worth by entrepreneurs and bankers. Consumption reacts in a partially offsetting manner, partly fed by the lower fiscal costs of bank default. Inflation falls in response to the decline in aggregate demand. Under the Taylor rule, the nominal interest rate falls in response to the fall in inflation and real activity, but does so only gradually due to its smoothing parameter $\rho_R > 0$, which captures realistic inertia in nominal policy rates. This slow reaction makes the real interest rate increase at the beginning of the transition, before falling in a persistent manner. The increase in capital requirements affects the economy very much as a demand shock would. Aggregate economic activity contracts and inflation undershoots the target. The fall in business investment is moderated by the monetary policy driven reduction in real interest rates but overall the contractionary effects of the rise in lending spreads dominate.

Figure 2 also describes the effects of a 1pp increase in ϕ (dashed line). The results evidence significant non-linear effects both in the achieved reduction in bank failure probabilities (proportionally bigger with the smaller rise in ϕ) and in the transitional impact on output and inflation (proportionally smaller with the smaller rise).

To gauge the importance of the transitional costs in welfare terms, Table 3 reports their size for an increase in capital requirements up to the level that maximizes long-run welfare. They are measured as the percentage of the long-run gains eaten up of the transitional costs. This is computed by comparing welfare over the whole transition path with welfare at the new steady state. For the baseline experiment (1.38pp rise in the requirements with $T = 8$ and monetary accommodation based on the Taylor rule), the transitional costs reduce the overall welfare gains by 25% (see Column A). Other results reported on the table correspond to variations of the baseline experiments explored in the rest of this section, which help us quantify the importance of determinants of the balance between the transitional costs and the long-run benefits of changes in capital requirements: the size of the rise, the speed of its implementation, the degree of monetary accommodation over the transition, and the degree of bank riskiness.

5.2 Implementation Horizon

A determinant of the size of the transition costs is the horizon over which the increase in capital requirements comes into force. In Figure 2 we compare the baseline implementation horizon of 8 quarters with one of 20 quarters. A slower phase-in period mitigates the transitional costs (see Column A, Table 3). It gives banks time to raise capital through retained profits thus allowing them to better maintain lending over the transition period. This is particularly important for large capital requirement increases.

5.3 Degree of Monetary Policy Accommodation

Given the presence of nominal rigidities, some of the transitional costs arise through a standard aggregate demand channel and, hence, are affected by the response of monetary policy to the implied real and nominal developments. In Figure 3, we examine the baseline capital requirement increase under different monetary policy regimes: the baseline Taylor rule (black solid line), strict inflation targeting, under which the monetary authority keeps $\pi_t = \pi_{ss}$ at all t, (blue dashed-dotted line) and the Ramsey optimal monetary policy response (red dashed line). The short-run effects of the rise in capital requirements are different across the three regimes and so they are the transitional welfare costs (see columns A-C of Table 3).

Strict inflation targeting completely offsets the distortions due to nominal rigidities and mitigates some of the aggregate demand effects under the baseline Taylor rule. However, this is not enough to avoid the impact of the contraction in credit supply on investment and output, which lasts until bankers manage to accumulate net worth so as to reach the level of bank equity financing associated with the new steady state. In welfare terms, the transitional costs fall only modestly relative to the Taylor rule regime. For the increase in capital requirements that maximizes long-run welfare, the short-run cost are now about 22% of the long-run gains.

The results under the Ramsey optimal monetary policy show that an even larger short term reduction in nominal interest rates manages to optimally reduce the real interest rate, providing an additional boost to consumption while also slightly mitigating the fall in investment. As a result, output declines much less over the transition path albeit at the cost of an initial spike in inflation.

Monetary policy can do little to mitigate the short term credit supply reduction since, on impact, banks' equity funding is limited by the predetermined amount of wealth accumulated by bankers. Yet monetary policy can help to sustain investment by increasing entrepreneurial net worth: the aggressive loosening of monetary policy at the beginning of the transition helps the entrepreneurial sector by increasing the value of its physical capital holdings, which boosts its net worth. The smaller drop in investment together with the larger consumption increase reduce the drop of output below its long term level. For the increase in capital requirements that maximizes long-run welfare, the Ramsey optimal monetary policy response reduces the transitional welfare costs to 17% of the long-run gains.

5.4 Impact of the Effective Lower Bound

In Figure 4 we compare the effects of the 2.5pp increase in capital requirements implemented over 8 quarters under the baseline (unconstrained) Taylor rule (black solid line) with the case in which the monetary policy response is constrained by an ELB (black dashed line).[18] The transition costs increase because monetary policy cannot be so accommodative: inflation declines by more and this increases short term real interest rates further than in the baseline experiment. Consumption fails to support aggregate demand and investment falls by more than in the baseline case, producing a much larger fall in GDP. Hence, when monetary policy is constrained by the ELB, the short-run negative effects of a rise in capital requirements on real activity can be quite sizable. As reported in Column D of Table 3, the size of the transition costs in welfare terms greatly depends on the proximity to the ELB. They are as large as 40% of the long-run welfare gains in the case of the ELB is 5 bps below the initial short term interest rate.[19]

5.5 Importance of Bank Risk

Making banks safer is a key reason for increasing capital requirements. Bank risk determines the size of the benefits from higher capital requirements so varying it modifies both the long-run gains and the welfare trade-offs associated with the transition to higher capital requirements.

Higher capital requirements have two opposing effects on banks' cost of funding. Other things equal, a higher share of expensive equity increases banks' weighted average cost of funds. However, making banks safer lowers the cost of bank debt funding, producing the opposite effect on the weighted average cost of funds. When the risk of bank failure is high, the reduction coming from the lower cost of deposit funding dominates and the benefits of higher capital requirements are larger. These trade-offs are also visible during the transition.

Figure 4 compares the transition under the baseline calibration (with and without an ELB, black lines) with the transition in an economy that features higher banks' idiosyncratic default risk (with and without an ELB, red lines). Specifically, we consider a dispersion of the idiosyncratic shocks to banks' loan portfolio returns, σ_b, such that before the increase in capital requirements takes place the probability of bank default is about 3.5% (instead of the 0.7% of the baseline calibration).[20] The figure shows that in the economy with a riskier banking sector not only the long-run benefits are larger, but also the short-run costs are smaller. The latter effect can be explained partly because the immediate gains from the risk reduction are bigger and partly because in anticipation of the larger long term gains the forward looking

[18]For the purposes of this analysis, the ELB is assumed to be 15 bps below the baseline short term interest rate at $t = 1$. This is consistent with the average EONIA rate of 15.9 bps observed in the EA during the initial period of implementation of Basel III (2012Q1-2013Q4).

[19]The model doesn't solve for ELB less than 5 bps below the baseline short term interest rate.

[20]At the beginning of the implementation of Basel III, Moody's expected default frequencies (EDF) for European financial institutions was between 3% and 4%. Achieving this in the model involves increasing σ_b by 20% relative to the baseline calibration.

households increase consumption by more, mitigating the drop in demand due to the shortage of credit over the transition path.

As reported in Column E of Table 3, in an economy with riskier banks, the transitional costs amount to 19% of the corresponding long-run welfare gains. Column E of the same Table documents that when the economy features larger bank risk, long-run welfare is maximized by rising the capital requirements by more than in the baseline model (2.19pp instead of 1.38pp).

6. Optimal Capital Requirement Increase

We now assess the optimality of capital requirement increases taking into account their effects both in the long run and over the transition to the higher level. The results in previous sections suggest that the transitional costs can be quite substantial in some circumstances. The presence of these transitional costs reduces the optimal increase in the requirements with respect to the optimal long-run level. The reason is the same as for the optimality of deviating from the Golden Rule in the neoclassical growth model, and it relies on the fact that impatient agents trade off the short term costs against the long-run gains.[21]

We compare the net welfare gains, in percentage points of permanent consumption, from moving to alternative capital requirement levels starting from the 8% baseline level.[22] The results depend on the extent to which monetary policy is able to offset the negative aggregate demand consequences of the capital increase, on the riskiness of the banking sector, and on the length of the implementation horizon. Figure 5 and Table 4 report the results for a rich variety of scenarios regarding these three dimensions. As a reference, the capital requirement increase that maximize long-run welfare and the corresponding long-run welfare gains (excluding transitional costs) are reported in Figure 5 (red solid lines) and Table 4 (Column F).

Baseline case. The left panel of Figure 5 shows the welfare gains of moving to higher capital requirements under the baseline level of bank riskiness. In addition to the long-run welfare gains (red solid line), it represents the welfare effects taking into account the transition under alternative assumptions regarding the monetary policy response. In all cases the implementation horizon is of 8 quarters. Once we include the transitional costs, the welfare curves shift downward, revealing the overestimation of the welfare gains that would result from neglecting such costs.

Degree of monetary policy accommodation. When monetary policy follows a standard Taylor rule (Column A of Table 4), the optimal capital requirement increase is of 1.20pp. A slower implementation

[21]To check this, we have computed for different values of households' discount factor β the long-run welfare gains and the size of the transitional costs associated with the 1.38 pp rise in capital requirements that maximizes long-run welfare in the baseline economy. For the baseline value of the discount factor ($\beta = 0.994$), these costs are 25% of the long-run gain. For $\beta = 0.998$, they fall to 10%, and for $\beta = 0.9999$ they are close to zero.

[22]We search over a grid with capital requirement increases from 0pp to 3pp and a step of 0.005.

horizon delivers a higher optimal increase in capital requirements and somewhat larger welfare gains. In the case of strict inflation targeting (Column B) the monetary authority pursues the goal of full price stability and strongly reacts to any change in inflation. This reduces the transitional costs and allows the macroprudential authority to implement a larger increase in capital requirements. As a result, the net welfare benefits from the increase in capital requirements are also larger. However, as expected, the optimal increase in capital requirements and the welfare gains are largest under the Ramsey optimal monetary policy response (Column C). Its stronger reaction at the beginning of the transition helps further relax the trade-off between short-run costs and long-run benefits.

Effective lower bound. In a proximity of the ELB, the ability of monetary policy to mitigate the transitional effects of the capital increase is limited.[23] The dashed curves in Figure 5 highlight that the closer is the ELB the larger are the differences with respect to the long-run welfare curve. Being closer to the ELB reduces both the optimal capital level and the welfare gains implied by a capital requirement increase (see also Column D of Table 4). A slower implementation horizon it is particularly useful in this case, as it reduces the probability of hitting the ELB.

Higher bank risk. In the previous section, we have shown that the long-run benefits of higher capital requirements are larger and the transitional costs are smaller when bank risk is higher. The comparison of the left and right panels of Figure 5 (and the results in Column E of Table 4) confirm that the optimal increase in the capital requirements and the welfare gains associated to it are sizably higher in an economy with higher bank risk. As in the baseline case, a Ramsey optimal monetary policy response helps mitigate the transition costs (relative to the Taylor rule), reducing the short- versus long-run trade-off. This allows the macroprudential authority to reach higher welfare gains by implementing a larger capital requirement increase.

The right panel of Figure 5 shows the implications of being in a proximity to the ELB when banks are riskier. This case resembles the situation of the EA economy during the recent financial crisis. The optimal capital requirement is lower in the proximity of the ELB but it remains higher than under the baseline bank riskiness.

7. Conclusions

This paper provides new results on the normative and positive implications of capital requirements by considering not only the long-run effects but also the transitional impact of tightening capital regulation. First, it shows that the transition to higher capital requirements entails short-term output costs due to the reduction in credit and aggregate demand on impact. Second, it finds that the size of these short term costs crucially depend on the conduct of monetary policy (including the potential constraint associated

[23] As in the experiments reported in Section 5., monetary policy is assumed to follow the Taylor rule except when constrained by the ELB.

with an ELB), the speed of implementation of the increase in capital requirements and the riskiness of the banking sector.

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Table 1: Model parameters

Preset parameters					
Disutility of labor	φ	1	Banks bankruptcy cost	μ_b	0.3
Frisch elasticity of labor	η	1	Capital adjustment cost parameter	ψ_k	4.567
Capital share in production	α	0.3	Price elasticity of demand	θ	0.2
Depreciation rate of capital	δ	0.03	Calvo probability	ξ	0.75
Population of entrepreneurs	x_e	1	Smoothing parameter (Taylor rule)	ρ_R	0.75
NFC bankruptcy cost	μ_f	0.3	Inflation response (Taylor rule)	α_π	1.5
Survival rate of entrepreneurs	θ_e	0.975	Output growth response (Taylor rule)	α_{GDP}	0.1
Population of bankers	x_b	1			
Calibrated parameters					
Discount factor of consumers	β	0.994	STD iid risk for banks	σ_b	0.029
Capital requirement for banks	ϕ	0.08	Survival rate of bankers	θ_b	0.873
Share of insured deposits	κ	0.54	Transfer from HH to entrepreneurs	χ_e	0.001
Steady-state inflation	$\overline{\pi}$	1.004	Transfer from HH to bankers	χ_b	0.859
STD iid risk for entrepreneurs	σ_f	0.298	Capital management cost	ς	0.006

Table 2: Model fit

Targets	**Definition**	**Data**	**Model**
Real risk-free rate	$(\beta^{-1} - 1) \times 400$	2.32	2.32
Inflation	$(\overline{\pi} - 1) \times 400$	1.77	1.77
Capital requirements	ϕ	0.08	0.08
Share of insured deposits	κ	0.54	0.54
NFCs' default	$F_f(\overline{\omega}_f) \times 400$	2.646	2.556
NFC loans to GDP	b_f/GDP	1.897	1.893
Spread NFC loans	$(R^f - R) \times 400$	1.244	1.295
Banks' default	$F_b(\overline{\omega}_b) \times 400$	0.665	0.665
Real equity return of banks	$(\rho_b - 1) \times 400$	7.066	6.937
Banks price to book ratio	v_b	1.148	1.148
Capital share of households	K_s/K	0.22	0.219

Table 3: Transitional costs as percent of long-run gains

Implementation Horizon	**(A)** Taylor Rule	**(B)** Inflation Targeting	**(C)** Optimal Ramsey	**(D)** ELB (-10 bp)	(-5 bp)	**(E)** High Bank Risk
8Q	24.85%	22.48%	16.82%	25.76%	39.09%	19.22%
40Q	22.73%	20.96%	13.71%	22.73%	26.16	18.10%

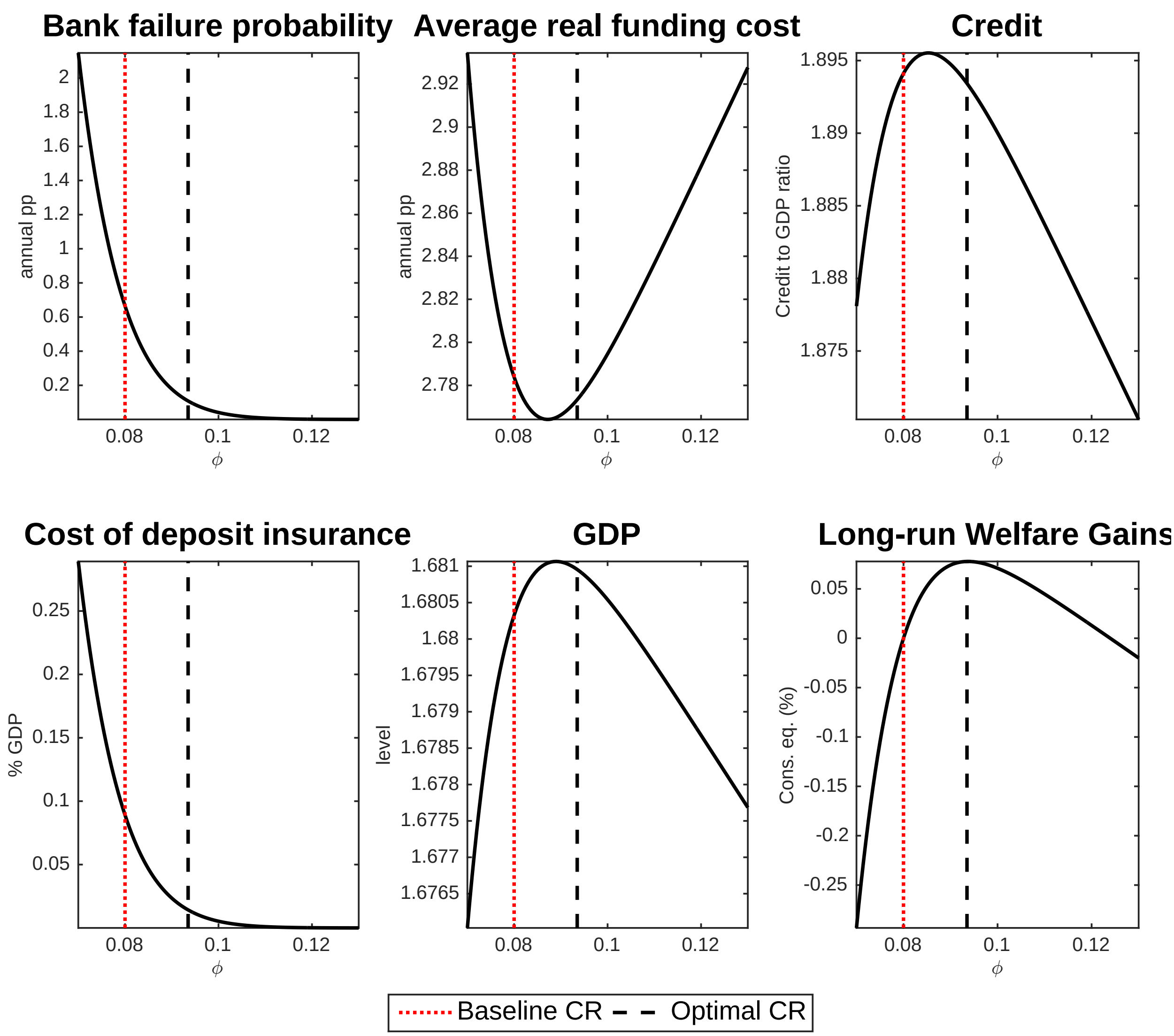
The transitional costs are computed as the percentage difference in welfare gains of increasing capital requirements to the long-run optimal level with and without taking into account the transition in alternative scenarios regarding monetary policy and bank risk: (A) Taylor-rule, (B) strict inflation targeting, (C) optimal Ramsey policy, (D) effective lower bound 10 bps and 5 bps below the baseline policy rate, and (E) higher bank risk. The optimal capital ratio increase without transitional cost is 1.38pp for cases A-D and 2.19pp for case E.

Table 4: Optimal capital requirement increases

Implementation Horizon		Including Transition (A) Taylor Rule	(B) Inflation Targeting	(C) Ramsey Optimal	(D) ELB (-10 bp)	(D) ELB (-5 bp)	(E) High Risk	Long Run (F) Baseline Risk	(F) High Risk
8Q	pp increase	1.20	1.23	1.29	1.17	0.84	1.95	1.38	2.19
	welfare gains %	0.0588	0.0605	0.0647	0.0586	0.0529	0.1930	0.0778	0.2383
40Q	pp increase	1.26	1.29	1.38	1.26	0.87	2.07	1.38	2.19
	welfare gains %	0.0601	0.0615	0.0672	0.0601	0.0558	0.1952	0.0778	0.2383

Welfare maximizing capital requirement (CR) increases are in percentage points. Welfare gains are computed as the percentage point equivalent increase in steady-state consumption. Optimal capital requirement increases accounting for transition costs are computed in alternative scenarios regarding monetary policy and bank risk: (A) Taylor-rule, (B) strict inflation targeting, (C) optimal Ramsey policy, (D) an effective lower bound 10 bps and 5 bps below the baseline policy rate, and (E) higher bank risk. (F) indicates the CR increase that maximizes long-run welfare in the baseline case and with higher bank risk.

Figure 1: Long-run impact of the capital requirement level (CR)



NOTE: Steady state of key variables as function of the level of the capital requirements, while keeping the other parameters equal to their calibrated value. The probability of bank default and the average funding cost are in annualized percentage terms, the deposit insurance cost is measured as percentage of GDP, welfare gains are computed as the percentage point equivalent increase in steady-state consumption.

Figure 2: Transitional effects of of the capital requirement increase: speed of implementation

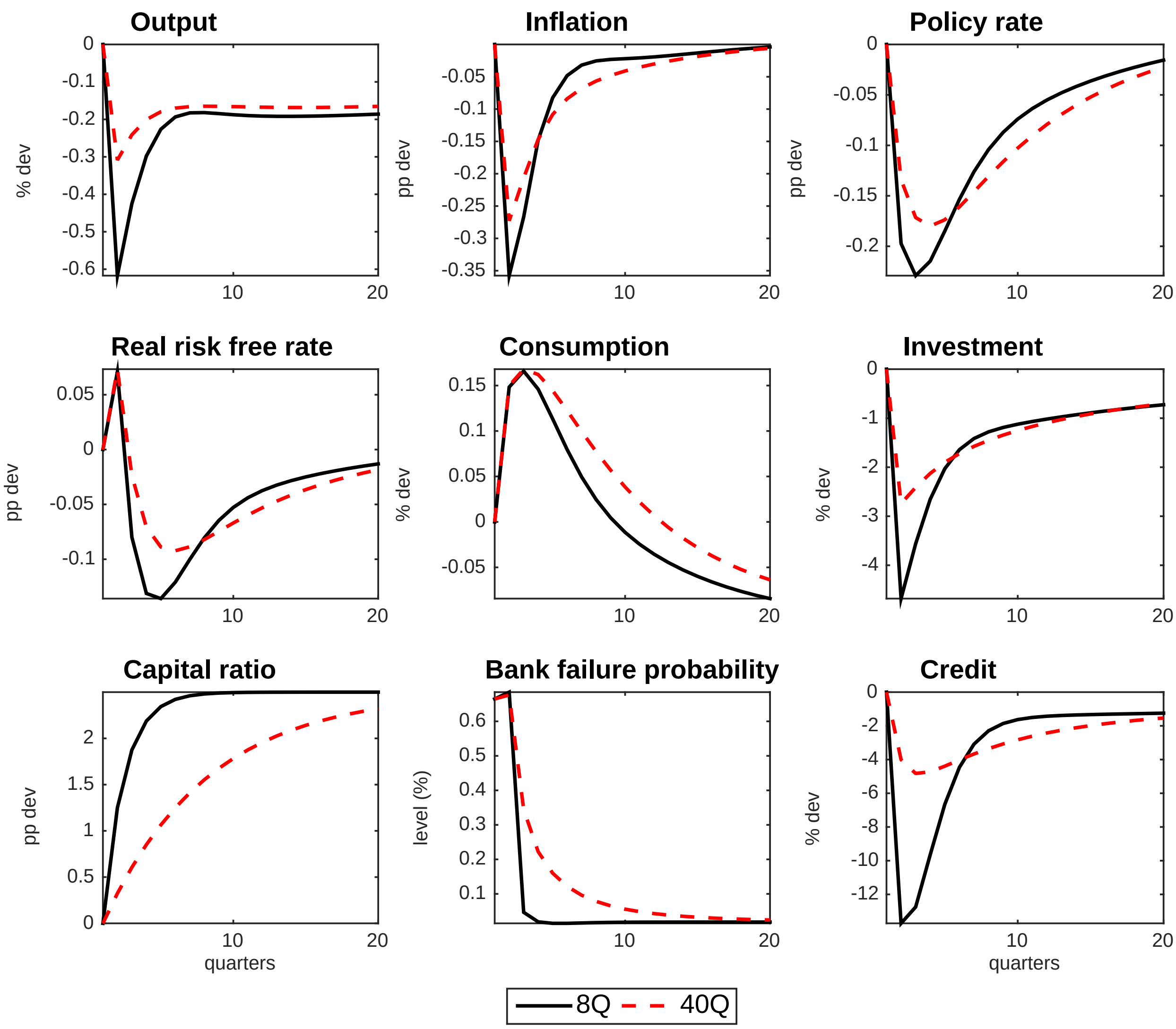


Figure 3: Transitional effects of of the capital requirement increase: monetary policy accommodation

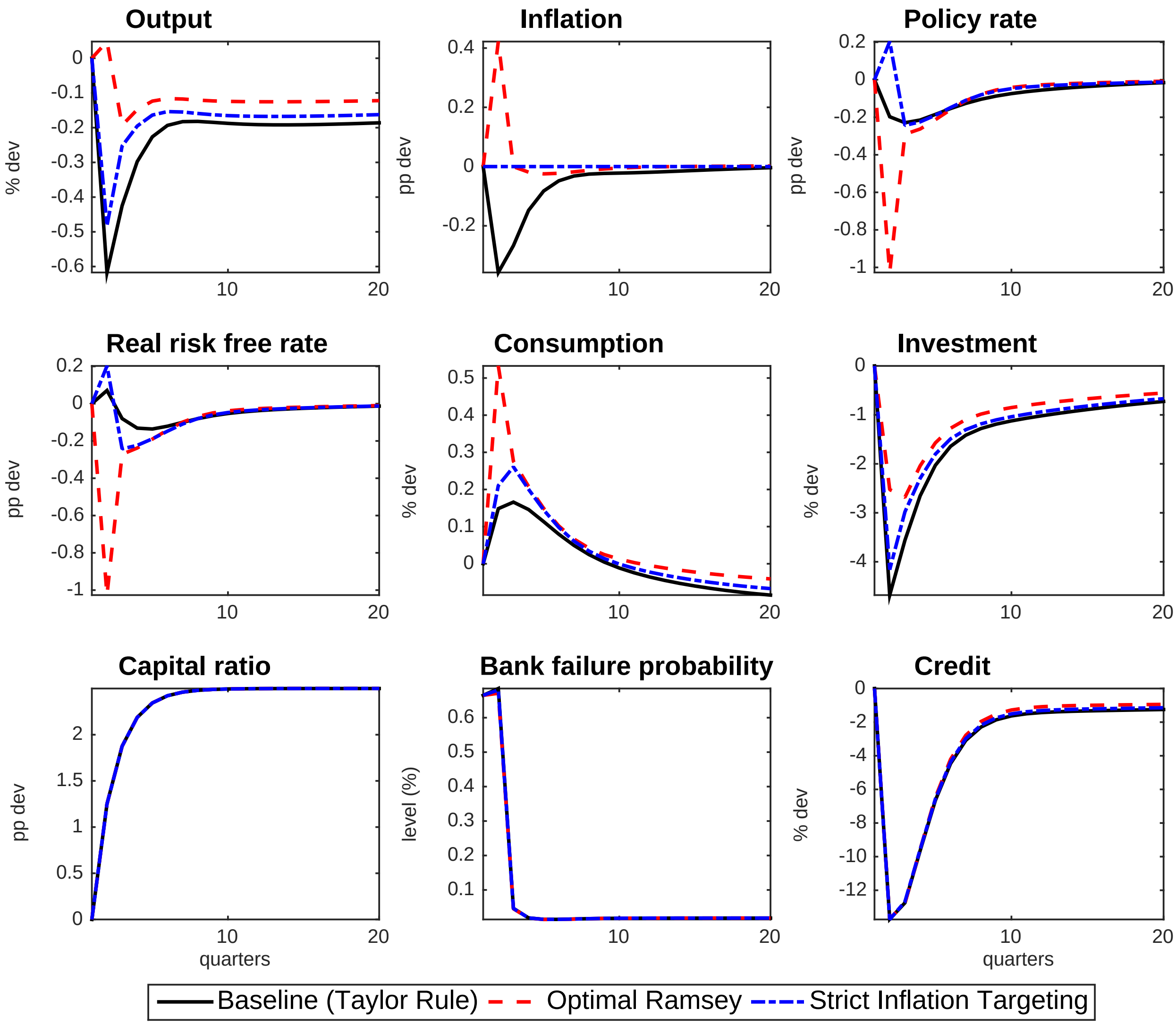


Figure 4: Transitional effects of of the capital requirement increase: with and without an ELB

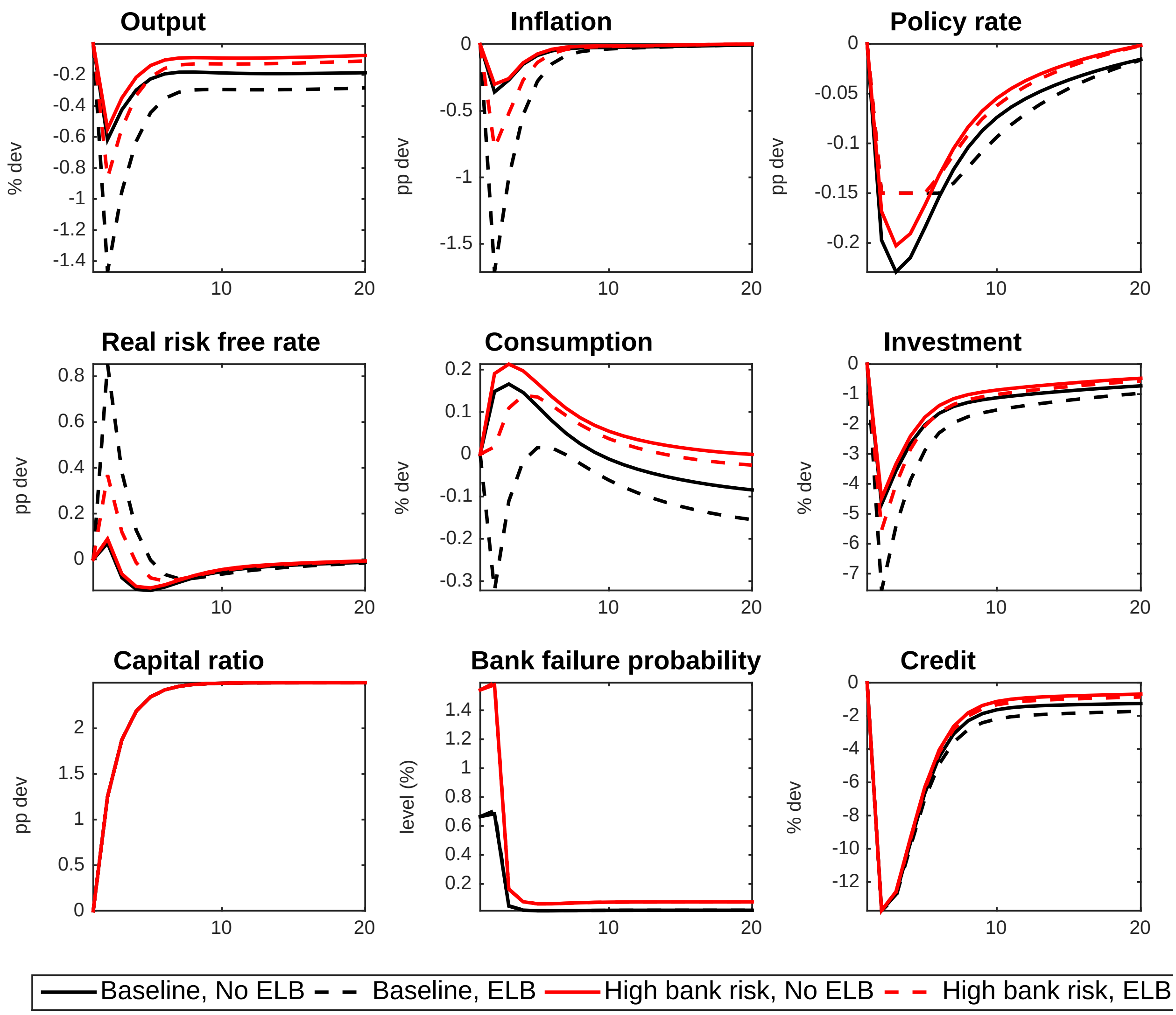
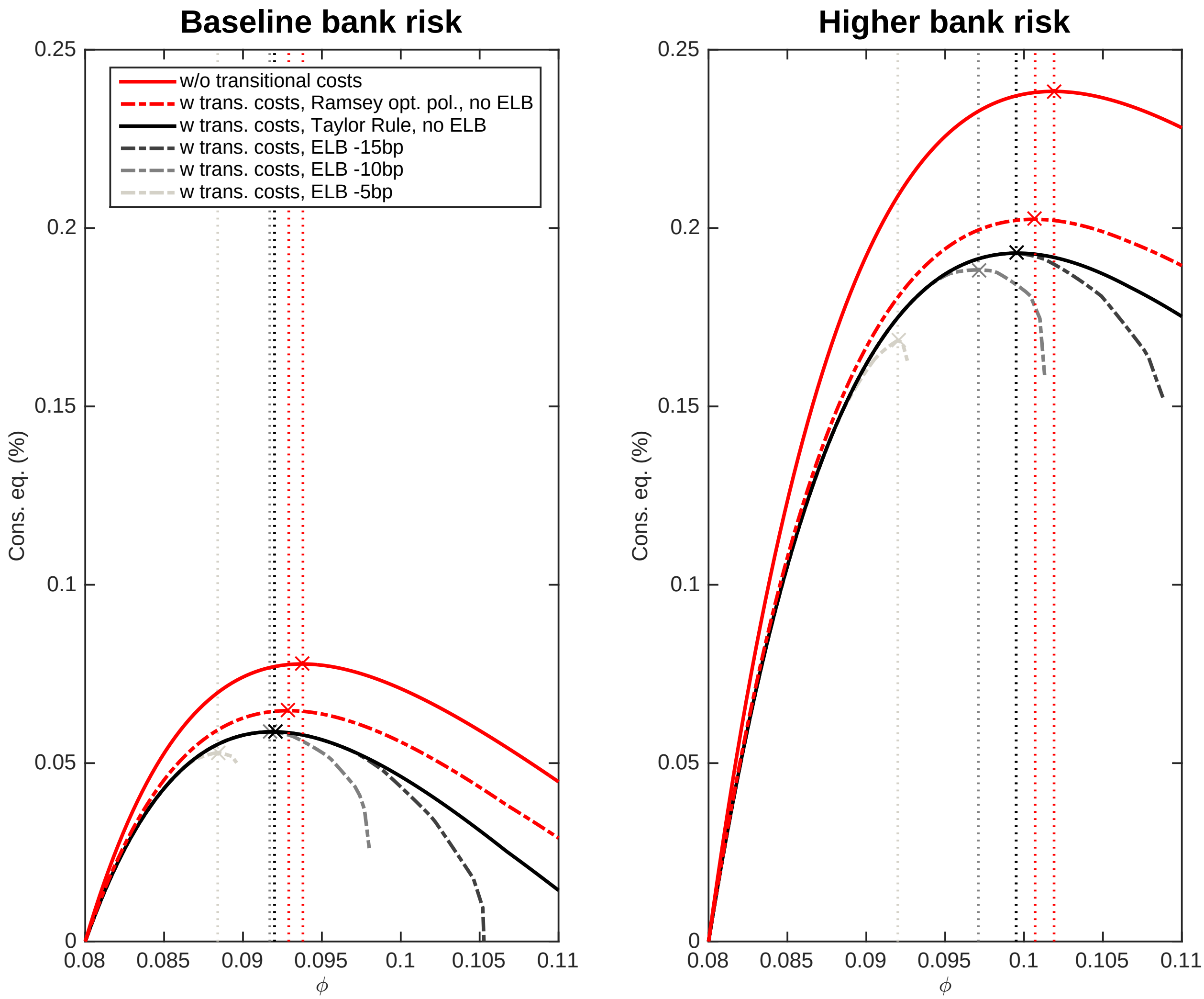


Figure 5: Welfare effects of capital requirements with and without transitional costs



NOTE: Consumption equivalent welfare effects of changes in the level of capital requirements, with respect to the baseline level of 8%. Other model parameters equal their calibrated value. Stars indicate the optimal capital requirement levels.

Online Appendix

A Model Details

Market Clearing Conditions
Aggregate supply:

$$Y_t = \frac{L_t^{1-\alpha} K_{t-1}^{\alpha}}{\Delta_t}, \tag{19}$$

where $\Delta_t = \int_0^1 \left(\frac{p_t(i)}{P_t} \right)^{-\frac{1+\theta}{\theta}} di$.
Equilibrium in the market for physical capital:

$$K_t = K_{s,t} + K_{f,t}. \tag{20}$$

Summary of balance sheet constraints and market clearing condition for banks:

$$B_{f,t} = E_{b,t} + D_t. \tag{21}$$

Equilibrium in the market for entreprenurial equity:

$$A_t = N_{e,t}.$$

Equilibrium in the market for bank equity:

$$E_{b,t} = N_{b,t}.$$

Definitions
The expected loss rate on bank deposits due to bank default is

$$\Omega_t = \frac{\left[\omega_{b,t} - \Gamma_b(\overline{\omega}_{b,t}) + \mu_b G_b(\overline{\omega}_{b,t})\right] \widetilde{R}_t^b B_{f,t-1}}{D_{t-1}}.$$

The losses covered by the DIS following bank default are $\kappa \Omega_t D_{t-1}$, so the lump-sum taxes changed on households to finance the DIS are:

$$T_t = \kappa \Omega_t D_{t-1}. \tag{22}$$

The rest of the losses due to bank default are directly assumed by the depositors (as a lower than promised return on the uninsured fraction of their deposit portfolio), so the nominal effective return on deposits is $\widetilde{R}_t^d = R_{t-1}^d - (1-\kappa)\Omega_t$ as specified in the main text.
The nominal rate of return on entrepreneurial equity can be written as

$$\rho_{f,t} = \frac{\left(1 - \Gamma_f\left(\overline{\omega}_{f,t}\right)\right)\left[P_t r_{k,t} + (1-\delta)\, Q_t\right] K_{f,t-1}}{A_{t-1}}$$

Similarly, the nominal rate of return on bank equity can be expressed as

$$\rho_{b,t} = \frac{\left(1 - \Gamma_b\left(\overline{\omega}_{b,t}\right)\right) \widetilde{R}_t^b B_{f,t-1}}{E_{b,t-1}} = \frac{\left(1 - \Gamma_b\left(\overline{\omega}_{b,t}\right)\right) \widetilde{R}_t^b}{\phi_t},$$

where, using (9),

$$\widetilde{R}_t^b = \frac{\left(\Gamma_f\left(\overline{\omega}_{f,t}\right) - \mu_f G_f\left(\overline{\omega}_{f,t}\right)\right)\left(P_t r_{k,t} + (1-\delta)\, Q_t\right) K_{f,t-1}}{B_{f,t-1}}.$$

The bank default rate (and ex ante probability of bank failure) is given by:

$$\Psi_{b,t} = F_b(\overline{\omega}_{b,t}). \tag{23}$$

We define the write-off rate (write-offs/loans) on loans to entrepreneurs that the model generates, $\Upsilon_{f,t}$, as the product of the fraction of defaulted entrepreneurial loans, $F_f\left(\overline{\omega}_{f,t}\right)$, and the average losses per unit of lending, which can be found from our prior derivations:

$$\begin{aligned}\Upsilon_{f,t} &= F_f\left(\overline{\omega}_{f,t}\right)\left[\frac{B_{f,t-1} - \frac{(1-\mu_f)}{F_f(\overline{\omega}_{f,t})}\left(\int_0^{\overline{\omega}_{f,t}} \omega f_f\left(\omega\right) d\omega\right) R_t^K Q_{t-1} K_{f,t-1}}{B_{f,t-1}}\right] \\ &= F_f\left(\overline{\omega}_{f,t}\right) - (1-\mu_f) G_f(\overline{\omega}_{f,t}) R_t^K \frac{Q_{t-1} K_{f,t-1}}{B_{f,t-1}}. \end{aligned} \tag{24}$$

B Data used in the calibration

- Gross Domestic Product: Gross domestic product at market price, Chain linked volumes, reference year 2005, Euro. Source: ESA - ESA95 National Accounts, Macroeconomic Statistics (S/MAC), European Central Bank.

- GDP Deflator: Gross domestic product at market price, Deflator, National currency, Working day and seasonally adjusted, Index. Source: ESA - ESA95 National Accounts, Macroeconomic Statistics (S/MAC), European Central Bank.

- Business Loans: Outstanding amounts at the end of the period (stocks), MFIs excluding ESCB reporting sector - Loans, Total maturity, All currencies combined - Euro area (changing composition) counterpart, Non-Financial corporations (S.11) sector, denominated in Euro. Source: MFI Balance Sheet Items Statistics (BSI Statistics), Monetary and Financial Statistics (S/MFS), European Central Bank.[24]

- Households Loans: Outstanding amounts at the end of the period (stocks), MFIs excluding ESCB reporting sector - Loans, Total maturity, All currencies combined - Euro area (changing composition) counterpart, Households and non-profit institutions serving households (S.14 & S.15) sector, denominated in Euro. Source: MFI Balance Sheet Items Statistics (BSI Statistics), Monetary and Financial Statistics (S/MFS), European Central Bank.

- Write-offs: Other adjustments, MFIs excluding ESCB reporting sector - Loans, Total maturity, All currencies combined - Euro area (changing composition) counterpart, denominated in Euro, as percentage of total outstanding loans for the same sector. Source: MFI Balance Sheet Items Statistics (BSI Statistics), Monetary and Financial Statistics (S/MFS), European Central Bank.

[24]All monetary financial institutions in the EA are legally obliged to report data from their business and accounting systems to the National Central Banks of the member states where they reside. These in turn report national aggregates to the ECB. The census of MFIs in the euro area (list of MFIs) is published by the ECB (see http://www.ecb.int/stats/money/mfi/list/html/index.en.html).

- Housing Investment: Gross fixed capital formation: housing, Current prices - Euro, divided by the Gross domestic product at market price, Deflator. Source: ESA - ESA95 National Accounts, Macroeconomic Statistics (S/MAC), European Central Bank.

- Housing Wealth: Household housing wealth (net) - Reporting institutional sector Households, non-profit institutions serving households - Closing balance sheet - counterpart area World (all entities), counterpart institutional sector Total economy including Rest of the World (all sectors) - Debit (uses/assets) - Unspecified consolidation status, Current prices - Euro. Source: IEAQ - Quarterly Euro Area Accounts, Euro Area Accounts and Economics (S/EAE), ECB and Eurostat.

- Bank Equity Return: Median Return on Average Equity (ROAE), 100 Largest Banks, Euro Area. Source: Bankscope.

- Spreads between the composite interest rate on loans and the composite risk free rate is computed in two steps. Firstly, we compute the composite loan interest rate as the weighted average of interest rates at each maturity range (for housing loans: up to 1 year, 1-5 years, 5-10 years, over 10 years; for commercial loans: up to 1 year, 1-5 years, over 5 years). Secondly, we compute corresponding composite risk free rates that take into account the maturity breakdown of loans. The maturity-adjusted risk-free rate is the weighted average (with the same weights as in case of composite loan interest rate) of the following risk-free rates chosen for maturity ranges:
  - 3 month EURIBOR (up to 1 year)
  - German Bund 3 year yield (1-5 years)
  - German Bund 10 year yield (over 5 years for commercial loans)
  - German Bund 7 year yield (5-10 years for housing loans)
  - German Bund 20 year yield (over 10 years for housing loans).

- Borrowers Fraction: Share of households being indebted, as of total households. Source: Household Finance and Consumption Survey (HFCS), 2010.

- Borrowers Housing Wealth: value household's main residence + other real estate - other real estate used for business activities (da1110 + da1120 - da1121), Share of indebted households, as of total households. Source: HFCS, 2010.

- Fraction of capital held by households: We set our calibration target for this variable by identifying it with the proportion of assets of the NFC sector whose financing is not supported by banks. To compute this proportion we use data from the EA sectoral financial accounts, which include balance sheet information for the NFC sector (Table 3.2) and a breakdown of bank loans by counterparty sector (Tables 4.1.2 and 4.1.3). From the raw NFC balance sheet data, we first produce a "net" balance sheet in which, in order to remove the effects of the cross-holdings of corporate liabilities, different types of corporate liabilities that appear as assets of the NFC sector get subtracted from the corresponding "gross" liabilities of the corporate sector. Next we construct a measure of leverage of the NFC sector

$$LR = \frac{\text{NFC Net Debt Securities} + \text{NFC Net Loans} + \text{NFC Net Insurance Guarantees}}{\text{NFC Net Assets}}$$

and a measure of the bank funding received by the NFC sector

$$BF = \frac{\text{MFI Loans to NFCs}}{\text{NFC Net Assets}}.$$

From these definitions, the fraction of debt funding to the NFC sector not coming from banks can be found as $(LR - BF)/LR$. Finally, to estimate the fraction of NFC assets whose financing is not supported by banks, we simply assume that the financing of NFC assets not supported by banks follows the same split of equity and debt funding as the financing of NFC assets supported by banks, in which case the proportion of physical capital in the model not funded by banks, K_s/K, should just be equal to $(LR - BF)/LR$. This explains the target value of K_s/K in Table 1.

- Price to book ratio of banks. Source: Datastream