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Optimal Dynamic Capital Requirements

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Abstract

We characterize welfare maximizing capital requirement policies in a macroeconomic model with household, firm and bank defaults calibrated to Euro Area data. We optimize on the level of the capital requirements applied to each loan class and their sensitivity to changes in default risk. We find that getting the level right (so that bank failure risk remains small) is of foremost importance, while the optimal sensitivity to default risk is positive but typically smaller than under Basel IRB formulas. When starting from low levels, initially both savers and borrowers benefit from higher capital requirements. At higher levels, only savers are in favour of tighter and more time-varying capital charges.

JEL Codes: E3, E44, G01, G21.

Keywords: Macroprudential policy, bank fragility, capital requirements, financial frictions, default risk.

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1. Introduction

The regulation of bank capital has become one of the most important policy issues of the post-financial crisis era. A consensus has emerged on the need to look at financial regulation from a macroprudential perspective. In parallel, significant research effort has been devoted to develop general equilibrium models that help understand the links between financial intermediation and the macroeconomy and, eventually, the channels of transmission of macroprudential policies.

This paper significantly extends and improves the model developed in Clerc et al. (2015), calibrates it to Euro Area data, and examines its implications for the optimal calibration of Basel-type dynamic capital requirement rules.[1] The analysis addresses upfront the potential conflicting interests of savers and borrowers regarding the adequate level of capital funding demandable to each class of loans and its time variation in response to changes in the default risk of the corresponding loans.[2]

The analysis differs from that in Clerc et al. (2015) in four important dimensions. First, we improve the model. To simplify the welfare analysis, we integrate bank owners and entrepreneurs into the dynasty of saving households. To examine the (un)importance of bailouts for our welfare results, we distinguish explicitly between insured and uninsured bank debt. And, to add realism and match the data better, we allow for the coexistence of bank funded and non-bank funded investment.

Second, we consider capital requirements policies that, as those associated with Basel II and III, make capital charges associated with the different types of exposures (mortgages, corporate loans) increasing in their anticipated default risk.

Third, we calibrate the model to match first and second moments of key Euro Area mac-

[1] Much of the literature on macroprudential policy relies on chacterizing social planner allocations in highly stylized models (e.g. Bianchi and Mendoza, 2011; Gersbach and Rochet, 2012; Jeanne and Korinek, 2013; Brunnermeier and Sannikov, 2014). The cost of the simplicity required for such analysis is that the policy tools considered (usually Pigouvian taxes) are not the ones used in practice. The focus on Basel-type regulatory tools links our work to the partial equilibrium analysis of the procyclical effects of capital requirements in, for example, Kashyap and Stein (2004) and Repullo and Suarez (2013).

[2] Most papers in the macroprudential policy literature abstract from heterogeneity because, under incomplete markets, there is no commonly accepted criterion for the assignment of welfare weights to the different agents. Notable exceptions are Goodhart et al (2013) and Lambertini, Mendicino and Punzi (2013) who, in discussing instruments such as loan-to-value (LTV) limits, show that macroprudential policy affects heterogeneous agents differently. Angelini, Neri and Panetta (2014) also examine macroprudential policy rules in a model with different types of agents, however they restrict their analysis to stabilization policies, rather than fully exploring the welfare implications of capital regulation.

roeconomic and banking data. Differently from related attempts (e.g. Christiano, Motto and Rostagno, 2008; Gerali et al, 2010), in addition to key macroeconomic variables, we match the moments of banking variables such as capital ratios, write-offs, loan spreads, loan-to-GDP ratios, etc. Importantly, we calibrate the capital requirements on mortgages and corporate loans in a way consistent with the internal ratings based (IRB) approach of Basel regulation, making their level related to the probability of default (PD) of the corresponding loans.

Fourth, we explore the welfare implications of capital policy rules in the fully stochastic economy. We solve the model using second order perturbation methods in order to capture the impact of aggregate uncertainty on macroeconomic aggregates, including default probabilities, and welfare. This allows us to examine the importance of different shocks in driving the welfare gains or losses of savers and borrowers.

In our setup bank fragility is key to the operation of bank-related transmission channels. Banks intermediate funds from saving households to borrowing households and entrepreneurs, and all borrowers, including banks, can default on their lenders. The model features three key distortions. First, banks operate under limited liability and safety net guarantees in the form of partially insured deposits. Second, uninsured bank debt is not priced according to the individual risk profile of each bank (which is treated as unobservable to the savers) but according to the expected economy-wide bank failure risk. Thus, individual banks have an incentive to excessively lever up and to relax their lending standards.[3] Last, all external financing is subject to costly state verification (CVS) frictions like in Bernake, Gertler and Gilchrist (1999) and takes the form of uncontingent debt.[4] Like in that tradition, inside equity financing is limited by the endogenously accumulated net worth of the borrowing households and the owners of the borrowing firms and banks.

In this context, optimal bank capital regulation trades off the distortions and deadweight losses from excessive bank fragility against the scarcity of bankers' net worth, which makes the

[3] When bank debtholders are unsophisticated and/or dispersed (Dewatripont and Tirole, 1994) or insured (Kareken and Wallace, 1978), they lack capability and/or incentives to monitor the banks and banks' leverage and risk taking need to be regulated.

[4] As in Gale and Hellwig (1985), CSV provides a rationale for the use of debt financing CSV can also be used to justify the existence of intermediaries who, by acting as delegated monitors à la Diamond (1984), economize on the potential duplication of verification costs when funding a borrower requires the funds of several savers (Williamson, 1987; Krasa and Villamil, 1992). Despite the presence of aggregate uncertainty, we assume debt to be uncontingent, mainly for realism and also because of the difficulty to optimally determine the allocation of aggregate risk when the default of both intermediaries and their borrowers entails deadweight losses.

imposition of higher capital requirements potentially costly for economic activity.

Our analysis yields several interesting policy conclusions. Most importantly, we find that, regardless of the Pareto weights given to saving and borrowing households, it is always optimal to impose capital requirements that keep bank defaults, and consequently the strength of bank-related amplification channels and their associated deadweight losses, sufficiently low.[5]

Further, we find that increasing capital requirements from their baseline levels is Pareto-improving up to a point and redistributive after that. Beyond a certain level, savers continue benefiting from the reduction in financial fragility, while borrowers start to lose. Savers gain from the reduction in the tax burden of deposit insurance and the higher profits associated with their holdings of bank equity. Borrowing households also benefit from the lower costs of bank default, but lose from the higher loan interest rates. Once bank default is close to zero, this second effect dominates.

Our analysis points to the optimality of making the capital requirements on corporate loans and, especially, mortgages higher in level than under Basel II, but less responsive to (time) variation in default risk than what a "point-in-time" estimate of the inputs of its IRB formula would imply.[6] While a high PD-sensitivity may help keep banks safe (and benefit savers), it amplifies the cyclical volatility in lending standards and destabilizes borrowers' consumption.[7] All in all, we interpret our results as supportive of regulators' attempts to reinforce banks' capitalization while ameliorating procyclicality.[8]

Our paper is part of a growing literature which incorporates banking in otherwise standard DSGE models. Our analysis differs from studies such as Curdia and Woodford (2010), Gertler and Kiyotaki (2010), Gerali et al. (2010), Meh and Moran (2010), and Gertler, Kiyotaki and Queralto (2012) in that we provide a normative assessment of capital regulation. The focus on

[5]Our results confirm the findings in Forlati and Lambertini (2011) and Christiano, Motto and Rostagno (2014) that aggregate risk shocks are important drivers of economic fluctuations. In our setup risk shocks are the source of important welfare losses due to their impact on banking instability. The importance of financial shocks more generally has also been emphasized by Jermann and Quadrini (2012), Liu, Wang and Zha (2013), and Iacoviello (2015).

[6]Basel II and III recommend banks to feed the IRB formulas with stable "through-the-cycle" (instead of point-in-time) estimates of the PDs. However, the practical implementation of a through-the-cycle approach is challenging (conceptually and in terms of accountability) and many banks follow a point-in-time approach.

[7]In any case, time-varying components of the optimal capital requirement rules have a lower (second order) effect on welfare than the (first order) level components.

[8]Additionally to further encouraging the use of through-the-cycle PDs, Basel III addresses procyclicality through the new countercyclical capital buffer, which is intended to be built up during upturns (up to a size of 2.5% of risk weighted assets) and to be released during downturns.

bank fragility is shared with Clerc et al. (2015), as already discussed, as well as papers such us Markovic (2006), Zhang (2009), and Hirakata, Sudo and Ueda (2009), which model bank default in a way similar to ours but do not provide a normative analysis of capital requirements. Angeloni and Faia (2013) and Kashyap, Tsomocos, and Vardoulakis (2014) look at the fragility induced by bank runs. Aoki and Nikolov (2015) focus on safety net distortions, Boissay, Collard, and Smets (2016) on interbank market frictions, and Collard et al. (2014) and Martinez-Miera and Suarez (2014) on excessive systemic risk taking.

The paper is structured as follows. Section 2 describes the model. Section 3 focuses on the banking sector and explains the determinants of bank lending standards in the model. Section 4 explains our calibration procedure and the data we use. Section 5 contains the main policy results. Section 6 discusses the sources of the welfare gains brought by the optimal capital requirement policies and the robustness of the results to changes in key parameters. Section 7 concludes. Appendices A and B provide further details on the equilibrium conditions of the model and the data used in its calibration, respectively.

2. Model Economy

We consider an economy populated by two dynasties: patient households (denoted by s) and impatient households (denoted by m). Households that belong to each dynasty differ in terms of their subjective discount factor, $\beta_m \leq \beta_s$. The total mass of households is normalized to one, of which an exogenous fraction x_s are patient and the remaining fraction $x_m = 1 - x_s$ are impatient. In equilibrium, impatient households borrow.[9]

The patient dynasty consists of three different classes of members, workers, entrepreneurs, and bankers, with measures given by x_ϱ for $\varrho = w, e, b$, respectively. Workers supply labor to the production sector and transfer their wage income to the household. Entrepreneurs and bankers manage entrepreneurial firms and banks, respectively, and can transfer their accumulated earnings back to the patient households as dividends or once they retire. They use their scarce net worth to provide equity financing to entrepreneurial firms and banks, respectively. Entrepreneurs and bankers receive consumption insurance from their dynasty, while the firms

[9] As in other papers in the literature (e.g. Iacoviello, 2005), the distinction between patient and impatient households is a minimal deviation from the infinitely lived representative household paradigm that allows to simultaneously have saving and borrowing households. For interpretation purposes, one can think of impatient households as representing the decisions and welfare of net borrowers such as younger or poorer households.

and banks that they own can individually default on their debts.

The impatient dynasty consists of workers only and its borrowing takes the form of non-recourse mortgage loans made against a continuum of the individual housing units subject to idiosyncratic return shocks. Similarly to entrepreneurs and bankers, impatient workers receive consumption insurance from their dynasty and can individually default on their mortgages.[10]

We assume two types of competitive banks that finance their loans by raising equity from bankers and debt from patient households.[11] The loans extended to impatient households and the banks extending them are denoted by M, while those extended to firms (denoted by f) and the banks extending them are denoted by F.[12] A fraction κ of bank debt are deposits insured by a deposit insurance agency (DIA) funded with lump sum taxes. Banks are subject to capital requirements set by a prudential authority.

2.1 Notation

All borrowers are subject to idiosyncratic return shocks $\omega_{i,t+1}$ which are iid across borrowers of class $i \in \{m, f, M, F\}$ and across borrower classes, and are assumed to follow a log-normal distribution with a mean of one and a stochastic standard deviation $\sigma_{i,t+1}$. We will denote by $F_{i,t+1}(\omega_{i,t+1})$ the distribution function of $\omega_{i,t+1}$ and by $\overline{\omega}_{i,t+1}$ the threshold realization below which a borrower of class i defaults, so that the probability of default of such borrower can be found as $F_{i,t+1}(\overline{\omega}_{i,t+1})$.[13]

Following Bernanke, Gertler and Gilchrist (1999), it is useful to define the share of total assets owned by borrowers of class j which end up in default as

$$G_{i,t+1}\left(\overline{\omega}_{i,t+1}\right) = \int_0^{\overline{\omega}_{i,t+1}} \omega_{i,t+1} f_{i,t+1}\left(\omega_{i,t+1}\right) d\omega_{i,t+1}, \tag{1}$$

and the expected share of asset value of such class of borrowers that goes to the lender as

$$\Gamma_{i,t+1}(\overline{\omega}_{i,t+1}) = G_{i,t+1}\left(\overline{\omega}_{i,t+1}\right) + \overline{\omega}_{i,t+1}[1 - F_{i,t+1}\left(\overline{\omega}_{i,t+1}\right)] \tag{2}$$

[10] Assuming that dynasties provide consumption risk-sharing to their members while members (or the firms and banks that they own) may default on their debts avoids having budget constraints with kinks and facilitates solving the model with perturbation methods.

[11] All the agents will be described as competitive because they are atomistic and take prices as given. However, the scarcity of entrepreneurs' and bankers' wealths will make them extract rents in equilibrium.

[12] Having banks specialized in each class of loans simplifies their pricing, avoiding cross-subsidization effects that would otherwise emerge due to banks' limited liability.

[13] The subscript $t + 1$ in the distribution function and in the functions $G_{i,t+1}(\cdot)$ and $\Gamma_{i,t+1}(\cdot)$ defined below is a shorcut to reflect the time-varying standard deviation of $\omega_{i,t+1}$.

where $f_{i,t+1}(\omega_{i,t+1})$ denotes the density function of $\omega_{i,t+1}$. In the presence of a proportional asset repossession cost μ_i, as we assume, the net share of assets that goes to the lender is $\Gamma_{i,t+1}(\overline{\omega}_{i,t+1}) - \mu_i G_{i,t+1}(\overline{\omega}_{i,t+1})$. The share of assets eventually accrued to the borrowers of class i is $(1 - \Gamma_{i,t+1}(\overline{\omega}_{i,t+1}))$.

2.2 Households

Dynasties provide consumption risk sharing to their members and are in charge of taking most household decisions. Each dynasty maximizes

$$E_t \left[\sum_{i=0}^{\infty} (\beta_{\varkappa})^{t+i} \left[\log(c_{\varkappa,t+i}) + v_{\varkappa,t+i} \log(h_{\varkappa,t+i}) - \frac{\varphi_{\varkappa}}{1+\eta} (l_{\varkappa,t+i})^{1+\eta} \right] \right] \tag{3}$$

with $\varkappa = s, m$, where $c_{\varkappa,t}$ denotes the consumption of non-durable goods and $h_{\varkappa,t}$ denotes the total stock of housing held by the various members of the dynasty (which is assumed to provide a proportional amount of housing services also denoted by $h_{\varkappa,t}$), $l_{\varkappa,t}$ denotes hours worked in the consumption good producing sector, η is the inverse of the Frisch elasticity of labor supply, $\varphi_{\varkappa}$ is a preference parameter and $v_{\varkappa,t}$ is a housing preference shock that follows an AR(1) process.

Patient Households. The patient households' budget constraint is as follows

$$c_{s,t} + q_{h,t}(h_{s,t} - (1-\delta_{h,t})h_{s,t-1}) + (q_{k,t} + s_t) k_{s,t} + d_t + B_t \leq (r_{k,t} + (1-\delta_{k,t}) q_{k,t}) k_{s,t-1} + w_t l_{s,t} + \widetilde{R}_t^d d_{t-1} + R_{t-1}^{rf} B_{t-1} + T_{s,t} + \Pi_{s,t} + \Xi_{s,t} \tag{4}$$

where $q_{h,t}$ is the price of housing, $\delta_{h,t}$ is the rate at which housing units depreciate, and w_t is the wage rate. Savers can hold physical capital $k_{s,t}$ with price $q_{k,t}$, depreciation rate $\delta_{k,t}$, and rental rate $r_{k,t}$, subject to a management cost s_t which is taken as given by households.

Each individual saver s can also invest in a risk free asset B_t (in zero net supply) and in a perfectly diversified portfolio of bank debt d_t. The return on such debt has two components. A fraction κ is interpreted as insured deposits that always pay back the promised gross deposit rate R_{t-1}^d. The remaining fraction $1-\kappa$ is interpreted as uninsured debt that pays back the promised rate R_{t-1}^d if the issuing bank is solvent and a proportion $1-\kappa$ of the net recovery value of bank assets in case of default.[14] Importantly, we assume banks' individual risk profiles to be

[14] One can alternatively interpret κ as the fraction of bank debt that will benefit from a government bailout in case of default. This formulation allows us to consider deviations from full bank debt insurance ($\kappa = 1$) without complicating banks' capital structure decisions.

unobservable to savers, so that they must base their valuation of bank debt on the anticipated credit risk of an average unit of bank debt. The return on bank debt for savers is

$$\widetilde{R}_t^d = R_{t-1}^d - (1-\kappa)\Omega_t, \tag{5}$$

where Ω_t is the average default loss per unit of bank debt as defined in Appendix A (equation (35)).[15] Hence, for $\kappa < 1$, bank debt is overall risky and, to make it attractive to savers, it will have to promise a contractual gross interest rate R_{t-1}^d higher than the free rate R_{t-1}^{rf}.

Finally, $T_{s,t}$ is a lump-sum tax used by the DIA to ex-post balance its budget, $\Pi_{s,t}$ are aggregate net transfers of earnings from entrepreneurs and bankers to the household at period t, and $\Xi_{s,t}$ are profits from firms that manage the capital stock held by the patient households.[16]

Impatient Households. The impatient households' budget constraint is different from (4) in that these households borrow, do not invest in capital, and do not receive transfers from entrepreneurs and bankers:

$$c_{m,t} + q_{h,t}h_{m,t} - b_{m,t} \leq w_t l_{m,t} + (1-\Gamma_{m,t}(\overline{\omega}_{m,t}))R_t^H q_{h,t-1}h_{m,t-1} - T_{m,t}, \tag{6}$$

where $b_{m,t}$ is the overall amount of mortgage lending granted by banks, $R_t^H = (1-\delta_{h,t})\, q_{h,t}/q_{h,t-1}$ is the gross unlevered return on housing, $(1-\Gamma_{m,t+1}(\overline{\omega}_{m,t}))R_t^H q_{h,t-1}h_{m,t-1}$ is net housing equity after accounting for the fraction of housing repossessed by the bank on the individual housing units that default on their mortgages, and $T_{m,t}$ is the lump-sum tax through which borrowers contribute to the funding of the DIA.

This formulation posits that individual household members default on their mortgages in period t when the value of their housing units, $\omega_{m,t}R_t^H q_{h,t}h_{m,t}$, is lower than the outstanding mortgage debt, $R_t^M b_{m,t}$, that is when $\omega_{m,t} \leq \bar{\omega}_{m,t} = x_{m,t-1}/R_t^H$, where

$$x_{m,t} = \frac{R_t^M b_{m,t}}{q_{h,t}h_{m,t}} \tag{7}$$

is a measure of household leverage and R_t^M is the gross rate on the corresponding loan.[17]

[15] This is consistent with the view (e.g. in Dewatripont and Tirole, 1994) that small unsophisticated savers lack the incentives and/or ability to monitor the banks and delegate such task into bank supervisors.

[16] As further specified in Appendix A (equation 37), the total costs of deposit insurance are shared by the patient and impatient households in proportion to their size in the population.

[17] In principle, the rate R_t^M is part of the housing loan contract and, hence, should be part of the decision variables of the impatient dynasty in period t. However, treating the intermediate variable $x_{m,t}$ as part of the contract signed with the lending bank (together with $b_{m,t}$ and $h_{m,t}$ and in replacement of R_t^M) allows us to solve the entire optimization problem of the dynasty without explicit reference to R_t^M.

Importantly, the problem of the borrowing households includes a second constraint, the participation constraint of the bank, which reflects the competitive pricing of the loans that banks are willing to offer for different choices of leverage by the household:

$$E_t\Lambda_{b,t+1}\left[(1-\Gamma_{M,t+1}(\overline{\omega}_{M,t+1}))(\Gamma_{m,t+1}\left(\overline{\omega}_{m,t+1}\right)-\mu_m G_{m,t+1}\left(\overline{\omega}_{m,t+1}\right))R^H_{t+1}\right]q_{h,t}h_{m,t}\geq v_{b,t}\phi_{M,t}b_{m,t}. \tag{8}$$

As further explained in subsection 2.3.5, (8) imposes that the expected, properly discounted payoffs that the bank generates to its owners by granting mortgages to the impatient households are large enough to compensate bankers for the opportunity cost of the equity financing contributed to such loans, $v_{b,t}\phi_{M,t}b_{m,t}$, where $v_{b,t}$ is the equilibrium shadow value of one unit of bankers' wealth and $\phi_{M,t}$ is the (binding) capital requirement for this class of loans. The term $\Lambda_{b,t+1}$ is bankers' stochastic discount factor, $(1-\Gamma_{M,t+1}(\overline{\omega}_{M,t+1})$ accounts for the fact that bankers obtain levered returns from the bank's loan portfolio, and $\overline{\omega}_{M,t+1}$ is the threshold of the idiosyncratic shock to bank asset returns below which the bank defaults.[18] The term $(\Gamma_{m,t+1}\left(\overline{\omega}_{m,t+1}\right)-\mu_m G_{m,t+1}\left(\overline{\omega}_{m,t+1}\right))R^H_{t+1}$ reflects the part of the returns on one unit of housing, net of repossession costs incurred when the borrower defaults, that is taken by the bank.

2.3 Entrepreneurs and Bankers

In each period some entrepreneurs and bankers become workers and some workers become either entrepreneurs or bankers.[19] Each period can be logically divided in three stages: payment stage, surviving stage, and investment stage. In the payments stage, previously active entrepreneurs ($\varrho = e$) and bankers ($\varrho = b$) get paid on their previous period investments. In the surviving stage, each agent of class ϱ stays active with probability θ_ϱ and retires with probability $1-\theta_\varrho$, becoming a worker again and transferring any accumulated net worth to the patient dynasty. At the same time, a mass $(1-\theta_\varrho)\,x_\varrho$ of workers become new agents of class ϱ, guaranteeing that the size of the population of such agents remains constant at x_ϱ. The cohort of new agents of class ϱ receives total net worth $\iota_{\varrho,t}$, from the patient dynasty. In the investment

[18] When solving this problem, the borrowing households take $\overline{\omega}_{M,t+1}$as given, since the impact of an infinitesimal marginal loan on bank solvency is negligible. Instead, the borrower internalizes the impact on his decisions on his own default threshold $\overline{\omega}_{m,t+1}$.

[19] This guarantees that active entrepreneurs and bankers never accummulate enough net worth for them not to be interested in investing all of in equity of firms and banks, respectively (see, e.g. Gertler and Kiyotaki, 2010)

stage entrepreneurs and bankers provide equity financing to entrepreneurial firms and banks, respectively, and can send their net worth back to the household in the form of dividends.

2.3.1 Individual entrepreneurs

Entrepreneurs are agents that invest their net worth into entrepreneurial firms. The problem of the representative entrepreneur can be written as

$$V_{e,t} = \max_{a_t, dv_{e,t}} \left\{ dv_{e,t} + E_t \Lambda_{t+1} \left[(1 - \theta_e) n_{e,t+1} + \theta_e V_{e,t+1} \right] \right\} \tag{9}$$

$$a_t + dv_{e,t} = n_{e,t}$$
$$n_{e,t+1} = \int_0^\infty \rho_{f,t+1}(\omega) dF_{f,t+1}(\omega) a_t$$
$$dv_{e,t} \geq 0$$

where $\Lambda_{t+1} = \beta_s c_{s,t}/c_{s,t+1}$ is the stochastic discount factor of the patient dynasty, $n_{e,t}$ is the entrepreneur's net worth, a_t is the part of the net worth symmetrically invested in the measure-one continuum of entrepreneurial firms further described below, $dv_{e,t} \geq 0$ are dividends that the entrepreneur can pay to the saving dynasty before retirement, and $\rho_{f,t+1}(\omega)$ is the rate of return on the entrepreneurial equity invested in a firm that experiences a return shock ω.

As in Gertler and Kiyotaki (2010), we guess that the value function is linear in net worth

$$V_{e,t} = v_{e,t} n_{e,t}, \tag{10}$$

where $\nu_{e,t}$ is the shadow value of one unit of entrepreneurial equity. Then we can write the Bellman equation in (9) as

$$v_{e,t} n_{e,t} = \max_{a_t, dv_{e,t}} \left\{ dv_{e,t} + E_t \Lambda_{t+1} \left[1 - \theta_e + \theta_e v_{e,t+1} \right] n_{e,t+1} \right\}. \tag{11}$$

Entrepreneurs find optimal not to pay dividends prior to retirement insofar as $\nu_{e,t} > 1$, which we verify to hold true under our parameterizations. Finally, (11) 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 takes a_t equity from entrepreneurs and borrows $b_{f,t}$ from banks at interest rate R_t^F to buy physical capital from capital producers at t. In the next period, the firm rents the available effective units of capital, $\omega_{f,t+1}k_t$, where $\omega_{f,t+1}$ is the firm-idiosyncratic return shock, to capital users and sells back the depreciated capital to capital producers. Firms live for a period and pay out their terminal net worth to entrepreneurs. Hence, assuming symmetry across firms, the problem of the representative entrepreneurial firm can be written as

$$\max_{k_t, R_t^F} E_t \Lambda_{e,t+1}(1 - \Gamma_{f,t+1}(\overline{\omega}_{f,t+1}))R_{t+1}^K q_{k,t} k_{f,t}$$

subject to the participation constraint of its bank

$$E_t \Lambda_{b,t+1}(1 - \Gamma_{b,t+1}(\overline{\omega}_{b,t+1}))\widetilde{R}_{t+1}^F b_{f,t} \geq v_{b,t}\phi_{F,t} b_{f,t} \tag{12}$$

where $R_{t+1}^K = ((1 - \delta_{k,t+1}) q_{k,t+1} + r_{k,t+1}) / q_{k,t}$ is the gross return on capital and $b_{f,t} = q_{k,t}k_{f,t} - a_t$ is the loan taken from the bank. As explained when presenting the problem of the borrowing households, the participation constraint of the bank can be interpreted as the equation capturing the competitive pricing of bank loans for different possible decisions on leverage by the firm. Further details on (12) appear in subsection 2.3.5.

The payoff that bank F receives from its portfolio of loans to entrepreneurial firms can be expressed as $\widetilde{R}_{t+1}^F b_{f,t} = (\Gamma_{f,t+1}(\overline{\omega}_{f,t+1}) - \mu_f G_{f,t+1}(\overline{\omega}_{f,t+1}))R_{t+1}^K q_{k,t} k_{f,t}$, which takes into account that a firm defaults on its loans when the gross return on its assets, $\omega_{f,t+1}R_{t+1}^K q_{k,t} k_{f,t}$, is insufficient to repay $R_t^F b_{f,t}$, i.e. for $\omega_{f,t+1} < \overline{\omega}_{f,t+1} = x_{f,t}/R_{t+1}^K$,where

$$x_{f,t} = \frac{R_t^F b_{f,t}}{q_{k,t} k_{f,t}} \tag{13}$$

is a measure of firms' leverage. Upon default, the bank recovers returns $(1 - \mu_f)\omega_{f,t+1}R_{t+1}^K q_{k,t} k_t$, where μ_f is a proportional asset repossession cost.

2.3.3 Law of motion of entrepreneurial net worth

Taking into account effects of retirement and the entry of new entrepreneurs, the evolution of active entrepreneurs' net worth can be described as:[20]

$$n_{e,t+1} = \theta_e \rho_{f,t+1} a_t + \iota_{e,t+1},$$

where $\rho_{f,t+1} = \int_0^\infty \rho_{f,t+1}(\omega) dF_{f,t+1}(\omega)$ is the return on a well-diversified unit portfolio of equity investments in entrepreneurial firms and $\iota_{e,t}$ is new entrepreneurs' net worth endowment, which we assume to be a proportion χ_e of the net worth of the exiting entrepreneurs:

$$\iota_{e,t} = \chi_e (1 - \theta_e) \rho_{f,t+1} a_t.$$

2.3.4 Individual bankers

Bankers can invest their net worth $n_{b,t}$ into two classes j of competitive banks that extend loans $b_{j,t}$ to either impatient households ($j = M$) or firms ($j = F$). There is a continuum of banks of each class. The problem of the representative banker is

$$V_{b,t} = \max_{e_t^M, e_t^F, dv_{b,t}} \left\{ dv_{b,t} + E_t \Lambda_{t+1} \left[(1 - \theta_b) n_{b,t+1} + \theta_b V_{b,t+1} \right] \right\} \tag{14}$$

$$e_{M,t} + e_{F,t} + dv_{b,t} = n_{b,t}$$

$$n_{b,t+1} = \int_0^\infty \rho_{M,t+1}(\omega) dF_{M,t+1}(\omega) e_{M,t} + \int_0^\infty \rho_{F,t+1}(\omega) dF_{F,t+1}(\omega) e_{F,t}$$

$$dv_{b,t} \geq 0$$

where $e_{j,t}$ is the diversified equity investment in the measure-one continuum of banks of class j. $dv_{b,t}$ is a dividend that the banker pays to the saving dynasty at retirement, and $\rho_{j,t+1}(\omega)$ is the rate of return from investing equity in a bank of class j that experiences shock ω.

As in the case of entrepreneurs, we guess that bankers' value function is linear

$$V_{b,t} = v_{b,t} n_{b,t},$$

where $\nu_{b,t}$ is the shadow value of a unit of banker wealth. The Bellman equation in (14) becomes

$$v_{b,t} n_{b,t} = \max_{e_t^M, e_t^F, dv_{b,t}} \left\{ dv_{b,t} + E_t \Lambda_{t+1} \left[1 - \theta_b + \theta_b v_{b,t+1} \right] n_{b,t+1} \right\}, \tag{15}$$

[20] To save on notation, we also use $n_{e,t+1}$ to denote the aggregate counterpart of what in (9) was an individual entrepreneur's net worth.

and bankers will find it optimal not to pay dividends prior to retirement ($dv_{b,t} = 0$) insofar as $\nu_{b,t} > 1$. From (15), bankers' stochastic discount factor can be defined as

$$\Lambda_{b,t+1} = \Lambda_{t+1}\left[(1-\theta_b) + \theta_b v_{b,t+1}\right].$$

From (15), interior equilibria in which both classes of banks receive strictly positive equity from bankers ($e_{j,t} > 0$) require the properly discounted gross expected return on equity at each class of bank to be equal to $v_{b,t}$:

$$E_t[\Lambda_{b,t+1}\rho_{M,t+1}] = E_t[\Lambda_{b,t+1}\rho_{F,t+1}] = v_{b,t}, \tag{16}$$

where $\rho_{j,t+1} = \int_0^\infty \rho_{j,t+1}(\omega)\, dF_{j,t+1}(\omega)$ is the return of a well diversified unit-size portfolio of equity stakes in banks of class j.

2.3.5 Banks

The representative bank of class j issues equity $e_{j,t}$ among bankers and debt $d_{j,t}$ that promises a gross interest rate R_t^d among patient households, and uses these funds to provide a continuum of identical loans of total size $b_{j,t}$. This loan portfolio has a return $\omega_{j,t+1}\widetilde{R}_{t+1}^j$, where $\omega_{j,t+1}$ is a log-normally distributed bank-idiosyncratic asset return shock and $\widetilde{R}_{t+1}^j$ denotes the realized return on a well diversified portfolio of loans of class j.[21] Banks only live for a period and give back all their terminal net worth, if positive, to the bankers in the payment stage of next period. When a bank's terminal net worth is negative, it defaults. Thus, the DIA takes possession of the returns $(1-\mu_j)\omega_{j,t+1}\widetilde{R}_{t+1}^j b_{j,t}$ where μ_j is a proportional asset repossession cost, pays off the fraction κ of insured deposits in full, and pays a fraction $1-\kappa$ of the reposed returns to the holders of the bank's uninsured debt.

The objective function of the representative bank of class j is to maximize the net present value of their shareholders' stake at the bank

$$NPV_{j,t} = E_t\Lambda_{b,t+1}\max\left[\omega_{j,t+1}\widetilde{R}_{t+1}^j b_{j,t} - R_t^d d_{j,t}, 0\right] - v_{b,t}e_{j,t}, \tag{17}$$

where the equity investment $e_{j,t}$ 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

[21] This layer of idiosyncratic uncertainty is an important driver of bank default and is intended to capture the effect of bank-idiosyncratic limits to diversification of borrowers' risk (e.g. regional or sectoral specialization or large exposures) or shocks stemming from (unmodeled) sources of cost (IT, labor, liquidity management) or revenue (advisory fees, investment banking, trading gains).

to the balance sheet constraint, $b_{j,t} = e_{j,t} + d_{j,t}$, and the regulatory capital constraint, $e_{j,t} \geq \phi_{j,t} b_{j,t}$,where $\phi_{j,t}$ is the capital requirement on loans of class j.

If the capital requirement is binding (as it turns out to be in equilibrium because partially insured debt financing is always "cheaper" than equity financing), we can write the loans of the bank as $b_{j,t} = e_t^j/\phi_{j,t}$, its deposits as $d_{j,t} = (1 - \phi_{j,t})e_{j,t}/\phi_{j,t}$, and the threshold value of $\omega_{j,t+1}$ below which the bank fails as $\overline{\omega}_{j,t+1} = (1 - \phi_{j,t})\, R_t^d/\widetilde{R}_{t+1}^j$, since the bank fails when the realized return per unit of loans is lower than the associated debt repayment obligations, $(1 - \phi_{j,t})R_{d,t}$. Accordingly, the probability of failure of a bank of class j is $\Psi_{j,t+1} = F_{j,t+1}(\overline{\omega}_{j,t+1})$, which will be driven by fluctuations in the aggregate return on loans of class j, $\widetilde{R}_{t+1}^j$, as well as shocks to the distribution of the bank return shock $\omega_{j,t+1}$.

Using (2), the bank's objective function in (17) can be written as

$$NPV_{j,t} = \left\{ E_t \Lambda_{b,t+1} \left[1 - \Gamma_{j,t+1}(\overline{\omega}_{j,t+1})\right] \frac{\widetilde{R}_{t+1}^j}{\phi_{j,t}} - v_{b,t} \right\} e_{j,t},$$

which is linear in the bank's scale as measured by $e_{j,t}$. So, banks' willingness to invest in loans with returns described by $\widetilde{R}_{t+1}^j$ and subject to a capital requirement $\phi_{j,t}$ requires having

$$E_t \Lambda_{b,t+1} \left[1 - \Gamma_{j,t+1}(\overline{\omega}_{j,t+1})\right] \widetilde{R}_{t+1}^j \geq \phi_{j,t} v_{b,t}, \tag{18}$$

which explains the expressions for the participation constraints (8) and (12) introduced in borrowers' problems. These constraints will hold with equality since it is not in borrowers' interest to pay more for their loans than strictly needed.[22] Under the definition $\rho_{j,t+1} = \left[1 - \Gamma_{j,t+1}(\overline{\omega}_{j,t+1})\right] \frac{\widetilde{R}_{t+1}^j}{\phi_{j,t}}$, if (18) holds with equality for $j = M, F$, bankers' indifference between investing their wealth in equity of either class of banks, (16), is also trivially satisfied.

2.3.6 Law of motion of bankers' net worth

Taking into account effects of retirement and the entry of new bankers, the evolution of active bankers' *aggregate* net worth can be described as:[23]

$$n_{b,t+1} = \theta_b(\rho_{F,t+1} e_{F,t} + \rho_{M,t+1} e_{M,t}) + \iota_{b,t}$$

[22] In fact, any pricing of bank loans leading to $NPV_{j,t} > 0$ would make banks wish to expand $e_{j,t}$ unboundedly, which is incompatible with equilibrium. So, we could have directly written (8) and (12) with equality, as a sort of zero (rather than non-negative) profit condition.

[23] To save on notation, we also use $n_{b,t+1}$ to denote the aggregate counterpart of what in (9) was an individual banker's net worth.

where $\iota_{b,t}$ is new bankers' net worth endowment (received from saving households), which we assume to be a proportion χ_b of the net worth of exiting bankers:

$$\iota_{b,t} = \chi_b(1-\theta_b)(\rho_{F,t+1}e_{F,t} + \rho_{M,t+1}e_{M,t}).$$

2.4 Production Sector

We assume a perfectly competitive production sector made up of firms owned by the patient agents. This sector is not directly affected by financial frictions.

2.4.1 Consumption goods

The representative goods-producing firm produces a single good, y_t, using l_t units of labor and k_t units of capital, according to the following constant-returns-to-scale technology:

$$y_t = z_t {l_t}^{1-\alpha} {k_{t-1}}^{\alpha}, \tag{19}$$

where z_t is an AR(1) productivity shock and α is the share of capital in production.

2.4.2 Capital and housing production

Producers of capital (X=k) and housing (X=h) combine investment $I_{X,t}$, with the previous stock of capital and housing, X_{t-1}, in order to produce new capital and housing which can be sold at price $q_{X,t}$.[24] The representative X-producing firm maximizes the expected discounted value to the saving dynasty of its profits:

$$\max_{\{I_{X,t+j}\}} E_t \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left\{ q_{X,t+j} \left[S_X \left(\frac{I_{X,t+j}}{X_{t+j-1}} \right) X_{t+j-1} \right] - I_{X,t+j} \right\} \tag{20}$$

where $S_X\left(\frac{I_{X,t+j}}{X_t+j-1}\right) X_t + j - 1$ gives the units of new capital produced by investing $I_X, t+j$. The increasing and concave function $S_X(\cdot)$ captures adjustment costs, as in Jermann (1998):

$$S_X\left(\frac{I_{X,t}}{X_{t-1}}\right) = \frac{a_{X,1}}{1-\frac{1}{\psi_X}} \left(\frac{I_{X,t}}{X_{t-1}}\right)^{1-\frac{1}{\psi_X}} + a_{X,2}, \tag{21}$$

where $a_{X,1}$ and $a_{X,2}$ are chosen to guarantee that, in the steady state, the investment-to-capital ratio is equal to the depreciation rate and $S'_X(I_X, t/X_t - 1)$ equals one (so that the implied adjustment costs are zero).

[24] We have examined a variation of the model with a fixed housing stock. The behaviour of the model as well as its policy implications were similar to the ones obtained in the current version.

From profit maximization, it is possible to derive the supply of new capital or housing:

$$q_{X,t} = \left[S'_X \left(\frac{I_{X,t}}{X_{t-1}} \right) \right]^{-1}, \tag{22}$$

which implies that in steady state $q_{X,t}$ is constant and equal to one. Finally, the law of motion of the corresponding stock is given by

$$X_t = (1 - \delta_{X,t}) X_{t-1} + S_X \left(\frac{I_{X,t}}{X_{t-1}} \right) X_{t-1}, \tag{23}$$

where $\delta_{X,t}$ is the time-varying depreciation rate, which follows an AR(1).

2.4.3 Capital management firms

The capital management cost s_t associated with households direct holdings of capital $k_{s,t}$ is a fee levied by a measure-one continuum of firms operating with decreasing returns to scale. These firms have a convex cost function $z(k_{s,t})$ where $z(0) = 0$, $z'(k_{s,t}) > 0$ and $z''(k_{s,t}) > 0$. Under perfect competition, maximizing profits $\Xi_{s,t} = s_t k_{s,t} - z(k_{s,t})$ implies the first order condition

$$s_t = z'(k_{s,t}), \tag{24}$$

which determines the equilibrium fees for each $k_{s,t}$.

We assume a quadratic cost function, $z(k_{s,t}) = \frac{\xi}{2} k_{s,t}^2$, with $\xi > 0$, so that (24) becomes

$$s_t = \xi k_{s,t}. \tag{25}$$

2.5 The Prudential Authority

The prudential authority is assumed to set the capital requirements applicable to mortgages and corporate loans in period t following simple policy rules:

$$\phi_{M,t} = \phi_M + \tau_M (E_t \Psi_{m,t+1} - \Psi_m), \tag{26}$$

$$\phi_{F,t} = \phi_F + \tau_F (E_t \Psi_{f,t+1} - \Psi_f), \tag{27}$$

where $\bar{\phi}_j$ and τ_j determine the steady state level and the time-varying component of the requirements applied to loans of each class $j = M, F$. The dependence of these rules on the deviations of the expected default risk of each class of borrowers, $E_t \Psi_{m,t+1}$ and $E_t \Psi_{f,t+1}$, from their corresponding steady-state values, Ψ_m and Ψ_f, captures the manner in which the practical implementation of the so-called IRB approach of Basel combined with possible measures to mitigate its procyclicality (such as the use of through-the-cycle inputs in the IRB formulas or the operation of the Countercyclical Capital Buffer) makes capital requirements vary over time with the expected probability of default (PD) of each class of loans.[25]

2.6 Sources of Fluctuations

The model economy features eight sources of aggregate uncertainty, namely shocks to productivity, z_t, housing preferences, v_t, the depreciation of housing, $\delta_{h,t}$, and capital, $\delta_{k,t}$, and the four *risk shocks.* The latter are the shocks to the standard deviation $\sigma_{j,t}$ of the idiosyncratic return shocks experienced by each of the four classes of borrowers $j = m, f, M, F$).[26] All aggregate shocks follow autoregressive processes of order one:

$$\ln \varkappa_t - \ln \bar{\varkappa} = \rho_{\varkappa} (\ln \varkappa_{t-1} - \ln \bar{\varkappa}) + u_{\varkappa,t},$$

where $\varkappa_t \in \{z_t, v_t, \delta_{h,t}, \delta_{k,t}, \sigma_{m,t}, \sigma_{f,t}, \sigma_{M,t}, \sigma_{F,t}\}$, $\rho_{\varkappa}$ is the corresponding (time invariant) persistence parameter, $\bar{\varkappa}$ is the unconditional mean of ϱ_t, and $u_{\varkappa,t}$ is the innovation to each shock, with mean zero and (time invariant) standard deviation $\sigma_{\varkappa}$.

2.7 Other Details

To save on space, market clearing conditions and the equations describing the determination of variables such as $T_{s,t}$, $T_{m,t}$, $\Omega_{M,t}$, $\Omega_{F,t}$, and $\Psi_{b,t}$ appear in Appendix A.

3. Determinants of Bank Lending Standards

The competitive pricing of loans by banks in our model is summarized by the bank's participation constraints that appear in each of the borrowers' problems, that is equations (8) and (12). Each of these constraints establishes the combination of loan rates and borrower leverage

[25] We acknowledge the existence of unexplored tax policies which might substitute for capital requirements in controlling bank instability, including the subsidization of equity financing (or the taxation of debt financing) and taxes devoted to influence the supply of loans of each class. However, without prejudicing the relative merits of each alternative, we focus on capital requirements because they are the centerpiece of the micro- and macroprudential regulation of banks under the Basel process.

[26] We refer to the shocks$\{\sigma_{j,t}\}_{j=m,f,M,F}$ as "risk shocks" as in Christiano, Motto and Rostagno (2014).

that guarantee the returns the bank needs to compensate bankers for the equity funding they contribute. This constraint is affected by the regulatory capital requirements, the default risk of the bank and its borrowers, asset prices, and asset repossession costs. From the point of view of borrowers, the participation constraint is the loan pricing schedule that determines the interest rate they must pay for each given leverage choice. From an aggregate perspective, the position of this schedule describes the "lending standards" of the corresponding bank. When the curve shifts downwards, banks loosen their lending standards and credit supply expands. When the curve shifts upwards, banks tighten their lending standards and credit supply shrinks.

The solid lines in each of the panels of Figure 1 depict the bank's participation constraint of the corresponding type of borrower at the steady state of the baseline calibration described in Section 4. We produce these curves in partial equilibrium: with debt funding rates, the shadow value of bankers wealth, and the aggregate determinants of bank and borrower default risk fixed at their steady state levels. Loan rates show up as an increasing and convex function of borrower leverage. At very low levels of leverage, the loan rate is locally insensitive to leverage because the probability of default is essentially zero. Once borrower leverage is sufficiently high, the probability of default begins to rise and the loan interest rate increases to compensate for the expected credit losses, which include the asset repossession costs incurred in the event of default.

The bank's own probability of failure affects lending standards due to the limited liability distortion and the safety net subsidy. The limited liability distortion reflects that the pricing of bank debt (irrespectively of fraction of it protected by the safety net) occurs before the bank makes the lending decisions that shape its own risk profile. So it occurs at terms that reflect a bank's expected risk profile rather than being a function of the bank's lending choices. Bank equityholders profit from asset risk because equity payoffs are convex functions of the returns of the loan portfolio. The safety net affects equityholders in a related manner. It makes a fraction of bank debt riskless, implying a subsidy to any risky bank. The effects of these forces can be better understood by examining the comparative statics of the loan pricing schedules depicted in Figure 1.

The dash-and-dotted lines in each of the panels of Figure 1 show the loan pricing schedules that emerge under higher values of the standard deviation of the bank-idiosyncratic asset return shocks, σ_M and σ_F, respectively. Lending standards of each type of bank get relaxed because shareholders' limited liability gains are, by force of competition, passed to borrowers in the form of cheaper or riskier loans.[27]

The dashed lines in each of the panels of Figure 1 describe the partial equilibrium effects of an increase in capital requirements. Such an increase forces the bank to reduce its leverage and to rely more on more expensive equity funding. Bank default risk falls and, with it, the implicit safety net subsidy. The result is an increase in the bank's weighted average cost of funding which is passed on to borrowers in the form of a tightening in lending standards (an outward shift in the loan pricing schedules).[28]

Finally, the dotted lines describe the effect of an increase in idiosyncratic borrower risk. Higher borrower risk makes the loan supply schedule steeper. This simply reflects that, other things equal, borrowers' higher idiosyncratic default risk makes loans less profitable to the bank's equityholders, so compensating them for the opportunity cost of their equity funding requires charging higher loan rates to the borrowers.

4. Calibration

The model is calibrated at the quarterly frequency using Euro Area macroeconomic and financial data for the period 2001:1-2014:4. Table 1 reports the calibration targets.[29]

In a first stage we set some parameters following convention. Other parameters that are tightly linked to a specific target can also be directly set at a first stage. The rest of the parameters are found simultaneously so as to minimize a loss function that weights equally the distance between the targeted first and second empirical moments and the corresponding unconditional first and second moments generated by the second-order approximation of the

[27]The exercise summarized in Figure 1 is conducted in partial equilibrium – i.e. holding the interest rate on bank debt constant. In general equilibrium, such interest rate will increase to reflect the anticipated rise in banks' riskiness. An increase in debt funding costs will increase the bank's weighted average cost of funds and shift the loan supply schedule upwards, partly or even fully off-setting the partial equilibrium shift.

[28]In general equilibrium, these effects get combined with the endogenous response in the interest rate on bank debt and on other relevant prices. In fact, if a bank's risk of failure is initially high enough (e.g. because its capital requirement is too low), increasing the capital requirement may effectively reduce the cost of bank debt to the extend of expanding rather than contracting loan supply.

[29]Series expressed in Euro amounts are deflated and their log value is linearly detrended before computing the targets for their standard deviations. Targets expressed as ratios, interest rates or rates of return are found after linearly detrending the corresponding series in levels. Appendix B describes the corresponding series and data sources in detail.

model.[30] Using a second order approximation and considering the unconditional moments of the stochastic model economy is important because aggregate and idiosyncratic shocks interact in determining borrowers' default risk, thus, affecting key target moments such as those referred to loans' interest rate spreads and write-off rates.[31]

Regarding the parameters set directly in the first stage, we calibrate the share of borrowers in the economy, x_m, to match the proportion of indebted households in the Euro Area of 44%, as documented in the 2010 ECB Household Finance and Consumption Survey (HFCS).[32] The labor disutility parameter ν_L, which only affects the scale of the economy, is inconsequentially normalized to one. 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 physical capital, δ_k, equal to 0.03. Similarly, the discount factor of the savers, β_s, is set to 0.995. The autoregressive coefficients in the AR(1) processes followed by all shock are set equal to a common value ρ=0.90 and the bankruptcy cost parameters are set equal to a common value μ=0.30 for all sectors.[33]

Although the second stage parameters are set simultaneously, there is a link between each of them and one of the target moments. The new bankers' endowment parameter, χ_b, is used to match the median return on average equity (ROAE) in the systemically significant Euro Area banks.[34] The weights on housing in the utility of savers and borrowers, v_s and v_m respectively, are key to match the share of housing wealth held by the indebted households in the Euro Area as reported by the 2010 HFCS and the complementary share held by the non-indebted households.[35]

The discount factor of borrowers, β_m, and the new entrepreneurs' endowment parameter, χ_e,

[30] Setting these parameters using a maximum likelihood method (see e.g. An and Schorfheide, 2007) would be computationally too demanding for a medium-scale model like ours solved with a second-order approximation.

[31] In other words, looking at the non-stochastic steady state would understate the importance of default risk and, thus, the mean and variance of those variables.

[32] https://www.ecb.europa.eu/pub/economic-research/research-networks/html/researcher_hfcn.en.html

[33] 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. Among non-listed bank-dependent firms these cost can be expected to be larger than among the highly levered publicly traded US corporations studied in Andrade and Kaplan (1998), where estimated financial distress costs fall in the range from 10% to 23%. Our choice of 30% is consistent with the large foreclosure, reorganization and liquidation costs found in some of the countries analyzed by Djankov et al. (2008).

[34] https://www.bankingsupervision.europa.eu/ecb/pub/pdf/list_of_supervised_entities_20160101en.pdf

[35] In terms of the 2010 HFCS, housing wealth is defined as the value of the household's main residence + other real estate – other real estate used for business activities.

help to match the ratios of household (HH) mortgages to GDP and bank loans to non-financial corporations (NFC) to GDP.[36] The housing depreciation rate, δ_h, is calibrated to match the ratio of residential investment to GDP. The share of insured deposits in bank debt κ is set to 0.54 in accordance with the evidence by Demirgüç-Kunt, Kane, and Laeven (2014) for EA countries. The parameter of the capital management cost function, ξ, is pinned down so as 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 (see Appendix B for details).

The variance of the four idiosyncratic shocks, the housing and capital adjustment cost parameters and the variance of the eight aggregate shocks are mainly useful to match the remaining targets.[37] In particular, we match the average write-off rates and the spreads between the loan rate and the risk free rate for both types of loans. According to bank accounting conventions, we can find the write-off rate (write-offs/loans) for loans of type j that the model generates, $\Upsilon_{j,t}$, as the product of the fraction of defaulted loans of that type, $F_j\left(\overline{\omega}_{j,t}\right)$, and the average losses per unit of lending experienced in the defaulted loans, which can be found from our prior derivations. For example, in the case of NFC loans, this decomposition produces:

$$\begin{aligned}\Upsilon_{f,t} &= F_{f,t}\left(\overline{\omega}_{f,t}\right)\left[\frac{b_{f,t-1}-\frac{(1-\mu_f)}{F_{f,t}\left(\overline{\omega}_{f,t}\right)}\left(\int_0^{\overline{\omega}_{f,t}}\omega_{f,t}f_{f,t}\left(\omega\right)d\omega\right)R_t^K q_{k,t-1}k_{f,t-1}}{b_{f,t-1}}\right] \\ &= F_{f,t}\left(\overline{\omega}_{f,t}\right)-(1-\mu_f)G_{f,t}(\overline{\omega}_{f,t})R_t^K\frac{q_{k,t-1}k_{f,t-1}}{b_{f,t-1}}. \qquad (28)\end{aligned}$$

An expression for the writte-off rate of mortgage loans, $\Upsilon_{m,t}$, can be similarly obtained. The volatility of the productivity shock helps us to match the volatility of GDP. We also match the volatility relative to GDP of house prices, HH loans, NFC loans, and of the write-offs rates and spreads of each type of loans.

[36] To avoid the counterintuitive impact of the resource costs of default on the measurement of output, we define GDP_t as

$$GDP_t = c_t + I_{h,t} + I_{k,t}.$$

A more comprehensive definition of aggregate output Y_t is provided in Appendix A.

[37] The model is calibrated under the assumption that the two types of banks have the same average probability of default.

4.1 Calibrating the Capital Requirements

Given the sample period used for the calibration, we set the capital requirements applied to mortgage and corporate loans to match the capital charges that these loans would receive under the IRB approach of Basel II. Under such an approach, capital charges depend on estimates of the probability of default (PD) of the loans.[38] We find the baseline capital requirements applicable to each class of loans, ϕ_M and ϕ_F, by feeding the corresponding regulatory formula with the steady state values of the annual PD of the corresponding loans, $\Psi_{m,}$ and Ψ_f.[39] The formula for mortgage exposures is

$$\phi_M = 0.45 \left[\Phi \left(\frac{\Phi^{-1}(\Psi_m) + 0.15^{0.5}\Phi^{-1}(0.999)}{(1-0.15)^{0.5}} \right) - \Psi_m \right], \tag{29}$$

while that for corporate exposures with one year maturity[40] is

$$\phi_F = 0.45 \left[\Phi \left(\frac{\Phi^{-1}(\Psi_f) + \varrho_f^{0.5}\Phi^{-1}(0.999)}{(1-\varrho_f)^{0.5}} \right) - \Psi_f \right], \tag{30}$$

where we have fixed the loss-given-default (LGD) parameters to their regulatory value of 0.45 under the "foundation IRB" approach, $\Phi(\cdot)$ denotes the cumulative distribution function of a standard normal distribution, and ϱ_f is a correlation parameter that for corporate exposures Basel II mandates to fix as $\varrho_f = 0.24 - 0.12(1 - \exp(-50\Psi_f))/(1 - \exp(-50))$.

Regarding the parameters τ_M and τ_F that control the time variation of the capital requirements in the policy rules (26) and (27), we set them equal to zero as under a perfect through-the-cycle approach.[41]

4.2 Resulting Parameters

As evidenced in Table 1, we match very closely the first and second moments established as targets. Table 2 reports all the parameter values resulting from our calibration. The preference

[38] See BCBS (2004).

[39] Our calibration implies mean annual probabilities of default for mortgage and corporate loans of 0.66% and 1.7%, respectively.

[40] The breakdown of NFC loans by maturity reveals that in the euro area 90% of loans to corporations are of one year maturity.

[41] When we tried to explore the alternative polar scenario in which τ_M and τ_F reproduce the implications of a strict point-in-time approach (that is, in which they match the derivatives of the IRB formulas with respect to Ψ_m and Ψ_f around the benchmark values of Ψ_m and Ψ_f), the model's solution was not stable. In the normative analysis below we explore lower values of Ψ_m and Ψ_f for which the model solves well.

Table 1: Calibration Targets

Description	Definition	Data	Model
A) Stochastic means			
Fraction of borrowers	x_m	0.437	0.437
Share of insured deposits	κ	0.54	0.54
Equity return of banks	$\rho * 400$	6.734	9.278
Borrowers housing wealth share	$x_m q_h h_m$	0.525	0.495
Housing investment to GDP	I_h/GDP	0.060	0.062
HH loans to GDP	$x_m b_m/GDP$	2.120	2.126
NFC loans to GDP	$x_e b_f/GDP$	1.770	1.746
Write-off HH loans	$\Upsilon_m * 400$	0.118	0.205
Write-off NFC loans	$\Upsilon_f * 400$	0.650	0.640
Spread HH loans	$(R^M - R^d) * 400$	0.821	0.450
Spread NFC loans	$(R^F - R^d) * 400$	1.080	1.148
Capital held by saving households	k_s/k	0.220	0.223
B) Standard deviations			
std(House prices)/std(GDP)	$\sigma(q_{h,t})/\sigma(GDP_t)$	2.668	2.420
std(HH loans)/std(GDP)	$\sigma(x_m b_{m,t})/\sigma(GDP_t)$	2.413	2.943
std(NFC loans)/std(GDP)	$\sigma(x_e b_{f,t})/\sigma(GDP_t)$	3.806	5.757
std(Write-offs HH)/std(GDP)	$\sigma(\Upsilon_{m,t})/\sigma(GDP_t)$	0.012	0.009
std(Write-offs NFC)/std(GDP)	$\sigma(\Upsilon_{f,t})/\sigma(GDP_t)$	0.050	0.027
std(Spread HH loans)/std(GDP)	$\sigma(R^M - R^d)/\sigma(GDP_t)$	0.056	0.069
std(Spread NFC loans)/std(GDP)	$\sigma(R^F - R^d)/\sigma(GDP_t)$	0.045	0.082
std(GDP)	$\sigma(GDP_t) * 100$	2.310	2.617

Interest rates, equity returns, write-offs, and spreads are reported in annualized percentage points. The standard deviation of GDP is in quarterly percentage points. Abbreviations HH and NFC stand for households and non-financial corporations, respectively, and are used to refer to mortgage and corporate loans in brief form.

and technology parameters we find are in line with the values used by other authors. Borrowers' discount factor falls within the two standard deviation bands estimated by Carroll and Samwick (1997).[42] Regarding the idiosyncratic shocks, the volatility of the shock to housing and entrepreneurial asset returns needed to match the data happen to be much larger than the volatility of the shock to bank asset returns. In contrast, the standard deviation of the aggregate risk shocks is larger for the shock to banks' asset returns than for the shock to households' and entrepreneurs' assets. The standard deviations of the productivity shock and housing preference

[42] That is, within the interval (0.91, 0.99). See Iacoviello (2005), Campbell and Hercowitz (2009), and Iacoviello and Neri (2010) for similar values.

Table 2: Parameters Values

Description	Par.	Value	Description	Par.	Value
A) Pre-set parameters					
Housing weight in s utility	υ_s	0.1	HH bankruptcy cost	μ_m	0.3
Disutility of labor ($\varkappa$=s, m)	$\varphi_\varkappa$	1	NFC bankruptcy cost	μ_f	0.3
Frisch elasticity of labor	η	1	Bank M bankruptcy cost	μ_M	0.3
Capital share in production	α	0.3	Bank F bankruptcy cost	μ_F	0.3
Capital depreciation	δ_k	0.03	Entrepreneurs' survival rate	θ_e	0.975
Savers' discount factor	β_s	0.995	Bankers' survival rate	θ_b	0.975
			Shocks persistence (all ϱ)	ρ_ϱ	0.9
B) Calibrated parameters					
Fraction of borrowers	x_m	0.437	Share of insured deposits	κ	0.54
Borrowers' discount factor	β_m	0.971	Entrepreneurs' endowment	χ_e	0.3666
Housing weight in $m$utility	υ_m	0.202	Bankers' endowment	χ_b	0.1032
Housing adjustment cost	ψ_h	2.422	Capital managerial cost	ξ	0.0014
Housing depreciation	δ_h	0.012	Capital adjustment cost	ψ_k	4.567
Std. productivity shock	σ_z	0.0316	Std. housing pref. shock ($\varkappa$=s, m)	$\sigma_{\upsilon_\varkappa}$	0.061
Mean std of iid HH shocks	$\bar{\sigma}_{\omega_m}$	0.069	Std. housing depr. shock	σ_{δ_h}	0.002
Mean std of iid NFC shocks	$\bar{\sigma}_{\omega_f}$	0.399	Std. capital depr. shock	σ_{δ_k}	0.002
Mean std of iid M bank shocks	$\bar{\sigma}_{\omega_M}$	0.012	Std. HH risk shock	σ_m	0.001
Mean std of iid F bank shocks	$\bar{\sigma}_{\omega_F}$	0.027	Std. NFC risk shock	σ_f	0.039
			Std. banks' risk shock (j=M,F)	σ_j	0.059

The parameters in A) are set to standard values in the literature, whereas those in B) are calibrated to match the data targets. Abbreviations HH and NFC stand for (borrowing) households and non-financial corporations, respectively.

shocks are not too different from what is estimated in other papers.[43] Our estimates also imply similar standard deviations for the housing and capital depreciation shocks.

Using (29) and (30), our baseline calibration yields values of the capital requirements ϕ_M and ϕ_F equal to 3.4% and 7.2%, respectively. The calibration also implies an untargeted yearly average bank default rate of 1.53% and a risk free rate of about 2%.[44]

[43] See, e.g. Iacoviello and Neri (2010) and Jermann and Quadrini (2012).

[44] We have not targeted the average bank failure rate due to the difficulty to estimate such a rate with a rather short time series. The rate produced by the model, however, does not seem excessive for a period that includes a severe bank crisis. Indeed, for the period 2008-2014, Moody's average yearly expected default frequencies (EDFs) for Euro Area banks stand well above 2%.

5. Capital Regulation and Welfare

In the following sections we analyze the welfare and real economy consequences of capital requirement policies in detail. We focus on the effects of policy parameters on the welfare of each class of agents and on the degree to which capital requirement policies help stabilize the impact of aggregate shocks. Importantly, using a second-order approximation method to solve the model allows us to take the effects of aggregate uncertainty into account, as required for the proper assessment of the welfare implications of the policy rules.[45]

5.1 The Impact of Capital Requirements on Savers and Borrowers

We first analyze the impact of *ceteris paribus* changes in the level of the capital requirements applicable to each class of loans, ϕ_M and ϕ_F on the welfare of savers and borrowers. The representative household of each type $\varkappa = s, m$ maximizes the expected lifetime utility:

$$V_{\varkappa,t} \equiv \max E_t \sum_{t=0}^{\infty} (\beta_{\varkappa})^t U(c_{\varkappa,t}, h_{\varkappa,t}, l_{\varkappa,t}), \tag{31}$$

which can be written in a recursive form as follows:

$$V_{\varkappa,t} = U(c_{\varkappa,t}, h_{\varkappa,t}, l_{\varkappa,t}) + (\beta_{\varkappa})^t E_t V_{\varkappa,t+1}, \tag{32}$$

where V_{st} and V_{mt} will be equivalently referred to as the welfare of the saving and borrowing households, respectively.

Figure 2 describes the welfare effects of varying each ϕ_j while keeping the other fixed at its calibrated baseline value. To help understand those effects, Figure 3 shows the effect on key equilibrium variables of changes in each of these parameters.

Column A of Figure 2 shows the welfare impact of changing the reference level of the capital requirement on mortgage loans, ϕ_M. Savers' welfare increases monotonically with ϕ_M, whereas borrowers' welfare first increases and then decreases with it. A higher requirement, by reducing bank leverage, reduces the probability of bank failure and, thus, deposit insurance costs and the bank debt spread (see Row A of Figure 3), which other things equal is good for both savers and borrowers. Tightening capital requirements also corrects the limited liability distortions

[45] First-order approximation methods are not locally accurate in evaluating the performance of different policies in terms of welfare (see e.g. Schmitt-Grohe and Uribe (2004)).

and forces banks to use a larger fraction of (more expensive) equity financing, which, other things equal, tightens the supply of loans and is bad for borrowers. The net effect of lowering debt funding costs while imposing a larger use of scarce equity funding makes credit supply not necessarily decreasing in ϕ_M, especially when this parameter is low enough.

Indeed, at low levels of ϕ_M, the sharp decline in bank failure risk and the cost of deposit insurance, together with the small (or even positive) effect on credit supply makes borrowers' welfare increasing in ϕ_M. However, for ϕ_M larger than about 5% (see Figure 3), the probability of failure of mortgage banks is already close to zero, so further increases in ϕ_M do not decrease average default rates, deposit insurance costs or bank debt spreads any further. Instead, they tighten the supply of mortgage loans, damaging the borrowers. Meanwhile, savers continue benefiting from these increases through their impact on bank profits and the dividends subsequently received from banks.

The welfare impact of changing the level of the capital requirement applied to corporate loans, ϕ_F, is qualitatively similar to that of changing ϕ_M (see Column B of Figure 2) and responds to the same logic (see Row B of Figure 3). The main difference with respect to changing the level of ϕ_M are quantitative. Starting from its higher baseline value of 7.2%, increasing ϕ_F has a smaller effect on bank failure risk, deposit insurance costs, and the bank debt spread. The smaller size of the latter explains that increasing ϕ_F does not have the same initial expansionary effect on total credit and borrowers' consumption as increasing ϕ_M. Yet, the reduction in deposit insurance costs and volatility induced by bank fragility (as we further discuss below) are enough to make borrowers' welfare initially increasing in ϕ_F. Once the impact on bank failure risk is exhausted, further increases in ϕ_F reduce borrower welfare.

5.2 Optimized Capital Requirement Rules

We now turn to the normative analysis of the capital requirement rules defined in (26) and (27). What would be the socially optimal choice of the level parameters ϕ_M and ϕ_F, and the PD-sensitivity parameters, τ_M and τ_F? We find them by maximizing a social welfare function defined as a weighted average of the expected lifetime utility of the two classes of households:

$$\tilde{V}_t \equiv \left[\zeta V_{s,t} + (1-\zeta)\, V_{m,t}\right], \tag{33}$$

where $\zeta \epsilon [0,1]$ is the weight on savers' welfare. Since with heterogenous agents and incomplete markets there is no commonly accepted criterion for the choice of the weights assigned to each agent, we will analyze what happens under all possible values of ζ. This is equivalent to exploring the whole Pareto frontier of expected lifetime utilities that can be reached by optimizing on our capital requirement policy rules.

For each weight on savers' welfare, ζ, we search over a multidimensional grid with the following dimensions: $\phi_M \in [0.02, 0.2]$, $\phi_F \in [0.05, 0.2]$, and $\tau_j \in [0, 5]$ for $j = M, F$.[46] As seen previously, changing policy parameters can increase the welfare of one of the two classes of agents while decreasing the welfare of the other. In some cases, maximizing the weighted sum of the welfare of the two groups of agents may generate outcomes that worsen the situation of one of the groups relative to the initially calibrated policy rule. To avoid such a redistributional impact, we constrain the social welfare maximization problem so as to ensure that the solution constitutes a Pareto improvement relative to the calibrated policy rule.

The solid line in Figure 4 displays the coefficients on the optimal reference level of capital requirements for corporate loans and mortgages for each value of $\zeta \in [0, 1]$, the implied average capital-to-asset ratio for banks, and the optimal sensitivities to time-variation in the PD of each class of loans.

The solid line in Figure 5 reports the associated welfare gains for savers and borrowers as a function of the social weight on savers' welfare, ζ. We report the welfare effects in terms of a consumption-equivalent measure calculated as the percentage increase in steady state consumption that would make each class of agents' welfare under the initially calibrated policy equal to their welfare under the optimized policy rule. Increasing ζ increases the welfare gains of the savers and diminishes those of the borrowers. The welfare gains of both classes of agents are strictly positive for all ζ lower than about 0.40. Even with $\zeta = 0$ (i.e. when the policymaker only maximizes borrowers' welfare), savers obtain gains equivalent to a non-negligible 0.5% (while borrowers gain the equivalent of a 0.65% permanent consumption increase).

Interestingly, for $\zeta = 0.26$, the optimal policy yields exactly the same consumption equivalent gains (as a percent of their baseline values) for savers and borrowers. Without prejudice of the normative merit of this specific solution, we will take it as our *benchmark optimized policy* and use it below to analyze further properties of the model.

[46] The four-dimensional grid is based on a step of 0.0025 for each parameter.

5.3 Optimal Sectoral Capital Requirement Curves

The implications of the normative analysis are very clear. Regardless of the weight on savers' welfare, capital requirements should be substantially higher than in the baseline calibration (Basel II). Putting a higher weight on savers' welfare leads to higher capital charges on both mortgages and corporate loans. In addition, the higher the weight on savers' welfare, the larger the sensitivity of the capital charges to time variation in the PDs of each class of loans. In other words, savers benefit less than borrowers from containing the cyclicality that the use of point-in-time PDs in the IRB formulas might impose on capital requirements.

We can put our results into perspective by comparing the capital requirement curves generated by the IRB formula when fed by different values of the PD of the corresponding class of loans, (29) and (30), with the curves associated with our linear policy rules, (26) and (27), under the optimized values of their parameters. The solid lines in Figures 6 and 7 describe the IRB curves for mortgages and corporate loans, respectively. These are derived under the calibrated values of ϕ_M and ϕ_F. The dotted line in each figure describes the optimized policy rule that emerges when all the weight is put on savers' welfare (i.e. for $\zeta = 1$ or, given the binding Pareto improvement constraint, for any $\zeta > 0.40$). Finally, the dashed line describes the optimized policy rule when all the weight is put on borrowers' welfare ($\zeta = 0$).

As already noted, in both classes of loans, the average capital charges should be higher and less varying in the corresponding PD than what a point-in-time implementation of the IRB formula would imply. In the case of mortgage loans, borrowers actually prefer an essentially flat curve, but with an average level about one percentage point higher than in Basel II. Borrowers dislike the time variation induced by the sensitivity of capital requirements to the PD of the loans since it reinforces the cyclical variation in lending standards, which damages their capability to smooth consumption. Savers' favorite policy would increase the average charge on mortgages in at least three more percentage points, more than doubling the Basel II level. Interestingly such policy involves some sensitivity to time variation in the corresponding PD, but significantly less than under a point-in-time implementation of the IRB formula. Thus, at the margin, savers also benefit from countercyclical adjustments such as those brought by the use of through-the-cycle inputs in the IRB formula or the introduction of the countercyclical capital buffer in Basel III.[47]

[47] For savers, the benefit of these adjustments may be transactional: keeping τ_j low while increasing $\bar{\phi}_j$

In the case of corporate loans, savers' and borrowers' favorite optimized policies coincide even more clearly than in the case of mortgages about the convenience of higher average capital charges than under Basel II, while the discrepancies regarding the sensitivity of these charges to time variation in the corresponding PD are larger: borrowers' preferred policy involves no cyclicality, while savers's preferred policy features roughly the same cyclicality as a point-in-time implementation of the IRB formula.

How would lending standard be affected by the switch from the calibrated to the optimized capital requirement policies? To discuss this, we focus on the optimized policy that maximizes savers' welfare ($\xi = 1$), which is the most restrictive. As discussed in Section 3, the increase in capital requirements has a number of different effects on lending standards. In Figure 1 before we only showed the direct effect from forcing banks to finance a larger fraction of the loans with more expensive equity financing and, hence, they enjoy less of a subsidy from insured deposits. Variables determined at market level, such as the bank debt spread, were held fixed. In equilibrium, however, higher capital requirements also imply lower bank fragility and, hence, lower debt funding costs for the bank. Figure 8, where the vertical line identifies borrowers' leverage under the baseline calibration, shows that the tightening direct effect dominates, although dampened by the debt funding cost effect. Quantitatively the tightening of the standards is bigger for mortgage loans than for corporate loans, which is consistent with the view that pre-crisis regulation might have been specially lax with respect to mortgage lending.

6. Understanding the Results

In this section we aim at understanding the role of shocks and parameters for the results. First we investigate the relative importance of shocks as sources of the welfare gains. Second, we explore the sensitivity of our main results to changes in key model parameters.

6.1 Sources of Welfare Gains

This paper explores the role of capital regulation policy in the presence of a rich stochastic structure. The optimal policy is not ex ante targeted to smooth any particular source of fluctuations. However, in order to understand the sources of the welfare gains observed in prior

contributes to make borrowers no worse off than under the baseline policy, hence satisfying the Pareto improving constraint of the social welfare maximization problem.

sections, we now assess the welfare gains under the benchmark optimized policy ($\zeta = 0.26$) when one or several of the aggregate shocks are shut down. This gives us a measure of which are the shocks whose accommodation matter the most for the welfare gains associated with the optimal capital requirement policy.

Table 3: Welfare Gains

	Savers	Borrowers
(i) All shocks	0.60	0.60
(ii) No risk shocks	0.44	0.15
- No *bank return risk* shocks	0.46	0.21
- No *housing return risk* shocks	0.60	0.60
- No *entrepreneurial capital return risk* shocks	0.59	0.51
(iii) No other shocks	0.60	0.57
(iv) No aggregate uncertainty	0.43	0.11

Second-order approximation to the welfare gains (% of permanent consumption) associated with the benchmark optimized policy vs. the calibrated policy across experiments in which no, several or all aggregate shocks are shut down.

Table 3 reports the welfare gains of savers and borrowers (in percent of permanent consumption) when all the shocks are present (part (i)) and when all or each of the three risk shocks are shut down (part (ii)).[48] It also shows the welfare gains that remain when aggregate shocks other than the risk shocks are shut down (part (iii)) and when all sources of aggregate uncertainty are shut down (part (iv)). Note that in all cases, agents are still subject to the idiosyncratic shocks to their assets' returns.

The most striking finding from this table is the drastic reduction in borrowers' welfare gains in the absence of risk shocks, which in positive terms means that stabilizing the impact of these shocks makes a large contribution to borrowers' welfare. Accommodating the shocks affecting the dispersion of the returns of bank assets is the most important source of gains: it explains about 65% and 23% of borrowers' and savers' welfare gains, respectively.[49] Dealing with risk shocks to entrepreneurial capital returns is important for borrowers (account for about 15% of their gains) but not for savers. Risk shocks to housing returns do not seem to explain the welfare gains of any of the two classes of agents. Differently from entrepreneurial risk

[48] The risk shocks are shocks to the standard deviation of the idiosyncratic shocks that affect the returns of the assets of each of the borrowing classes of agents in our economy.

[49] The fractions of bank default explained by aggregate and idiosyncratic shocks are about 40 and 60 per cent, respectively. Thus, aggregate shocks are important drivers of bank fragility in the model.

shocks (which affect physical capital and get transmitted to the whole economy via wages), the housing risk shock only affects the borrowers, who, faced with larger default risk, reduce their leverage and put downward pressure on house prices. Saving households, however, respond in an offsetting manner by increasing their demand for housing and their consumption. Eventually, the aggregate effects turn out to be tiny.

To complete this discussion, Figures 9 and 10 show how the economy reacts to risk shocks to bank returns and entrepreneurial capital returns, which are the shocks whose accommodation under the optimized policy makes a larger contribution to welfare gains. Both shocks have a positive impact on bank default probabilities under the baseline calibrated policy (solid lines). Bank fragility, with its impact on the bank debt spread, bankers' net worth, and, through it, the supply of loans, is key to the transmission of these shocks. The contraction in credit supply gets transmitted to the real economy in the form of lower investment, depressed wages, and eventually lower consumption and lower GDP.

Under the benchmark optimized policy (dashed lines) the effects of both risk shocks get significantly dampened. Higher capital requirements (and, secondarily, a lower sensitivity of the requirements to time variation in the PD of the corresponding loans) make the economy more resilient to these shocks. The optimized policy almost completely offsets the effects of a bank risk shock (Figure 9): the high level of capital requirements, by keeping bank defaults and bankers' net worth losses close to zero, avoids the contractionary impact of the rise in bank funding costs and the fall in credit supply that would have otherwise occurred. In contrast, the capacity of capital requirement policy to dampen the impact of entrepreneurial capital return risk shocks is more limited (Figure 10). Entrepeneurial risk shocks affect in first instance the default risk of the entrepreneurs, who react by deleveraging and, thus, by reducing their demand for bank loans and their investment, even if loan supply remains little or not affected. Higher capital requirements help by protecting banks from solvency risk when an entrepreneurial risk shock hits. Such shock increases corporate loan defaults. Well capitalized banks can withstand the implied losses without failing in large numbers, so preventing a large rise in the cost of debt funding for all banks, a large loss of bankers' net worth and a large contraction in credit.

Part (iv) in Table 3 also shows that a large fraction of savers' welfare gains (67%) remains even after all sources of aggregate uncertainty are shut down. Thus, the benchmark optimized policy benefits the savers largely through steady state gains. The root of such gains is the way capital requirements deal with the idiosyncratic shocks that hit the asset returns of borrowing agents, most notably the banks. Protected by limited liability and deposit insurance, the bankers fail to internalize part of the bankruptcy costs caused by high leverage and capital requirements can contribute to reduce the implied deadweight losses. Savers appropriate part of the saved resources through the reduction in the taxes needed to cover deposit insurance costs and through the higher dividend payouts received from entrepreneurial firms and banks, which are in turn the result of a more restricted supply of credit.

In the case of borrowers, the net welfare gains appropriated in the absence of aggregate uncertainty are more limited (less than 20% of their total gains), because their gains coming from the reduction in bank default risk (e.g. the lower taxes needed to cover deposit insurance costs) are offset by the higher cost of bank loans and more restricted credit access. On net, borrowers benefit mainly from the stabilization of aggregate risk, whereas savers benefit from a better absorption of both aggregate and idiosyncratic risk.

6.2 Sensitivity Analysis

In this section we examine how our policy and welfare results depend on the following key model parameters: (i) the rate at which bankers survive and reinvest their net worth as bank capital (θ^b), which determines the scarcity of bank capital in the model; (ii) the insured fraction of bank debt (κ), which measures the importance of the safety net subsidies enjoyed by banks; (iii) the parameter that governs deadweight default losses (μ), which are the key source of first order losses associated with financial fragility. We present our results compactly through the secondary (non solid) lines included in Figures 4 and 5. Each of those lines show the optimal policy parameters and the associated welfare gains under a ceteris paribus variation in our benchmark calibration. The overall message is that, although the quantitative results get somewhat modified, our main conclusions are remarkably robust.

Cost of equity (dashed-dotted lines). Increasing θ^b so as to reduce the average rate of return on bank equity to 7.2% (from 9.3% in the baseline calibration) leads to higher optimal capital requirements for the two types of loans. Intuitively, with more abundant equity funding, reaching a given level of resilience is less costly in terms of credit supply and the optimal policy reacts to this by demanding banks to operate with more capital. As reflected in Figure 5, in the setup in which equity is more abundant borrowers tend to gain more from optimal capital regulation since the implied credit contraction effects are smaller, while savers' gains are quite similar to those under the baseline calibration.

Safety net guarantees (dashed lines). We look at the interesting polar case where all bank debt is uninsured (κ=0) and hence bank failures produce no tax cost on either savers or borrowers. Importantly, the safety net subsidies disappear but the limited liability distortion associated with the assumption that the cost of bank debt is not explicitly contingent on banks' leverage remains.[50] In these conditions, removing deposit insurance makes banks' debt funding more expensive and more responsive to shocks, reducing banks' resilience and increasing their potential contribution to the propagation of shocks. In response, the optimal capital requirements for both types of loans increase, although the quantitative impact is not dramatic. Without safety net subsidies, savers' gains from optimal capital regulation are smaller (since there are no gains from the reduction in the tax cost of deposit insurance), while, somewhat paradoxically, borrowers' gains from tightening the requirements are larger (because reinforcing banks' resilience when starting from low values reduces bank funding costs and, in general equilibrium, may relax lending standards).

Deadweight default losses (dotted lines)**.** A lower value for the fraction of borrower assets that are lost in the event of bankruptcy (μ) leads to lower capital requirements for both mortgage and corporate loans. Intuitively, capital regulation is the tool used, among other things, to make banks internalize the implications of default for the wider economy. In fact, economizing on these costs is the main source of first order gains from reducing banks' leverage. Higher capital requirements, through their impact on lending standards and banks' resilience, reduce the default risk of all borrowing sectors. When default implies smaller deadweight losses, the required reinforcement of capital requirements is smaller than under the baseline calibration. As one can see in Figure 5, in this situation, the optimal policies imply lower welfare gains (relative to the regulatory baseline) for both savers and borrowers than under the baseline calibration.

[50] Intuitively, we assume that individual banks are too opaque to make their funding costs explicitly contingent on their risk profile. Instead, each individual bank pays an interest rate on its debt which depends on the average risk of the banking system, which is beyond the control of any individual atomistic bank. This provides incentives for individual banks to take on risk in the form of as much leverage as permitted by capital regulation.

7. Conclusions

This paper significantly extends and improves the model developed in Clerc et al. (2015), calibrates it to Euro Area data, and examines its implications for the optimal calibration of Basel-type dynamic capital requirement rules. The analysis addresses upfront the potential conflicting interests of savers and borrowers regarding the adequate level of capital funding demandable to each class of loans and its time variation in response to changes in the default risk of the corresponding loans.

We find that if capital requirements start from low levels, as under the pre-crisis Basel II regime, both savers and borrowers gain from increasing them. Capital requirements should be much higher, especially for mortgage loans, and feature less sensitivity to time-variation in the PDs of the underlying loans than if using point-in-time estimates of them to feed the current IRB formulas. Borrowers benefit generally more than savers from dampening the potential procyclical effects of such IRB formulas.

A close look at the optimized policy rules uncovers that the most important aspect of capital requirement policy is to ensure that bank default is close to zero. Micro- and macroprudential considerations seem aligned in this respect. Having resilient banks minimizes the deadweight costs of bank defaults and shuts down bank-related amplification channels, thus stabilizing the reaction of the economy to aggregate shocks. Our results confirm that capital charges for a typical mortgage must generally be lower than capital charges for a typical corporate loan, but the differences between those charges under the optimized policy rules are generally lower than those implied by the current IRB formulas.

The parameters that control the extent to which the capital requirements vary in response to time variation in the default risk of the corresponding loans have a less sizeable impact on social welfare since they affect volatilities and, hence, second order terms. Our results suggest that such variation benefits savers at the expense of borrowers because it helps to keep banks safe but destabilizes borrowers' consumption. Borrowing households dislike the time variation induced by PD-sensitive capital charges because it increases their borrowing costs in states of the world in which their consumption is already low. This finding supports the convenience of using 'through-the-cycle' as opposed to 'point-in-time' default frequencies when computing bank capital requirements over the cycle, as well complementary cyclicality-dampening tools such as the countercyclical capital buffer of Basel III.

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Appendices

A Market clearing conditions

In equilibrium the following add-up and market clearing conditions must hold. The total mass of households has been normalized to one, so savers and borrowers have measures $x_s = x_w + x_e + x_b = 1 - x_m$ and x_m, respectively, where x_m as well as the composition of x_s are exogenous. The aggregate housing stock equals the house holdings of the two dynasties:

$$h_t = x_s h_{s,t} + x_m h_{m,t}.$$

Total demand for households' labor by the consumption good producing firms equals the labor supply of the two dynasties:

$$l_t = x_w l_{s,t} + x_m l_{m,t}.$$

total households' consumption equals the consumption of the two dynasties:

$$c_t = x_s c_{s,t} + x_m c_{m,t}.$$

Bank debt held by patient households, d_t, must equal the sum of the debt issued by banks making loans to households, $(1 - \phi_{M,t})x_m b_{m,t}$, and to entrepreneurs, $(1 - \phi_{F,t})x_e b_{f,t}$:

$$d_t = (1 - \phi_{M,t})x_m b_{m,t} + (1 - \phi_{F,t})x_e b_{f,t}.$$

Equity financing provided by bankers (equal to their entire net worth) must equal the sum of the demand for bank equity from the banks making loans to households, $e_{M,t} = \phi_{M,t} x_m b_{m,t}$, and entrepreneurs, $e_{F,t} = \phi_{F,t} x_e b_{f,t}$:

$$n_{b,t} = \phi_{M,t} x_m b_{m,t} + \phi_{F,t} x_e b_{f,t},$$

where our prior derivations imply

$$b_{f,t} = [q_{k,t} k_{f,t} - a_t]$$

and

$$b_{m,t} = \frac{q_{h,t} h_{m,t} x_{m,t}}{R_t^M},$$

so total bank loans are given by

$$b_t = x_m b_{m,t} + x_e b_{f,t}.$$

The capital held by patient households and by entrepreneurs must sum up to the total capital stock:

$$x_s k_{s,t} + x_e k_{f,t} = k_t.$$

Total output Y_t equals households' consumption c_t, plus the resources absorbed in the production of new housing $I_{h,t}$ and new capital $I_{k,t}$ plus the resources lost in the repossession by banks of the proceeds associated with defaulted bank loans and in the repossession by the

DIA and the holders of uninsured bank debt of the proceeds associated with defaulted bank debt:

$$\begin{aligned} Y_t &= c_t + I_{h,t} + I_{k,t} \\ &\quad + x_m \mu_m G_{m,t}\left(\overline{\omega}_{m,t}\right) R_t^H q_{h,t-1} h_{m,t-1} + x_e \mu_f G_{f,t}\left(\overline{\omega}_{f,t}\right) R_t^K q_{k,t-1} k_{f,t-1} \\ &\quad + \mu_b \left[G_{M,t}\left(\overline{\omega}_{M,t}\right) \widetilde{R}_t^M x_m b_{m,t} + G_{F,t}\left(\overline{\omega}_{F,t}\right) \widetilde{R}_t^F x_e b_{f,t} \right]. \end{aligned}$$

The risk free asset is assumed to be in zero net supply

$$x_s B_t = 0.$$

The total costs to the DIA due to losses caused by M and F banks, and hence the total lump sum tax imposed on agents in order to finance the agency on a balanced-budget basis, are given by

$$T_t = \kappa \Omega_t d_{t-1} \tag{34}$$

where Ω_t is average default loss per unit of bank debt, which is the properly weighted average of the losses realized at each class of bank:

$$\Omega_t = \frac{d_{M,t-1}}{d_{t-1}} \Omega_{M,t} + \frac{d_{F,t-1}}{d_{t-1}} \Omega_{F,t} \tag{35}$$

with

$$\Omega_{j,t} = \left[\overline{\omega}_{j,t} - \Gamma_{j,t}\left(\overline{\omega}_{j,t}\right) + \mu_j G_{j,t}\left(\overline{\omega}_{j,t}\right)\right] \frac{\widetilde{R}_{j,t}}{1-\phi_{j,t}}$$

for $j = M, F$.[51]

Similarly, for reporting purposes, we define banks' average probability of default as

$$\Psi_{b,t} = \frac{d_{M,t-1}}{d_{t-1}} \Psi_{M,t} + \frac{d_{F,t-1}}{d_{t-1}} \Psi_{F,t}, \tag{36}$$

where $\Psi_{j,t} = F_{j,t}(\overline{\omega}_{j,t})$ for $j = M, F$.

The lump-sum tax T_t is paid by households of each class in proportion to their size in the population, implying

$$T_{\varkappa,t} = \frac{n_\varkappa}{n_s + n_m} T_t \tag{37}$$

for $\varkappa = s, m$.

[51] Remember that the remaining fraction $1-\kappa$ of the default losses are directly incurred by the saving households, as reflected in (5).

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.[52]

- 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.

- 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

[52] All monetary financial institutions in the Euro Area 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).

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 Euro Area 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.

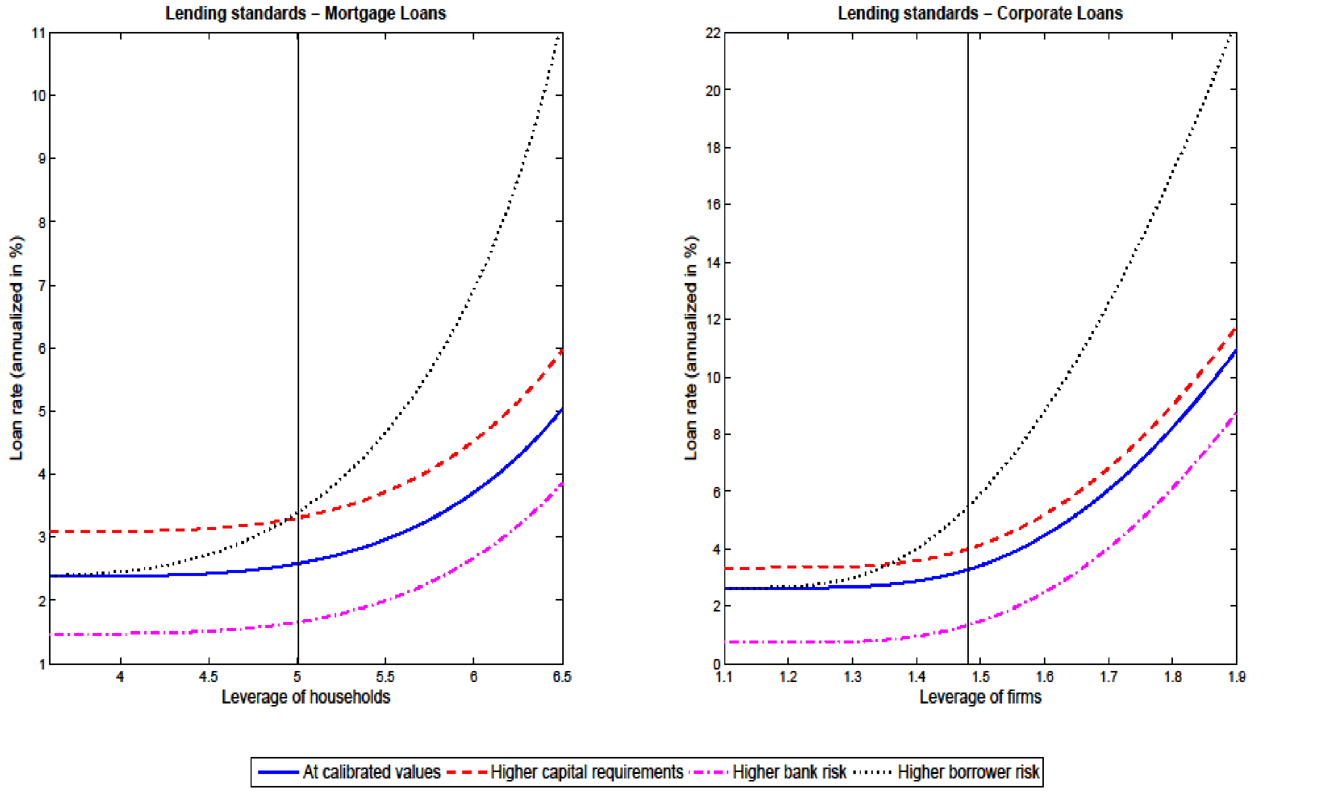

Figure 1. Determinants of Bank Lending Standards. Bank lending standards at calibrated parameters (solid line), higher standard deviation of the idiosyncratic shocks to loan portfolio returns (dashed-dotted line), higher capital ratios (dashed line), and higher standard deviation of idiosyncratic shocks to borrowers' asset returns (dotted line). Vertical lines identify borrowers' leverage under the baseline calibration.

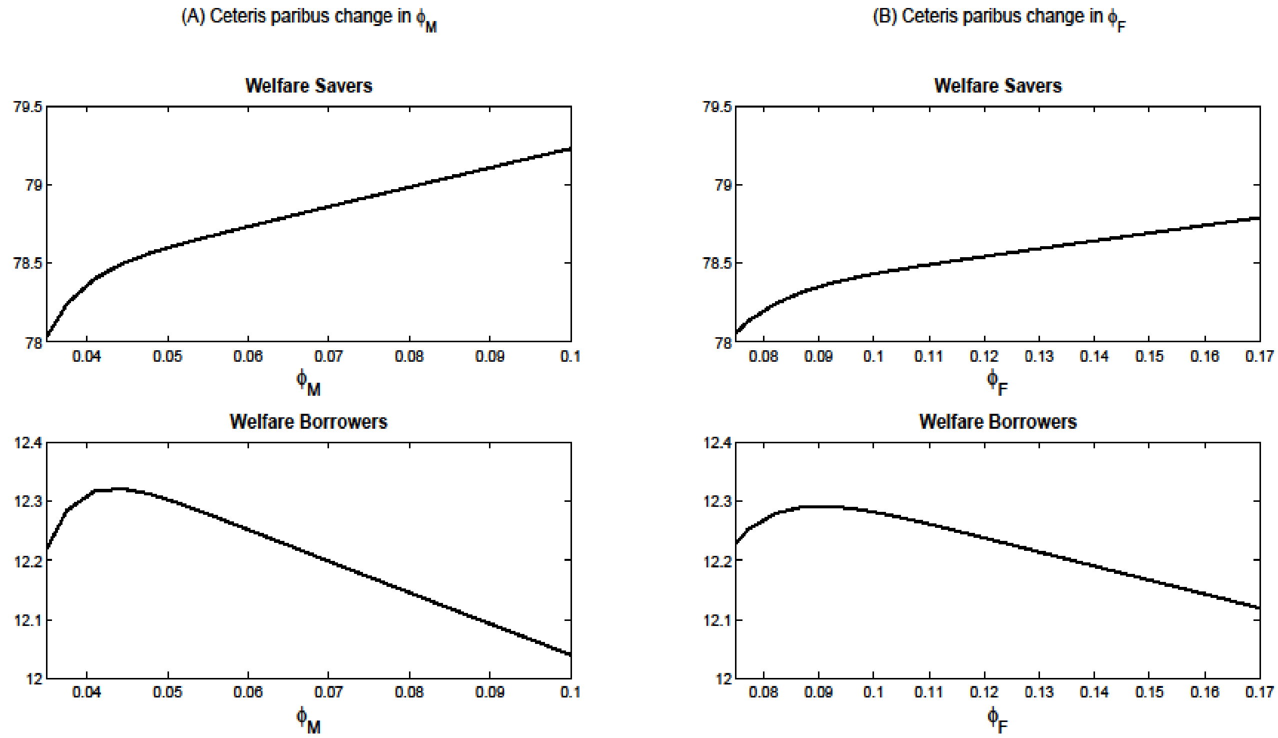

Figure 2. Welfare Impact of Changes in Capital Requirement Levels. Savers' and borrowers' welfare are depicted as functions of the policy parameter determining the level of the capital requirements applicable to mortgage loans (column A) and corporate loans (column B). While changing one parameter, we keep the other equal to its calibrated value.

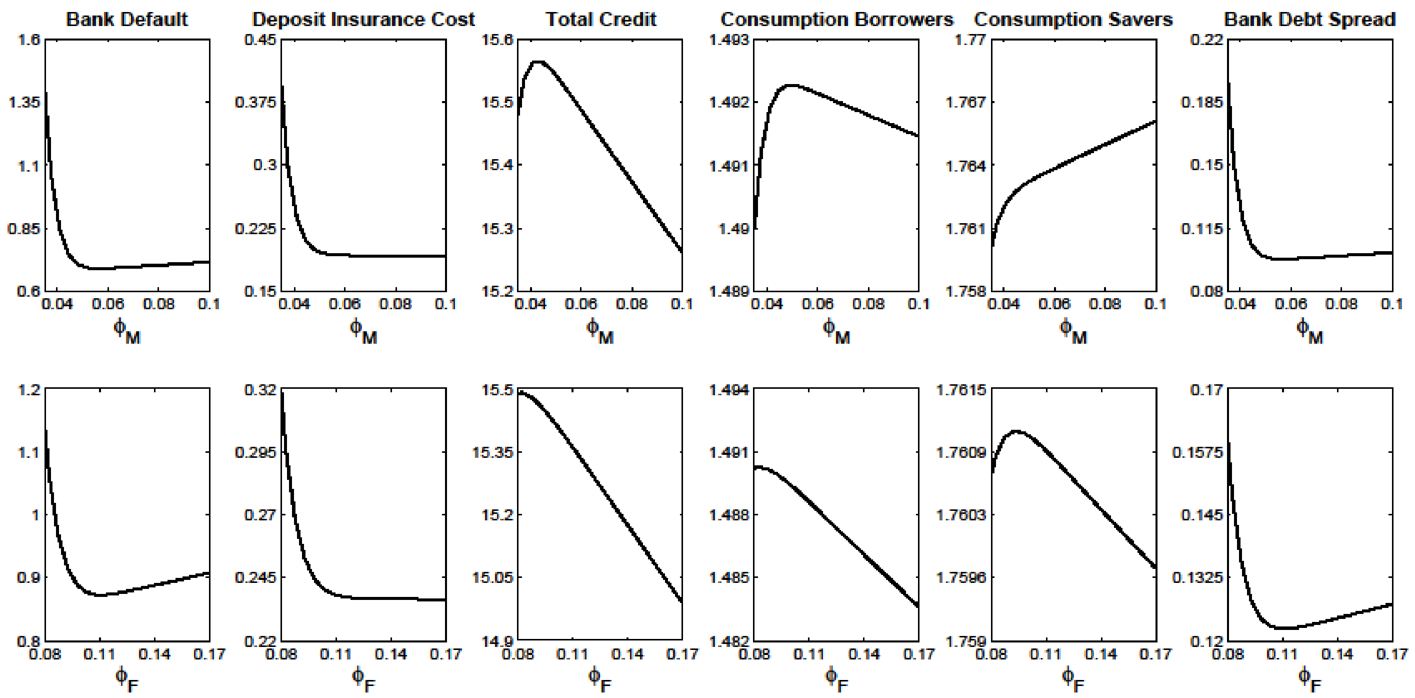

Figure 3. Impact of Changes in Capital Requirement Levels on Key Variables. Stochastic means of key variables as function of the policy parameter determining the level of the capital requirements applicable to mortgage loans (row A) and corporate loans (row B). While changing one parameter, we keep the other equal to its calibrated value. The probability of bank default and the bank debt spread are in annualized percentage terms, the deposit insurance cost is measured as percentage of GDP.

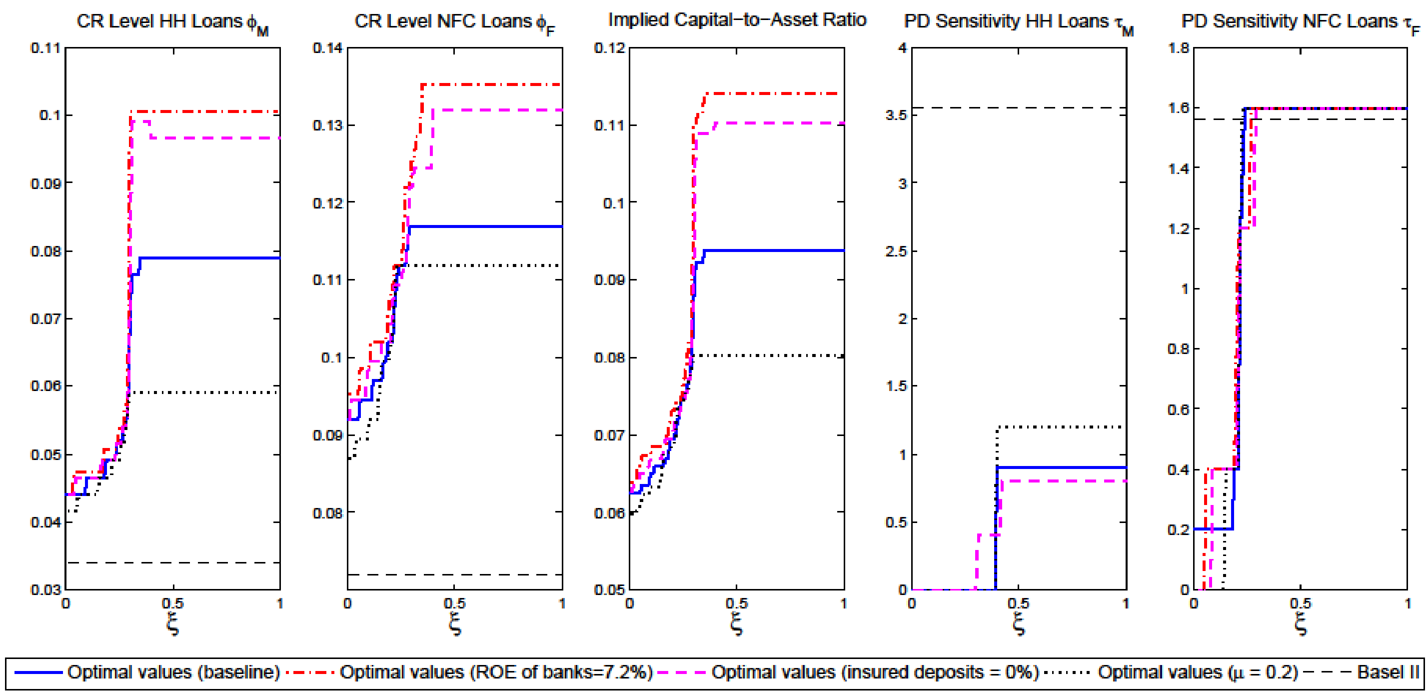

Figure 4. Optimal Dynamic Capital Requirements. Parameters characterizing the welfare maximizing policy rule and the implied average capital-to-asset ratio for each banks are depicted as functions of the weight ξ that the maximized social welfare measure puts on savers' welfare. The two panels on the left describe the optimized values of the parameters that determine the average level of the capital requirements for mortgage (HH) and Corporate (NFC) loans. The two panels on the right describe the optimized PD sensitivities of the requirements to time changes in the PDs of the corresponding loans.

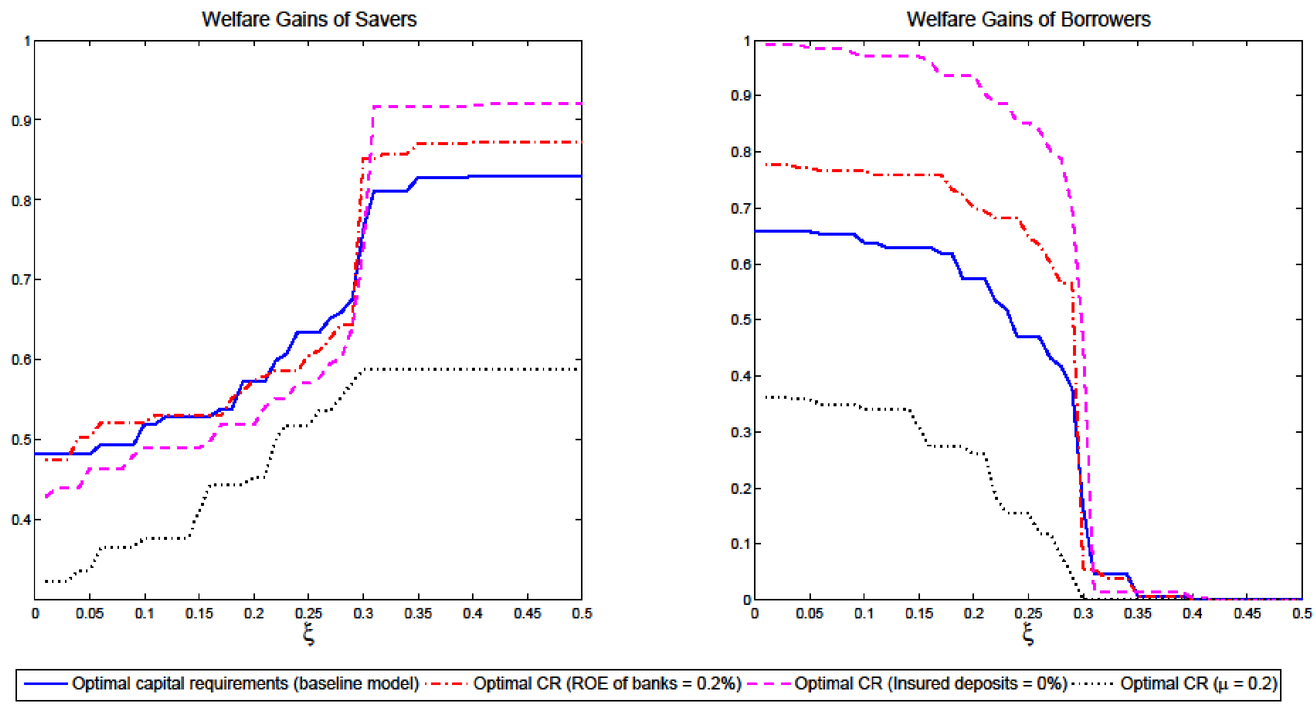

Figure 5. Sensitivity Analysis: Welfare Gains. Individual welfare gains implied by the optimal policy corresponding to each value of the weight ξ that the maximized social welfare measure puts on savers' welfare under the baseline and alternative values of key parameters. The gains are measured in consumption-equivalent terms, as the percentage increase in the consumption of each agent that would make his welfare under the initially calibrated policy rule equal to his welfare under each optimized poliy rule.

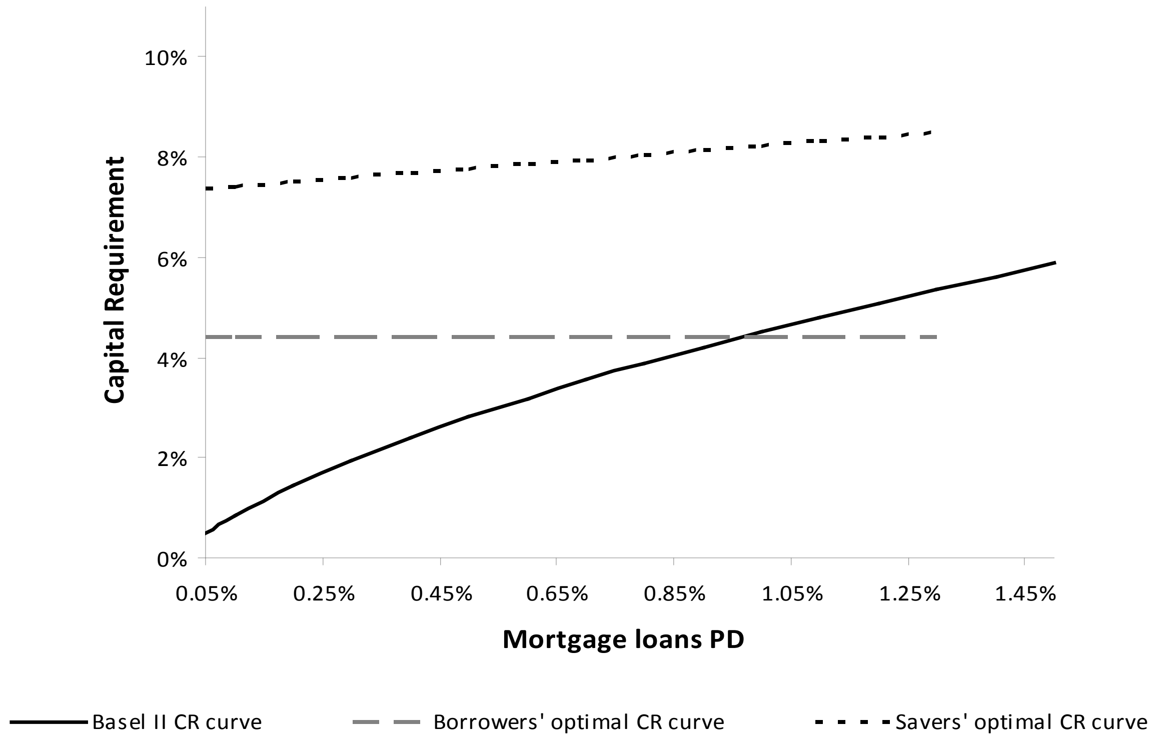

Figure 6. Basel vs. Optimal Capital Requirements: Mortgage Loans. The solid line depicts the capital requirements (CR) curve implied by the formula of the internal ratings based (IRB) approach of Basel II and III. The dotted line describes the (linear) CR curve implied by savers' preferred optimized policy (ξ =1). The dashed line describes the (linear) CR curve implied by borrowers' preferred optimized policy (ξ =0). These lines are described over the range covering two standard-deviation bands around the stochastic mean of the PD of loans under the corresponding policy.

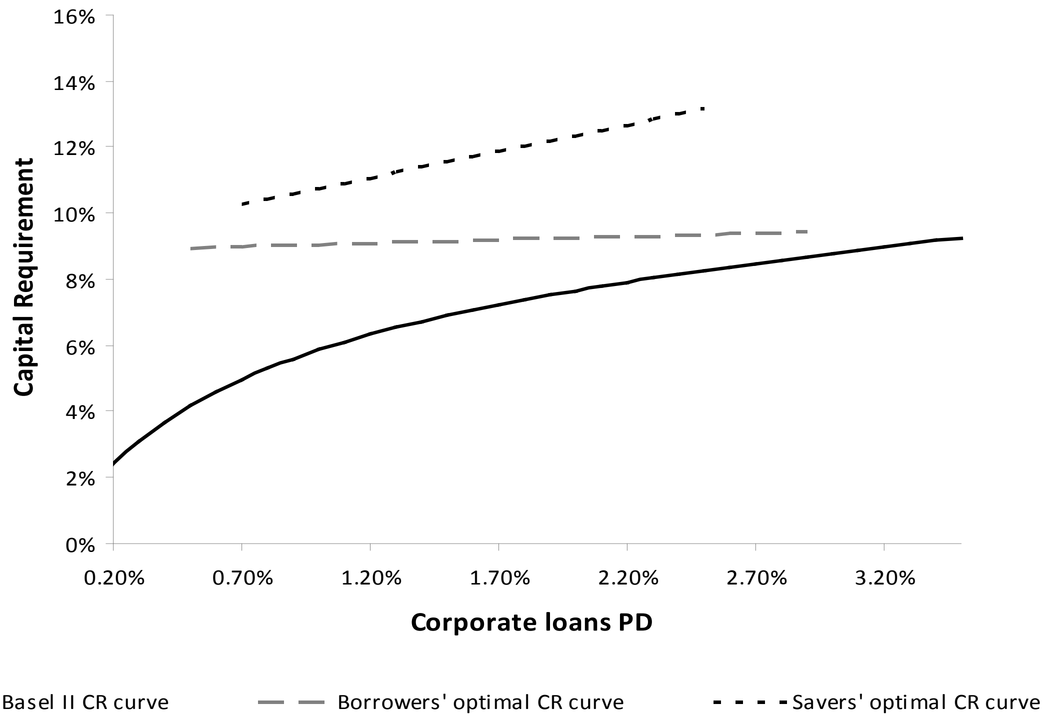

Figure 7. Basel vs. Optimal Capital Requirements: Corporate Loans. The solid line depicts the capital requirements (CR) curve implied by the formula of the internal ratings based (IRB) approach of Basel II and III. The dotted line describes the (linear) CR curve implied by savers' preferred optimized policy (ξ =1). The dashed line describes the (linear) CR curve implied by borrowers' preferred optimized policy (ξ =0). These lines are described over the range covering two standard-deviation bands around the stochastic mean of the PD of loans under the corresponding policy.

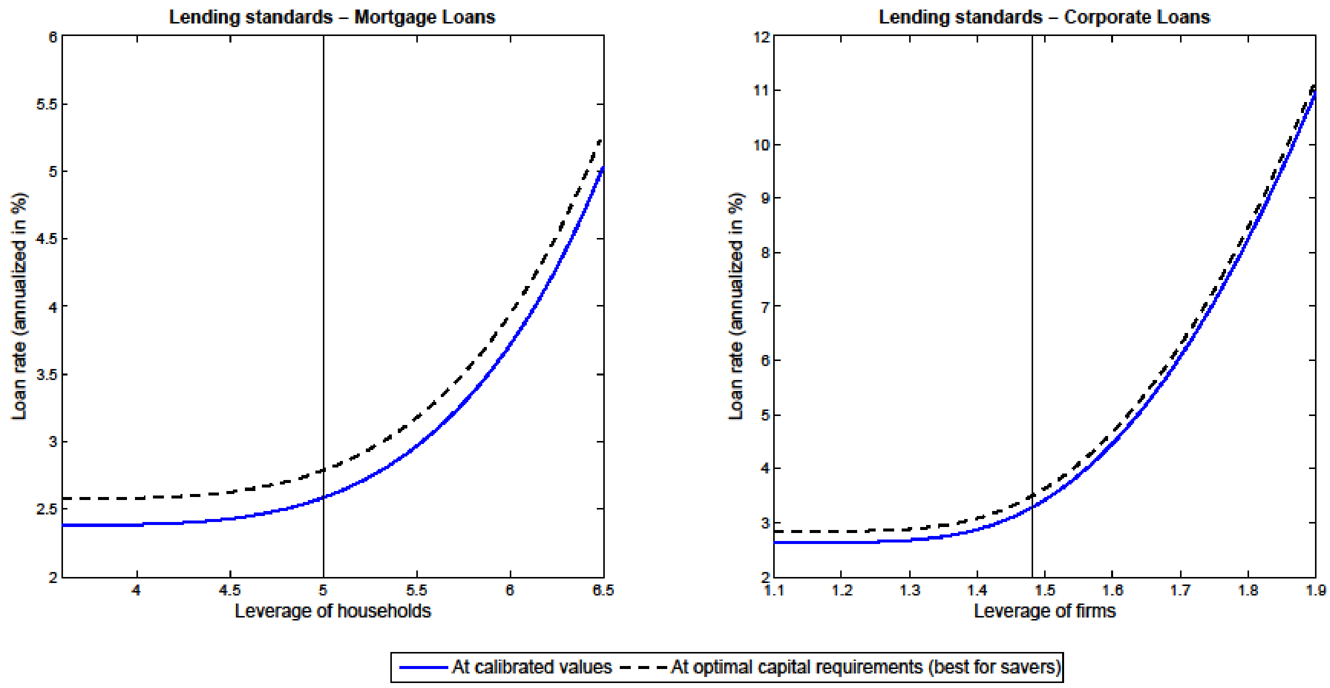

Figure 8. Impact of the Optimal Capital Requirements on Lending Standards. Bank lending standards at calibrated capital requirements (solid line) and at savers' preferred optimized capital requirement policy (dashed line). Vertical lines identify borrowers' leverage under the baseline calibration.

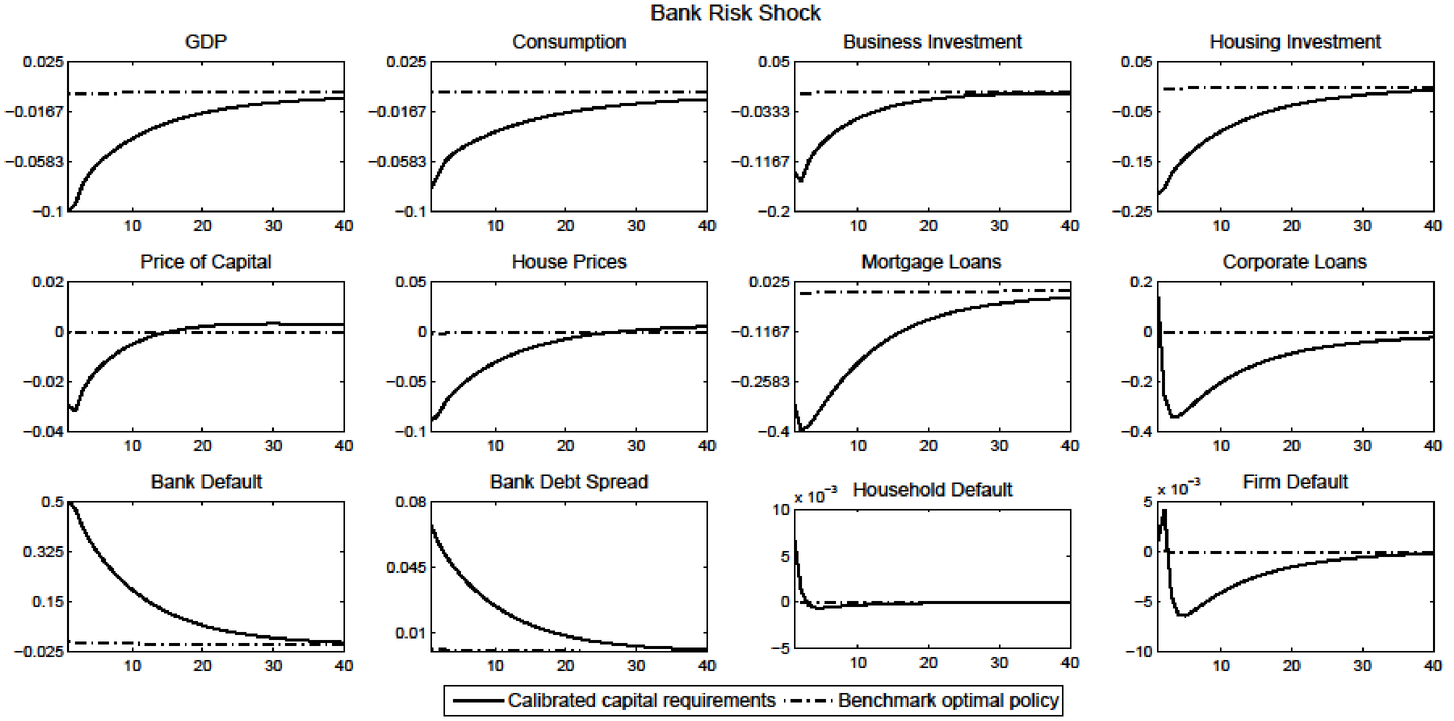

Figure 9. Impact of Policy on the Transmission of a Bank Risk Shock. Impulse-response functions to a one-standard deviation negative risk shock to bank asset returns under two alternative capital regulation policies: calibrated (solid line) and benchmark optimized (dashed-and-dotted line) policy. The response of the bank default rate, bank debt spread, and the default rates of mortgage and corporate loans are reported in annualized percentage-point deviations from the steady state. All other variables are in percentage deviations from the steady state.

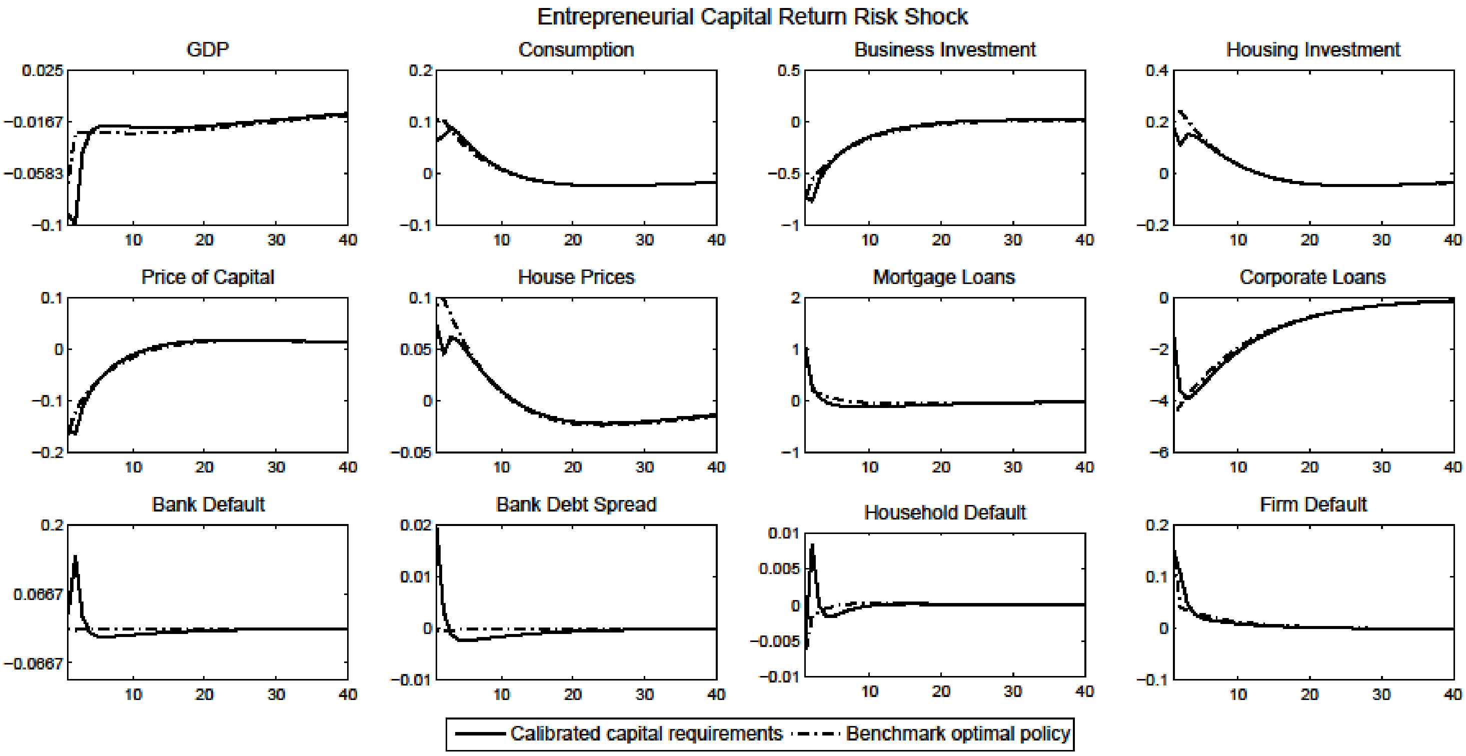

Figure 10. Impact of Policy on the Transmission of an Entrepreneurial Capital Return Risk Shock. Impulse-response functions to a one-standard deviation negative risk shock to entrepreneurial capital returns under two alternative capital regulation policies: calibrated (solid line) and benchmark optimized (dashed-and-dotted line) policy. The response of the bank default rate, bank debt spread, and the default rates of mortgage and corporate loans are reported in annualized percentage-point deviations from the steady state. All other variables are in percentage deviations from the steady state.