IHS Working Paper 13
April 2020

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ZVR: 066207973

Funder(s)

Austrian Science Fund (FWF)

Long-term bank lending and the transfer of aggregate risk*

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April 2, 2020

Abstract

Long-term debt contracts transfer aggregate risk from borrowing firms to lending banks. When aggregate shocks increase the future default probability of firms, banks are not compensated for the default risk of existing contracts. If banks are highly leveraged, this can lead to financial instability with severe repercussions in the real economy. To study this mechanism quantitatively, we build a macroeconomic model of financial intermediation with long-term defaultable loan contracts and calibrate it to match aggregate firm and bank exposure to business cycle risks. Our model exhibits banking crises that closely resemble observed crisis episodes. We find that such crises do not arise in an economy with short-term debt.

Our results on the role of long-term debt completely reverse if financial regulation is implemented to increase banks' risk bearing capacity. The financial sector is then well equipped to take on the aggregate risk, such that long-term lending stabilizes the business cycle by providing insurance to the corporate sector.

JEL Classification: E32, E43, E44, G01,G21

Keywords: Banking; Financial frictions; Maturity transformation

*We thank Charles Calomiris, Tom Cooley, Florian Exler, Thomas Gehrig, Joachim Jungherr, Anton Korinek, Michael Kumhof, Iacopo Morchio, Paul Pichler, Hugo Rodriguez, Martin Summer, Oreste Tristani, Stijn Van Nieuwerburgh, Pablo Winant, Martin Wolf, and conference participants at the ECB Invited Speaker Seminar Series in the Directorate General Research 2017, the Barcelona GSE Summer Forum 2017 and the VGSE for useful comments and discussions. The authors gratefully acknowledge the financial support by the Austrian Science Fund (FWF) Grant Nr. I 3840-G27. Leopold Zessner-Spitzenberg further gratefully acknowledges the financial support by the Vienna Graduate School of Economics funded by the FWF: W 1264 Doktoratskollegs (DKs).

1 Introduction

What is the role of the banking sector for the macroeconomy? In "normal times", such as the period from the 1950s until the late 1980s or the 'Great Moderation' between the early 1990s and 2008, the state of the banking sector is not on the radar screen of most macroeconomists. Both of these periods of calm, however, ended with financial crises which had large and persistent adverse consequences for the macroeconomy.

We argue that these facts can be explained by two features of the banking sector. First, banks are highly leveraged and cannot easily issue new equity. Second, they extend long-term loans and these loans are subject to default risk. The return on a portfolio of long-term loans is affected little by small macroeconomic fluctuations, but is very sensitive to (persistent) changes in the borrower default rate. Since borrowers can buffer small losses without going bankrupt, the economy wide default rate increases significantly only in case of large shocks. These features explain why highly leveraged banks can operate most of the time without affecting the macroeconomy, and why severe crises can be caused by relatively modest increases in borrower defaults.

Notice that this argument relies on the *asset* side of bank balance sheets. Some very well known economic models (classical references are Diamond and Dybvig (1983) and Bryant (1980), a recent contribution is Gertler and Kiyotaki (2015)) attribute banking crises to the debt side, where bank financing by demand deposits can give rise to multiple equilibria, and one of them includes a bank run that makes banks illiquid. Our explanation is simpler: banks hold assets with an asymmetric and highly nonlinear return structure. The transfer of aggregate risk from borrowers to banks subjects the banking sector to a solvency risk. The two approaches have different policy implications: runs can be avoided by deposit insurance or a lender of last resort, we will argue that the solvency problem needs to be addressed by precautionary regulation.

Our main contribution is to develop a macroeconomic model of financial intermediation with long-term defaultable loan contracts, which establishes the quantitative importance of the mechanism described above. In the model, banks collect deposits from households and lend to firms in order to finance their investment.[1] Banks are subject to regulatory capital requirements in the spirit of the Basel II regulations in place before 2008, and firms are subject to financing frictions as in Bernanke, Gertler, and Gilchrist (1999). As a result, losses incurred in either sector can affect the flow of funds from savers to ultimate borrowers. We then calibrate the model to match each sectors' exposure to aggregate risk, targeting first and second moments of corporate and bank default rates and the interest rate spread. With the introduction of long-term loans our model can

[1] We don't explicitly model why banks perform this intermediation. See e.g.Calomiris and Kahn (1991) for a model where intermediearies with this balance sheet structure emerge endogenously.

match a wide range of business cycle moments. Our focus lies on moments related to bank and firm financing, which are informative about the mechanisms we study. In particular the model generates levels and dynamics of investment, corporate and bank defaults as well as the interest rate spread close to the data.

We find that the calibrated model endogenously gives rise to financial crises which are qualitatively and quantitatively similar to the crises observed in the data. First, bank financing frictions play no role during normal times. As long as shocks are small or medium-sized, economic dynamics is not significantly affected by the presence of the financial sector. Second, occasionally severe financial crises occur due to the interaction of several nonlinearities. Adverse shocks have a strongly nonlinear effect on borrower defaults, which translate to losses in the banking sector. Banks accumulate small equity buffers in good times, which allow them to absorb some losses. However, in the face of a large shock the equity buffer quickly erodes. A significant fraction of banks default and are at risk of violating their regulatory capital requirements, which leads them to reduce credit supply and raise lending rates. Finally, rising credit spreads reduce the value of outstanding long-term loans, giving rise to a financial accelerator mechanism, which further exacerbates bank financing problems. In a typical crisis episode, close to 0.8 percent of intermediaries default in the peak quarter, while the risk free rate falls close to zero and the lending rate spikes. The trouble in the financial sector amplifies the contraction in investment from 11 percent to 18 percent at the trough and leads to persistent losses in output. We show that these effects arise from the transfer of aggregate default risk, not because of the interest rate risk.

The mechanism described above rests crucially on the fact the bank assets are long-term loans. Previous macroeconomic theories have either assumed that banks invest in short-term loans (cf. for example (Chen 2001)) or in equity claims (Gertler and Karadi 2011). Short-term debt means that loans have a maturity of one model period, which is usually one quarter. It has the same payoff asymmetry as long-term debt, but it exposes lenders to very little business cycle risk since its return is only affected by the current default and interest rate. Begenau, Piazzesi, and Schneider (2015, Figure 5) shows that an asset portfolio with 5 year maturity carries aggregate risk that is an order of magnitude larger than that of an otherwise identical portfolio with 1-quarter maturity. This is reflected in our model: if debt contracts are short-term, banks never face significant losses, no financial crises occur, and bank balance sheets never affect business cycle dynamics. Equity, on the other hand, carries even more risk than long-term debt, but its payoff is not asymmetric. If banks mainly hold equity claims, any change in macroeconomic fundamentals directly affects their returns and bank balance sheets become major drivers of normal business cycles.

Since the underlying economic mechanisms are nonlinear, it is essential to use a nonlinear numerical solution method. Solving the benchmark calibration of our model by linearization (first-order perturbation), one would conclude that the banking sector does not affect business cycles at all. Financial crises occur in the model only when higher-order approximations are used. This argument seems to apply much more generally: if linear approximations are used, the financial sector is found to either drive business cycles always, as in Gertler and Karadi (2011), or never.

Our findings have important consequences for financial regulation. One can think of regulatory interventions to shorten loan maturities, and of macroprudential regulation of bank capital. We do not interpret our results in the direction that loan maturities should be shortened. It is widely recognized that long-term lending by banks is socially valuable, because it allows individual borrowers to transfer idiosyncratic refinancing risk to the bank. This value is not fully captured in our model. We rather think that the risk transfer inherent in long-term lending, and the resulting occurrence of financial crises, call for a macroprudential regulation of bank capital. We show that implementing higher and time-varying capital requirements in the spirit of Basel III strongly reduces the impact of banking sector frictions on economic dynamics. The effect of long-term lending on business cycle volatility reverses if banks are better capitalized. Our baseline economy features stronger business cycle fluctuations than an economy with the same fundamentals but short-term loans, due to rare crisis episodes. When macroprudential regulation requires banks to hold more equity, they are better equipped to absorb aggregate risk, and long-term lending makes business cycles smoother.

Given the importance of long-term bank credit, one might wonder why only a few papers in the macroeconomic literature model it. One possible reason is the difficulty of dealing with the incentive distortions, in particular debt overhang, associated with long-term corporate debt (seminal early contribution include Jensen and Meckling (1976) and Myers (1977); in a business cycle context, cf. Gomes, Jermann, and Schmid (2016), Jungherr and Schott (2019), Poeschl (2017)). Since the use of long-term debt is so widespread in the real world, we assume that banks have found a way to contain the incentive problems. We build on Jungherr and Schott (2018) and introduce debt covenants into our model that eliminate the incentive distortions.

In this paper we have tried to provide the simplest possible model that generates our key mechanisms, but we have designed the model such that it can be solved by standard higher-order perturbation techniques, which makes it very tractable numerically, and easy to extend. For this it is key to avoid run equilibria and occasionally binding constraints. Features that are probably relevant for a full understanding of the emergence of crises, and that we have left out here, include other borrower types, such as households, and other forms of loans, such as mortgages, which imply the same risk transfer mechanism that we study here. Introducing nominal rigidities, one could analyze the role of nominal bank assets and monetary policy for bank balance sheets and financial crises.

The rest of the paper proceeds as follows. Section 2 discuss the relationship over our paper to the existing Literature. Section 3 presents the model, which is calibrated in Section 4. Section 5 presents the results. Section 6 concludes.

2 Relationship to Existing Literature

2.1 Empirical literature

The empirical relevance of our key mechanism, the transfer of aggregate risk from firms to banks, is well established. Begenau, Piazzesi, and Schneider (2015) study the risk exposure of various bank asset and maturity classes in a factor model with aggregate interest and default factors. They find that the exposure to both types of risks increases steeply in maturity for a wide range of asset classes. English, Van den Heuvel, and Zakrajšek (2018) focus on the effects of interest rate surprises on bank equity valuations. Their results show that banks are exposed to significant interest rate risks, due to the maturity mismatch on their balance sheets. Drechsler, Savov, and Schnabl (2018) on the other hand find that the interest rate risk of long-term assets is hedged by bank's deposit taking franchise, which becomes more profitable when interest rates rise due to sticky deposit rates. While our framework is not rich enough to capture such an effect, our results do not depend on banks' exposure to fluctuations in the risk free interest rate. This is because fluctuations in default rates and credit spreads are the main source of risk to the financial sector in our model.

2.2 Theoretical literature

Following the empirical results, a number of recent contributions have developed business cycle models with long-term bank lending and borrower defaults. We see our analysis as complementary to the existing papers. Some of the mechanisms that we are studying might also be present in those models, but due to differences in the numerical solution method and/or the analytical focus, they are not coming to the forefront.

Our paper appears to be closest to Landvoigt, Elenev, and Nieuwerburgh (2018), who also solve a model with long-term debt and firm default. They analyze the effect of long-term debt on liquidity-based firm default, not the transfer of aggregate risk to the banking sector. Moreover, they limit the macroeconomic consequences of financial crises by assuming fixed labor input. Since they model banking regulation as an occasionally binding constraint that limits bank lending in aggregate downturns, they have to solve the model by global nonlinear methods, which is much more complicated than the perturbation approach that we use. Paul (2015) studies the endogenous emergence of financial instability during booms through the deterioration of lending standards. Illiquidity of the long-term loan portfolio can cause creditor runs, once default rates increase, leading to a credit crisis. The mechanisms triggering financial crises are very different to our paper, as crises emerge from fundamental insolvency in the banking sector in our model, while they are related to a loss of creditor confidence in Paul (2015). Ferrante (2019) solves a rich model with a financial sector that extends long-term corporate and mortgage loans in the presence of nominal rigidities. In his model defaults in one sector can cause intermediary capital to erode, leading to a contraction of lending in the other sector. He computes a first order solution and therefore does not capture precautionary behavior and the non-linearities associated with financial crises, which are at the core of our analysis. Boissay, Collard, and Smets (2016) provide a further mechanism, how rare and severe financial crises emerge in normal business cycles. They show that interbank markets can freeze due to information asymmetries and moral hazard. When overall bank profitability is low, weak banks have an incentive to mimic sound banks in order to attract interbank loans and default on them. Adverse selection then leads to a complete breakdown in interbank financing and a contraction in loans to the real economy. Similarly to a bank run this mechanism relies on discrete switches between different equilibria of the underlying game and is therefore difficult to handle by standard solution methods.

Our findings are in stark contrast to Andreasen, Ferman, and Zabczyk (2013). They study the role of long-term bank lending in a framework without borrower default. In the absence of default, long-term contracts shield the financial sector from business cycle risk. As a result, bank balance sheets matter less for business cycle dynamics if lending is long-term. The possibility of borrower default reverses this result in our model. In another theoretical contribution, Segura and Suarez (2017) study the consequences of maturity transformation, focusing on the risk arising from the short-term nature of bank funding. In their framework, an increase in banks' funding maturity can reduce the severity of liquidity crises. Essentially long-term funding provides banks with the same insurance as firms in our model. With longer maturity, they have to roll over less of their debts in periods when external funding is expensive. Our contribution is complementary to theirs, since we focus on the risk associated with long-term assets, rather than short-term funding.

3 The model

The setup of our model economy can be seen in Figure 1. The basic structure is similar to earlier contributions by Chen (2001) and Sunirand (2002). More recent studies with similar model setups include Iacoviello (2015), Landvoigt, Elenev, and Nieuwerburgh (2018) and Mendicino, Nikolov, Suarez, and Supera (2016).

Time in our model economy is discrete. There are two classes of agents, each with unit mass: households and entrepreneurs. Each agent holds a diversified portfolio of one type of firm. Households own banks and entrepreneurs invest in production firms.[2] Households supply labor, consume and save in bank equity and one-period bank deposits. Banks are subject to regulation: their deposits are insured and their leverage is limited by capital requirements. Entrepreneurs consume and invest their remaining net worth in production firms. In addition to their internal funds, firms use bank loans to finance their operations. Loans are long-term and expose banks to interest and default risks. Both, banks and firms face frictions in their access to debt financing, similar to those in Bernanke, Gertler, and Gilchrist (1999). We choose preferences to ensure that these financing frictions impact both credit supply and demand in equilibrium.

Except for our handling of the long-term lending contract, the model is close to the existing literature. We keep it as simple as possible in many dimensions, as our focus lies on studying the economic mechanisms associated with the presence of long-term debt contracts. The model is designed so that the numerical solution can be computed by standard perturbation techniques. The essential mechanisms of this paper can therefore be easily incorporated into larger models as they are used for policy analysis.

3.1 Households

Households choose consumption c_t and supply labor l_t. They save in risk free bank deposits d_t at interest rate R_t and a diversified portfolio of bank shares s_t^B, which pay dividends f_t^B. We assume that households have a linear preference ξ to hold safe and liquid deposits. This assumption creates a wedge between the required rates of return on equity and deposits, which gives banks an incentive to use deposit financing in equilibrium.[3] T_t is a lump-sum transfer related to the deposit insurance scheme. Households

[2] In equilibrium entrepreneurs would not want to invest in banks, but households have an incentive to invest in production firms. We assume that these firms do not have access to capital markets, which is why they rely on bank loans.

[3] Preference for liquid assets is a common assumption to create a motive for banks to use external financing. We follow Stein (2012) by assuming linear utility in deposits.

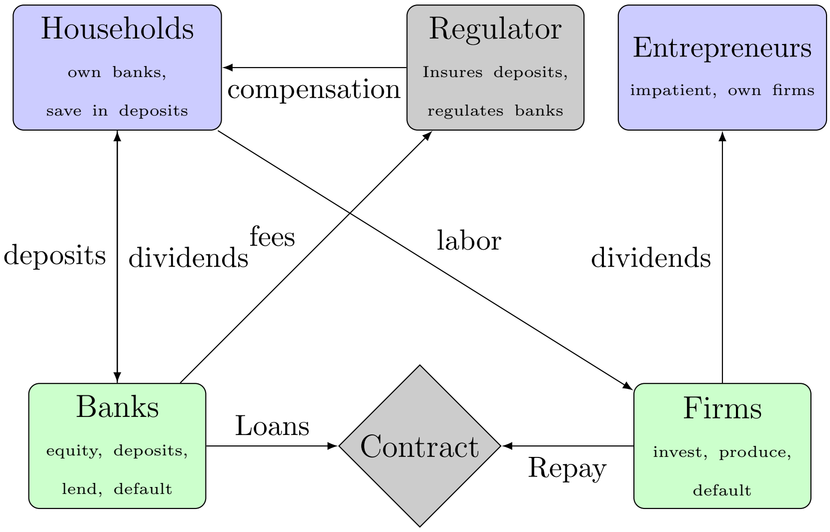

Figure 1: Structure of the model economy. Blue shaded boxes refer to the agents in our economy, green to the firms. The regulator does not solve an optimization problem, but conducts policy according to a given rule, the box is therefore shaded gray.

solve the following optimization problem:

$$\begin{aligned} \max_{\{c_t,d_t,s_t,l_t\}_{t=0}^{\infty}} \quad & \sum_{t=0}^{\infty} \beta^t \left(u^H(c_t,l_t) + \xi d_t\right) && (1) \\ \text{s.t.} \quad & \\ d_t = \quad & R_t d_{t-1} + w_t l_t - c_t + s_{t-1}^B f_t^B + T_t + P_t^B (s_t^B - s_{t-1}^B). \end{aligned}$$

Their consumption-savings decision is described by the Euler equation:

$$u_c^H(c_t,l_t) = \xi + \beta R_t \mathbb{E} u_c^H(c_{t+1},l_{t+1}). \tag{2}$$

Note that the liquidity premium ξ creates a wedge between the discount factor β and the risk free interest rate R. Households supply labor according to the standard static optimality condition:

$$w_t u_c^H(c_t,l_t) = u_l^H(c_t,l_t). \tag{3}$$

Households are homogeneous, so shares are not traded, and in equilibrium $s_t^B = 1$. Since banks are fully owned by the representative household, they use the following discount factor in their optimization problem:

$$\Lambda_{t,t+1}^H = \beta \frac{u_c^H(c_{t+1},l_{t+1})}{u_c^H(c_t,l_t)}. \tag{4}$$

3.2 Production and technology

The final output good is produced in a competitive sector with Cobb-Douglas technology. Aggregate capital K_t is owned by production firms, which are described in the next section. These firms rent aggregate labor L_t for wage w_t. The shares spent on each factor are α and $1-\alpha$ respectively. Total factor productivity is denoted by Z_t.

$$F(Z, K, L) = ZK^{\alpha}L^{(1-\alpha)}. \tag{5}$$

Competitive factor markets imply the wage

$$w_t = F_L(Z_t, K_t, L_t) \tag{6}$$

and the return on capital

$$R_t^k = F_K(Z_t, K_t, L_t). \tag{7}$$

New capital can be created from old capital and new investment with CRS technology, with quadratic adjustment costs:

$$\Phi(K, I) = (1-\delta)K + I - (1-\delta)\frac{(I-\delta K)^2}{\iota K}. \tag{8}$$

This formulation ensures that no profits are made in the production of new capital. The price of new capital is given by the marginal cost of producing one unit of capital:

$$q_t = \frac{1}{\Phi_I(K_{t-1}, I_t)}. \tag{9}$$

For convenience we also define the market value of old capital as its marginal product in the creation of new capital:

$$q_t^o = q_t \Phi_K(K_{t-1}, I_t). \tag{10}$$

Aggregate capital evolves according to the following law of motion:

$$K_t = \Phi(K_{t-1}, I_t). \tag{11}$$

3.3 Firms

There is a continuum of limited liability firms that operate the constant-returns-to-scale technology described above. At the beginning of a period an existing firm j is described by its capital stock k_{t-1}^j and outstanding loans b_{t-1}^j from a bank. Firms are owned by a representative entrepreneur who is more impatient than the saving household, i.e., $\beta^E < \beta$. This gives firms an incentive to use debt financing in equilibrium. Entrepreneurs consume c_t^E and invest in shares of firms s_t^F, from which they receive dividends f_t^F. Each entrepreneur holds a fully diversified portfolio of firm equity shares. They solves the following optimization problem:

$$
\begin{aligned}
\max \quad & \sum_{t=0}^{\infty} (\beta^E)^t u^E(c_t^E) \\
\text{s.t.} & \\
& c_t^E = s_{t-1}^F f_t^F - P_t^F (s_t^F - s_{t-1}^F).
\end{aligned}
\tag{12}
$$

Firm shares are not traded in equilibrium, so $s_t^F = 1$. In equilibrium the consumption of the representative entrepreneur equals aggregate firm dividends f_t^F. Entrepreneurs therefore discount the future consumption with the stochastic discount factor

$$
\Lambda_{t,t+1}^E = \beta^E \frac{u_c^E(f_{t+1}^F)}{u_c^E(f_t^F)}, \tag{13}
$$

which is therefore the relevant discount factor firms use to discount their dividend stream.

There is free entry and new firms can be set up at no cost by entrepreneurs at the end of each period. Firms have no access to capital markets, so they cannot issue external equity or debt to the saver household directly.[4]

3.3.1 Idiosyncratic risk and default

At the beginning of each period each firm receives an idiosyncratic capital quality shock:

$$
\alpha^j \sim G_t(\alpha) \qquad with: \quad G_t(\alpha) = \mathcal{N}(0, \sigma_t^F). \tag{14}
$$

This shock turns the firm's capital stock into $(1 + \alpha^j)k_{t-1}^j$ units of old capital. After observing this shock, the firm decides whether to default, in which case it is closed down and its assets are seized by its creditors. In default, only a share δ^F of the firm's capital is recovered by its creditors, while the rest is destroyed. Idiosyncratic risk in combination with default costs create a friction, which limits firm borrowing relative to net worth. This standard friction can be understood as a cost that creditors incur for verifying the true state of the firm and goes back to Townsend (1979). It has been used widely in macroeconomic models since Bernanke, Gertler, and Gilchrist (1999).

In our model the standard deviation of the firm specific capital shock is time varying,

[4] This assumption is valid for small firms, for which capital market frictions are prohibitive

which affects the strength of the financing friction. In particular an increase in idiosyncratic uncertainty raises the cost of external financing as firm default becomes more likely. The importance of variations in idiosyncratic uncertainty at firm level are well established in the macroeconomic literature since Bloom (2009). See Christiano, Motto, and Rostagno (2014) and Bloom, Floetotto, Jaimovich, Saporta-Eksten, and Terry (2018) for important contributions on the role of these *risk shocks* in business cycle dynamics. Before we state the full optimization problem, we discuss the details of the long-term lending contract.

3.3.2 The lending contract

In general the introduction of multi-period contracts leads to a distribution of loans across firms and dates of issuance. Moreover, outstanding long-term debt distorts firm incentives due to debt overhang and dilution, which make the dynamic optimization problem time-inconsistent. There could be interesting interactions between incentive distortions and business cycle (Jungherr and Schott 2019), but these features would considerably complicate numerical solutions of the model. For conceptual clarity and tractability we therefore design a lending contract that allows aggregation both across firms and vintages and eliminates the incentive distortions and allows us to focus on the question of aggregate risk distribution.[5] A loan in our model has three features: A repayment schedule, an initial payment from the bank to the borrowing firm, and a covenant, which specifies additional payments conditional on future firm behavior.

Repayment A standardized loan contract in our model has a principal of 1, which is repaid in geometrically declining coupon payments at rate μ, unless the firm defaults.[6] In addition, each period the borrower pays interest $\tilde{R}_t$ on the outstanding principal. For a loan made in period t, repayment and remaining principal in period t+i are given by:

$$\text{Repayment}(t+i) : (\mu + \tilde{R}_t)(1-\mu)^{i-1} \qquad \text{Principal}(t+i) : (1-\mu)^{i-1}. \tag{15}$$

The parameter μ determines the repayment maturity of the loan. The average time at which the principal is repaid is given by $\frac{1}{\mu}$. We assume that $\tilde{R}_t$ is fixed at the beginning of the contract, so that banks are taking on the full interest rate risk. In principle we

[5] An alternative approach to deal with the time-inconsistency has recently been used by Gomes, Jermann, and Schmid (2016) and Ferrante (2019). It relies on making parametric assumptions on the first derivatives of future policy functions with respect to current choices. This approach, however, only works in first order solutions of the model, while we are interested in the precautionary effects of the distribution of aggregate risks.

[6] Similar contracts have been widely used to model long-term loans since Leland (1994). See Andreasen, Ferman, and Zabczyk (2013), Paul (2015) and Landvoigt, Elenev, and Nieuwerburgh (2018)

could allow $\tilde{R}$ to be (partially) indexed to the risk free interest rate, which is common in many real world contracts. We discuss the implications of this assumption for model dynamics in Section 5.3.

Note that the level of $\tilde{R}_t$ is not pinned down in the model, as it scales the entire repayment stream and therefore size of the loan. As a normalization we choose to fix the interest rate component of repayment at the steady state risk free rate $\tilde{R}_t = \bar{R}$. [7] Since agents in the model only care about the fundamental value of assets, dynamics in the model are not affected by this assumption.

In case a firm defaults, all loans have the same seniority independently of the date of issuance. This repayment structure allows us to aggregate loans of different vintages, as one unit of outstanding loans can simply be converted into $(1-\mu)$ units of new loans.[8]

Loan price Each period banks offer a price schedule for loans, taking into account the ability of the firm to repay the loan in the future. Since banks are homogeneous in equilibrium, there is a unique price schedule offered by all banks. Since firm operations are constant returns to scale, the loan price schedule $p_t(cl)$ offered by banks is a function of its debt to asset ratio $cl = \frac{b}{k}$. This claim is verified below, as default rate, recovery rate and future leverage only depend on current leverage. From now on we refer to cl as the corporate leverage. In particular $p_t(cl)$ is decreasing, as more debt relative to capital reduces the probability of the loan being repaid.

The loan price schedule is time varying, as it depends on the expected profitability of the firm and on banks' internal cost of funds. On average, loans are priced at a discount, i.e. $p_t < 1$, which means that there is a positive spread between the risk-free and the lending rate. This spread arises because of equilibrium firm defaults and bank financing frictions. We use the following definition of the interest rate spread between loans and deposits in terms of market values:

$$ispread_t = \mathbb{E}\left(\frac{p_{t+1}(1-\mu)+\mu+\tilde{R}}{p_t} - R_t\right) \tag{16}$$

This definition captures the expected one-period ahead interest rate spread, if a firm borrows long-term today and refinances the loan tomorrow, which reflects well the cost of borrowing for firms. The concept of the spread is only used to interpret simulation results, and does not play any role for the behavior of agents in our economy.

[7] This normalization implies that the value of a loan in the steady state of a frictionless model would be equal to 1. We could also set $\tilde{R} = 0$, but we find the presentation clearer if there is a distinction between interest rate and coupon payment.

[8] If R_t is time-varying, aggregation is still possible and loans have to be rescaled by the interest rate rate at the time of issuance.

Covenants We assume that the loan contract contains a covenant that eliminates the incentive of the firm to dilute the bank's claim through excessive future risk taking. For classical references on these distortions see Jensen and Meckling (1976) and Myers (1977)). Covenants are common in corporate loans and have appealing efficiency properties.[9] In fact, Jungherr and Schott (2018) show that long-term debt with a covenant similar to the one used here is the optimal contract in a framework with debt issuance costs. The contract stipulates that the firm has to make a compensation payment $CP(cl_t^j)$ to the bank for every outstanding loan if it deviates from the contracted leverage ratio, which we assume to be equal to the average corporate leverage ratio CL_t in the economy.[10] The compensation payment is set as

$$CP_t(cl_t^j) = p_t - p_t(cl_t^j) \qquad where \quad p_t = p_t(CL_t), \tag{17}$$

so that it exactly offsets the difference in the market value of the firm's debt relative to the average market value of debt in the economy. This formulation allows any firm to take on more risk than an average firm if it compensates its long-term lenders. In equilibrium, however, all firms choose the same leverage ratio, so no compensation payments are made.[11]

Two things should be noted. First, limited liability still applies, so owners can refuse to make the payment and let the firm default. Second, banks are only compensated for individual firm risk taking. If the aggregate value of outstanding debt changes due to a change in the interest rate or due to an increase in the economy wide default rate, banks are not compensated and bear the losses. This is exactly the risk transfer we study in this paper.

3.3.3 The firm problem

Firm j enters the period with capital k_{t-1}^j and the amount of debt b_{t-1}^j. It then draws a capital efficiency shock α_t^j, which transforms one unit of capital last period into $(1+\alpha_t^j)$ units of old capital today, and decides whether to default. If the firm does not default, it optimally chooses dividends f_t^j, productive capital k_t^j and loans b_t^j. The firm uses the stochastic discount factor provided by the representative entrepreneur to discount future

[9] See Demiroglu and James (2010) and Smith Jr (1993) as well as Tirole (2010).

[10] Other specifications are in principle tractable, but aggregation becomes more complicated.

[11] While we cannot analytically establish convexity of the firm problem, which would ensure a unique optimal leverage ratio chosen by all firms, we check numerically that firms have no incentive to deviate from the average leverage ratio.

dividends. Its value is therefore given by[12]

$$\begin{aligned}
V^F(k^j_{t-1}, b^j_{t-1}, \alpha^j_t) &= \max_{b^j_t, k^j_t, f^j_t} f^j_t + \mathbb{E}\Lambda^E_{t,t+1} \int_{\alpha \in \mathbb{R}} max(V^F(k^j_t, b^j_t, \alpha), 0) dG^F_{t+1}(\alpha) \qquad (18)\\
\text{s.t.} & \\
q_t k^j_t &= n^j_t + p_t(cl^j_t) b^j_t - f^j_t + R^k_t k^j_t, \\
n^j_t &= (1 + \alpha^j_t) k^j_{t-1} q^o_t - [p_t(cl^j_t) - CP_t(cl^j_t)](1 - \mu) b^j_{t-1} - (\mu + \bar{R}) b^j_{t-1}, \\
cl^j_t &= \frac{b^j_t}{k^j_t}.
\end{aligned}$$

We define the firm's net worth n^j_t at the beginning of the period as the difference between the market value of assets and the market value of liabilities, net of any compensation payments made to the bank. Notice that the market value of liabilities depends on choices made in this period, but net worth does not, because the compensation payment exactly offsets the effect of current decisions on the market value. Moreover, capital, debt and the current efficiency shock only affect the decision problem through their effect on net worth.

By substituting out f^j_t, using the budget constraint, it is straightforward to see that the value of the firm is linear in n^j_t, conditional on choosing not to default. Due to free entry, the value of a firm with zero net worth is equal to zero. This establishes that owners would prefer to set up a new firm, rather than investing in a firm with negative net worth. The default threshold for the capital efficiency shock is therefore given by:

$$\alpha^F_t(cl^j_{t-1}) = \frac{(1-\mu)p^j_t + \mu + \bar{R}}{q^o_t(1-\delta)} cl^j_{t-1} - 1. \qquad (19)$$

The default probability before the idiosyncratic shock is realized is given by

$$\pi^F_t(cl^j_{t-1}) = G^F_t(\alpha^F_t(cl^j_{t-1})). \qquad (20)$$

Note that π^F_t depends only on the debt-to-capital ratio, as was asserted above. In combination with the linearity of the value in net worth, this establishes that the firm problem is constant returns to scale in k^j_t and b^j_t. We establish numerically that there is a unique optimal debt-to-asset ratio, therefore all firms are homogeneous at the end of each period. It follows that the only relevant variable for the loan price is current firm leverage.

[12] Alternatively this problem could be formulated sequentially as an optimal stopping time problem, with somewhat more involved notation.

Optimal borrowing of firms is determined by the following Euler equation:

$$p_t(cl_t^j) + \frac{b_t^j}{k_t^j}\frac{\partial p_t^j(cl_t^j)}{\partial cl} = \mathbb{E}\Lambda_{t,t+1}^E[p_{t+1}(1-\mu)+\mu+\bar{R}][1-\pi_{t+1}^F(cl_t^j)]. \tag{21}$$

The left hand side is the amount of funds a firm receives for taking out an extra loan. Due to the debt covenant the firm internalizes that an extra loan raises default risk and lowers the value of all its outstanding debt. The right hand side is the expected repayment, in case the firm does not default, plus the continuation value of the outstanding loan. This continuation value is given by next period's equilibrium loan price. Here we have already used the fact that it is impossible for the firm to dilute the continuation value of the bank's claim next period because of the covenant.

The Euler equation for capital holdings is given by:

$$q_t - \left(\frac{b_t^j}{k_t^j}\right)^2 \frac{\partial p_t(cl_t^j)}{\partial cl} = R_t^k + \mathbb{E}\Lambda_{t,t+1}^E q_{t+1}^o(1-\delta)[1+\mathbb{E}_{G_{t+1}^F}(\alpha|\alpha > \alpha_{t+1}^F)][1-\pi_{t+1}^F(cl_t^j)]. \tag{22}$$

Here the left hand side is the cost of purchasing an extra unit of capital. Again, the firm internalizes that an extra unit of capital increases the value of its outstanding debt. The right hand side is the return on capital plus the value of the old, depreciated capital tomorrow in those states of the world where the firm does not default. Note that the change in the default probability does not enter either of the firm's optimality conditions. This is due to the fact that firm value is zero at the default threshold.

3.3.4 Aggregation of the corporate sector

Since all firms chose the same debt-to-asset ratio, we can aggregate their decisions at the end of each period. The aggregate behavior of firms can therefore be described by the aggregate versions of the two Euler equations and the firm budget constraint. The default rate π_t^F on a well diversified portfolio of loans equal the individual default probability:

$$\pi_t^F = \pi_t^F(CL_{t-1}). \tag{23}$$

The total return on a loan portfolio is the repayment and continuation value of loans to non-defaulting firms plus the recovery rate on defaulting loans:

$$R_t^b = (1-\pi_t^F)[\mu + \bar{R} + (1-\mu)p_t] + \pi_t^F RR_t, \tag{24}$$

where the aggregate recovery rate on a portfolio of defaulting loans is given by

$$RR_t = \delta^F q_t^o (1 + \mathbb{E}_{G_t^F}(\alpha | \alpha < \alpha_t^F)) \frac{1}{cl_{t-1}}. \tag{25}$$

These formulas already use the fact that in equilibrium all firms are choosing the same leverage and therefore no compensations payments are made. Out of equilibrium, banks would also include the value of future compensation payments of deviating firms in their computation of the loan return.

3.4 The banking sector

There is a continuum of limited liability banks, which are owned by households.[13] The structure of the banks' problem is similar to that of production firms. There are two major differences between firms and banks. First, bank liabilities are insured by a regulator, who limits the leverage of banks. We discuss the regulatory environment in the following subsection. Second, banks have access to capital markets but there is a friction, which makes it difficult to adjust their equity quickly. We model this friction by imposing convex costs for banks that deviate from the their target dividend to equity ratio. In particular we set:

$$h(f, n) = f + \frac{100\omega}{2} n \left(\frac{f}{n} - \frac{\bar{F}}{\bar{N}} \right)^2, \tag{26}$$

where f are bank dividends, n is the bank's equity or net worth[14], and $\bar{F}$ and $\bar{N}$ are their respective aggregate steady state values. This functional form implies that banks target their steady state dividend-equity ratio. For deviating from this optimal ratio, banks incur quadratic costs, scaled by their current equity. We interpret these costs as utility costs and assume that no resources are lost. Since banks perceive dividend reductions as costly, losses in the banking sector can lead to an aggregate shortage of bank equity and a contraction in credit supply. Notice that dividend adjustment cost in our framework slightly differ from the standard form used in Jermann and Quadrini (2012). To keep the bank problem constant-returns to scale, we set a target dividend to equity ratio, rather than a dividend level. As a result, aggregate dividends fluctuate in our model, even without deviations from the target.

[13] Due to the difference in time preference, entrepreneurs endogenously choose to invest all their net worth in their own firms rather than banks.

[14] We use the terms net worth and equity interchangeably from now on.

3.4.1 Bank regulation

We follow Benes, Kumhof, and Laxton (2014) in setting up banking regulation. Bank i enters period t with liabilities in the form of one-period deposits d^i_{t-1} and assets in the form of a loan portfolio b^i_{t-1}. As for firms we define bank leverage as the debt to asset ratio $bl^i = \frac{d^i}{b^i}$. Each bank draws an idiosyncratic shock to its portfolio return.[15] In particular the return on the loan portfolio of bank i is given by:

$$R^{bi}_t = R^b_t + \alpha^i_t, \qquad \alpha^i_t \sim \mathcal{N}(0, \sigma^B). \tag{27}$$

After the idiosyncratic shock is realized, the regulator monitors whether the bank satisfies a minimum capital requirement of the form:

$$\frac{\tilde{n}^i}{b^i R^b_t} \geq \psi. \tag{28}$$

This requirement states that the ratio of regulatory equity capital $\tilde{n}$ to assets of a bank must not fall below ψ. The regulator imposes a penalty of $\kappa(R^b_t b^i_t)$ on banks who fail to meet the capital requirement. As in Benes, Kumhof, and Laxton (2014), these costs reflect loss of franchise value due to regulatory intervention. Banks are aware of both aggregate and idiosyncratic risks and they choose to hold capital buffers accordingly in order to avoid paying the regulatory penalty or defaulting. However, due to idiosyncratic risk, each period some banks violate the capital requirement and some default.

We deviate from Benes, Kumhof, and Laxton (2014) by assuming that only a fraction $\gamma\alpha^i$ of idiosyncratic returns is reported on the balance sheet and is used for the computation of regulatory capital, that means we define $\tilde{n}^i = (R^b_t + \gamma\alpha^i_t)b^i_t - d^i_t$. This simple assumption allows us to quantitatively match observed bank defaults in equilibrium, even though banks are required to hold substantial amounts of equity be the regulator. As pointed out in Benes, Kumhof, and Laxton (2014), the probability of a bank reaching negative equity and defaulting is effectively zero under realistic calibrations if the idiosyncratic return is fully reported on the balance sheet. Regulatory violations are already rare events, but only a much larger shock would actually turn bank equity negative. We avoid this problem by assuming that banks can hide some of their losses from the eyes of the regulators. While the regulators may conjecture that this is happening, they cannot do anything against it. To see that this assumption is not totally unrealistic, notice that

[15] The underlying assumption is that idiosyncratic risk arises from differences in management efficiency, returns on trading activities or imperfect diversification of loan portfolios. Modeling these features explicitly is beyond the scope of this paper. The same assumption is made for example in Benes, Kumhof, and Laxton (2014), Begenau and Landvoigt (2017) and Landvoigt, Elenev, and Nieuwerburgh (2018)

Lehman failed with book equity of $28 billion on its balance sheet in 2008.[16]

Compared to the regulatory framework of the Basel accord, which includes risk-sensitive deposit insurance premia and various (time-varying) capital and liquidity requirements, our modeling of banking regulation is clearly stylized. In particular, we assume that the regulatory regime evaluates bank balance sheets at market values, while in reality many assets are evaluated at book value. We maintain this assumption for theoretical consistency, as market equity is the relevant statistic in banks' decisions; the same assumption is made in Landvoigt, Elenev, and Nieuwerburgh (2018). As a consequence, our results potentially overstate the effects of asset price fluctuations on banks' decisions. Furthermore, the Basel regulations, in particular the internal-ratings-based (IRB) approach, contain an adjustment for asset maturity. This shows that policy makers are clearly aware of the risk associated with long asset maturities. We do not adjust the capital requirement for maturity, for two reasons. First, the comparison of the two economies, with short- and with long-term lending, is easier to interpret if the same regulations apply in both cases. Second, these regulations did not seem to play a large role for the period we calibrate our model to.[17]

3.4.2 The bank problem

As for firms, we formulate the bank problem recursively. In the beginning of a period, every bank is supervised by the regulator and potentially pays regulatory costs. The net worth of bank i, after paying the regulatory fine, is denoted by n^i. Banks with negative net worth are liquidated and their assets are seized by the regulator, who fully repays the bank's debt.[18] If the bank does not default, it faces the following problem:

$$\begin{aligned} V^B(b^i_{t-1}, d^i_{t-1}, \alpha^i_t) &= \max_{f^i_t, d^i_t, b^i_t} \quad f^i_t + \mathbb{E}\Lambda^H_{t,t+1} \int_{\alpha^B(bl^i_t)}^{\infty} V^B(b^i_t, d^i_t, \alpha) dG^B_t(\alpha) \qquad (29) \\ \text{s.t.} & \\ b^i_t p_t &= n^i_t - h(f^i_t, n_t) + d^i_t / R_t, \\ n^i_t &= (R^b_t + \alpha^i_t) b^i_{t-1} - d^i_{t-1} - \kappa \mathbb{1}_{\alpha^B_t(bl^i_{t-1}) < \alpha^i < \alpha^R_t(bl^i_{t-1})} R^b_t b^i_{t-1}, \\ bl^i_t &= \frac{d^i_t}{b^i_t}. \end{aligned}$$

[16]See Ball (2016).

[17]By the end of 2016 10 large US banks, who hold 57% of total US bank assets, were subject to the IRB approach. Implementation of the IRB approach began only in 2010. Moreover, our model fits better for smaller commercial banks, which engage mainly in traditional lending activities and are not subject to the IRB approach. See "The future of US banking regulation in question" (Choulet 2017).

[18]Due to deposit insurance a bank with negative equity could potentially continue to operate, if it is not forced to shut down.

The threshold for default α^B and the threshold for violating the capital requirement α^R are given by:[19]

$$\alpha_t^B = bl_{t-1} - R_t^b(1-\kappa), \qquad \alpha_t^R = \frac{bl_{t-1} + R_t^b(1-\psi)}{\gamma}. \tag{30}$$

For convenience, we define the probability of default and regulatory violation, before the realization of idiosyncratic risk:

$$\pi_t^B = G^B(\alpha_t^B); \qquad \pi_t^R = G^B(\alpha_t^R). \tag{31}$$

We also define expected payments to the regulator per unit of loan on the balance sheet:

$$RC_t = [\pi_t^R - \pi_t^B]\kappa R_t^b. \tag{32}$$

Even though the realized cost has a kink, expected cost is a smooth function, which allows us to differentiate the bank's objective function.

Optimal bank behavior is characterized by the following Euler equations for deposits and loans.[20] Deposits are determined by

$$\frac{1}{R_t} = \mathbb{E}_t \Lambda_{t,t+1}^H \frac{h_f(f_t^i, n_t^i)(1 - h_n(f_{t+1}^i, n_{t+1}^i))}{h_f(f_{t+1}^i, n_{t+1}^i)}[(1-\pi_{t+1}^B) + g^b(\alpha_{t+1}^R)\kappa R_{t+1}^b]. \tag{33}$$

Equation (33) shows the trade-off faced by a bank that considers issuing an extra deposit. The left hand side reflects the marginal gain of raising $\frac{1}{R_t}$ more units of funds as deposits. The right hand side contains the expected discounted cost of repaying, if the bank does not default, plus the expected increase in costs arising from potential violation of the capital requirement.

Loans are determined by

$$p_t = \mathbb{E}_t \Bigg[\Lambda_{t,t+1}^H \frac{h_f(f_t^i, n_t^i)(1 - h_n(f_{t+1}^i, n_{t+1}^i))}{h_f(f_{t+1}^i, n_{t+1}^i)} \times \\ \Big([R_{t+1}^b + \mathbb{E}_{G^B}(\alpha | \alpha \geq \alpha_{t+1}^B)](1 - \pi_{t+1}^B) - RC_{t+1}(bl_t^i) + g^b(\alpha_{t+1}^R)\kappa bl_t R_{t+1}^b \Big) \Bigg]. \tag{34}$$

The left hand side of equation (34) is the marginal cost of giving out an extra loan,

[19] Note that the variables defined below are all functions of bl_{t-1}^i from the perspective of the bank. We omit this expicit dependence for ease of exposition, but take it into account when solving the bank's optimization problem.

[20] In appendix A the optimality condition for loans is derived formally. The optimality condition for deposits can be derived analogously.

which equals the equilibrium loan price p_t. The right hand side is the return on the loan next period, in case that the bank does not default. It is given by the value of the loan in the states where the bank does not default and the expected change in payments made to the regulator associated with the increase in lending.

While equation (34) pins down the price that a bank is willing to pay for a loan to a firm with equilibrium leverage CL_t, the firm optimality conditions depend on the slope of the loan price schedule with respect to firm-specific leverage. The dependence of the loan price on an individual firm's capital-to-loan ratio is given by the partial derivative of equation (34) with respect to cl_t^j:

$$\frac{\partial p_t(cl_t^j)}{\partial cl} = \mathbb{E}_t\Bigg[\Lambda^H_{t,t+1}\frac{h_f(f_t^i,n_t^i)(1-h_n(f_{t+1}^i,n_{t+1}^i))}{h_f(f_{t+1}^i,n_{t+1}^i)}\frac{\partial R^b_{t+1}(cl)}{\partial cl}\times \left(1-\pi^B_{t+1}+g^b(\alpha^R_{t+1})(1-\psi)\frac{\kappa}{\gamma}R^b_{t+1}-[\pi^R_t-\pi^B_t]\kappa\right)\Bigg] \tag{35}$$

The derivation of this equation is slightly more involved and given in appendix A, but the intuition is straightforward: if a firm adjusts its leverage, the bank will set a bond price, which compensates it for the changes in expected, discounted returns. Higher leverage increases default risk and lowers expected returns. Moreover a bond with higher risk will also increase the likelihood of violating the regulatory constraint, which the bank has to be compensated for. The bond price is therefore decreasing in firm leverage.[21]

3.4.3 Aggregation of the banking sector

Since the function $h(f,n)$ in equation (26) is linearly homogeneous in f and n, the derivatives are homogeneous of degree zero, and the first order conditions (33) and (34) are invariant to the scale of f and n. In analogy to non-financial firms, the beginning of period value of a bank is therefore linear in net worth. As a result all banks choose the same leverage ratio $BL_t = \frac{D_t}{B_t}$ in equilibrium.[22]

Since the banks' problem yields the same optimal leverage ratio for all continuing banks, we can aggregate all bank decisions at the end of each period. Similar to firms, the aggregate versions of the Euler equations (33) and (34) and the budget constraint in (29) characterize bank decisions. The bank default rate is given by equation (31) and total penalties by equation (32).

[21]This equation is similar to Gomes, Jermann, and Schmid (2016). However since debt overhang is eliminated through the covenant in our model, the return next period in case of no default is independent of todays choice. This allows us to use standard perturbation techniques.

[22]Since convexity of the bank problem cannot be proven, we numerically check that optimal leverage is indeed unique in the neighborhood of the steady state.

We close the model by assuming that the regulator distributes any gains or losses lump sum across households. The regulator receives penalties paid by banks and proceeds from selling assets of defaulted banks, minus a dead-weight loss share of $1 - \delta^B$. In turn she has to compensate depositors of defaulted banks. The total transfer is:

$$T_t = RC_t + \delta^B(RL_t - \mathbb{E}_{G^B}(\alpha|\alpha \leq \alpha^B))\pi_t^B L_{t-1} - D_{t-1}\pi_t^B \tag{36}$$

3.5 Aggregate uncertainty

There are two sources of aggregate uncertainty. Total factor productivity follows a standard AR-1 process:

$$Z_t = (1 - \rho^Z)\bar{Z} + \rho^Z Z_{t-1} + s_z \epsilon_t^Z \tag{37}$$

where ϵ_t^Z is an i.i.d. innovation with standard normal distribution. The second source of uncertainty are fluctuations in the dispersion of idiosyncratic firm returns. This 'risk shock' is found to be an important driver of macroeconomic dynamics in Bloom (2009),Bloom, Floetotto, Jaimovich, Saporta-Eksten, and Terry (2018) and Christiano, Motto, and Rostagno (2014). This shock is particularly relevant in our framework, as it allows us to study the effect of persistent changes in corporate default rates, which transfer losses from the corporate to the financial sector. The standard deviation of idiosyncratic returns follows an AR-1 process as well:

$$\sigma_t^F = (1 - \rho_V)\bar{\sigma}^F + \rho_V \sigma_{t-1}^F + s_v \epsilon_t^V \tag{38}$$

Again the innovation ϵ_t^V is i.i.d. and standard normal. Following (Bloom, Floetotto, Jaimovich, Saporta-Eksten, and Terry 2018) we assume that ϵ_t^Z and ϵ_t^V are correlated, with the correlation coefficient denoted by $\rho_{V,Z}$.

4 Calibration

Table 1 shows the baseline calibration of our model. A number of parameters in our model are set to standard values in the business cycle literature. We set the remaining parameters by targeting first and second moments of aggregate quarterly US data. Standard national accounts data is collected from the Federal Reserve Database and information on bank balance sheets from the FDIC.[23] For national accounts data we use all quarters from 1947 to 2015. For loan charge-off (default rate net of recovery rate) and bank equity we use data starting in 1988 and for bank defaults we use data from 1990.

[23] Data is available at https://fred.stlouisfed.org/ and https://www.fdic.gov/bank/statistical/guide/data.html respectively

For the interest rate spread we use the measure of bond spreads developed by Gilchrist and Zakrajšek (2012) from 1973 to 2015.[24] To allow for natural interpretations, we refer to interest rates and the interest rate spread in annualized terms, while we report bank and firm default rates as quarterly rates. The calibrated model moments and their targets are given in Table 3. As our focus lies on capturing the distribution of risk in the economy, our calibration strategy relies heavily on targeting moments related to bank default rates, charge-off rates on bank loans and interest rate spreads.

Most preference and technology parameters are standard. The household instantaneous utility function is given by:

$$u^H(c_t, l_t) = log(c_t) - \eta \frac{l_t^{(1+\nu)} - 1}{(1+\nu)} \tag{39}$$

We also choose a logarithmic utility function in consumption for entrepreneurs, which ensures that differences in risk aversion do not affect our results. The household discount factor β^H of .99, the capital share α of 0.3 and the capital depreciation rate of 2.5% are standard values. The labor supply elasticity $\frac{1}{\nu}$ is set to 4, which is an upper bound in the literature[25]. The disutility of labor η is chosen to generate a steady state labor supply of 1/3. We set the capital adjustment cost parameter ι to 0.50, to match the business cycle standard deviation of investment. Following the evidence in Krishnamurthy and Vissing-Jorgensen (2012), we calibrate ξ to match an annualized liquidity premium of 73bps. In combination with the discount factor this implies a steady state deposit rate of 3.2%.

Default costs for non-financial and financial firms are set to 30% and 10% of their asset values respectively. The 30% cost for non-financial firms lies in the range of 0.2 to 0.35 given in Carlstrom and Fuerst (1997), while the cost of bank defaults are estimated in James (1991). To calibrate the parameters related to production firms, we target steady state values for corporate leverage of 38% and an annualized average charge-off rate on corporate loans of 0.89%. This yields an entrepreneurial discount factor β^E of 0.985 and a steady state standard deviation of idiosyncratic firm returns $\bar{\sigma}^F$ of 23%. In our baseline calibration we set $\mu = 0.05$ which implies an average maturity of 5 years, following Landvoigt, Elenev, and Nieuwerburgh (2018). This corresponds to the average repricing maturity of bank assets found by Drechsler, Savov, and Schnabl (2018).

The next set of parameters are related to the banking sector. We choose a regulatory

[24]The data is available at https://www.federalreserve.gov/econresdata/notes/feds-notes/2016/updating-the-recession-risk-and-the-excess-bond-premium-20161006.html. We aggregate the data to quarterly frequency.

[25]See Chetty et al. (2012) for a discussion. As we show below, labor input in the model is still not as volatile as in the data.

Parameter		Value
Household discount factor	β^H	0.99
Labor supply elasticity	ν	0.25
Entrepreneur discount factor	β^E	0.985
Capital depreciation rate	δ	0.025
Capital share in production	α	0.3
Capital adjustment cost	ι	0.50
Liquidity premium	ξ	0.001825
Firm default cost	δ^F	0.3
Bank default cost	δ^B	0.1
Capital requirement	ψ	0.08
Penalty for regulatory violation	κ	0.008
Sd firm specific shock	$\bar{\sigma}^F$	0.23
Sd bank specific shock	σ^B	0.0452
Share of bank shock observed by regulator	γ	0.51
Loan maturity	μ	0.05
Dividend adjustment cost	ω	5

Table 1: Calibration

capital requirement of 8% in line with Basel II regulations. The two parameters governing idiosyncratic bank returns and the regulatory penalty parameter are set to target a mean and a standard deviation of the quarterly bank default rate of 0.17% and 0.44%, respectively, and a standard deviation of the annualized interest rate spread of 0.72%. The resulting standard deviation for idiosyncratic bank shocks is 4.52% and regulators observe 51% of idiosyncratic returns. The penalty parameter for violating capital requirements ψ is set to 0.8% of the bank's assets. Finally we choose a dividend adjustment cost parameter of $\omega = 5$, to target the autocorrelation of bank equity of 0.78.

Table 2 summarizes the calibration of the stochastic processes for the exogenous state variables of the model. We choose a standard calibration for the productivity process. The innovation has a standard deviation of 0.007 and the autocorrelation of TFP is 0.95. To capture the business cycle risk that banks are exposed to, we calibrate the magnitude of the risk shock to match the fluctuations in loan charge-off rates. To match an annualized standard deviation of loan charge-offs of 0.65 percentage points and an autocorrelation of 0.85, we set the standard deviation of the risk shock to 0.013 and the persistence to 0.88. As pointed out in Bloom, Floetotto, Jaimovich, Saporta-Eksten, and Terry (2018) the introduction of a second moment shock leads to a low correlation between output and consumption. We follow Bloom, Floetotto, Jaimovich, Saporta-Eksten, and Terry (2018) and assume a negative correlation between first and second moment shocks. To match a correlation of output and consumption of 0.77, we choose a correlation between the TFP and idiosyncratic volatility process of -0.1.

Parameter		Value
Sd of TFP	σ_z	0.007
Persistence of TFP	ρ_z	.95
Sd of risk shock	σ_v	0.013
Correlation of TFP and idiosyncratic risk	$\rho_{V,Z}$	-0.1
Persistence of risk shock	ρ_V	0.88

Table 2: Stochastic processes

While we split our calibrated parameters into different sets for the purpose of exposition, it should be noted that in general target moments depend on all parameters. In particular bank default rates are highly dependent on firm risk, not only the regulatory parameters. As a result we jointly set all parameters to best match the given targets. Table 3 shows the model moments and their relative targets. Given the number of parameters and the nonlinearity of the model we consider the fit satisfying overall. Note that even with long-term debt and equity issuance frictions in place, the model is not fully able to capture the business cycle risk that banks are exposed to. In particular the bank default rate is not quite as volatile, while write-offs on loans are already more volatile than in the data.

A point that warrants some discussion is that our calibration strategy implies a high value for ω, which determines the cost of adjusting dividends. The calibrated value effectively rules out equity issuance, because the marginal benefit of reducing dividends becomes negative before dividends reach zero. This feature of our calibration is a consequence of the fact that it is difficult for the model to fully match banks exposure to business cycle risk, even with long-term loans. Lowering ω leads to a slightly worse fit in two of our target moments, the standard deviation of bank defaults and autocorrelation of bank equity, without improving the fit in other dimensions. We find, however, that our main conclusions are robust to substantially lower values of ω.[26]

Table 4 compares the standard deviations of model simulations to their data counterparts. The relative standard deviation of investment to output was targeted and is close to the data. The fluctuations of labor input and the interest rate are smaller than in the data, but similar to most other RBC models.

Business cycle correlations are reported in table 5. The model matches the correlation of both investment and consumption with output well. This is unsurprising, however, as the correlation of output and consumption is a target, and investment is essentially the residual in the aggregate resource constraint. The results for financial variables are more revealing. The correlation of output with the risk free rate and loan charge-offs are

[26]Setting $\omega = 0.25$, we find that reported moments and figures do not change substantially. This implies a marginal cost of raising equity of 10% at zero dividends, which does not appear excessive.

Variable	Value	Target
Std(Inv)/Std(GDP)	4.12	4.53
Corr(Consumption,GDP)	0.77	0.77
Mean(Corporate Leverage)	0.38	0.38
Mean(Charge-off)	0.86	0.89
Std(Charge-off)	0.71	0.65
AC(Charge-off)	0.83	0.85
Mean(Bank default)	0.15	0.17
Std(Bank default)	0.25	0.44
AC(Bank equity)	0.72	0.78
Std(Interest Rate Spread)	0.74	0.72

Table 3: Model moments and targets
Model moments are computed from a simulation of 1 000 000 periods; for quantity variables logarithms were taken and HP-filter ($\lambda = 1600$) applied for both data and model; for interest and default rates unfiltered data was used.

	Absolute		Relative	
Variable	Model	Data	Model	Data
GDP	1.35	1.64	1.00	1.00
Investment	5.57	7.43	**4.12**	**4.53**
Consumption	0.73	1.26	0.54	0.77
Labor	0.77	1.90	0.57	1.16
Risk free rate	0.38	1.03	0.28	0.63

Table 4: Selected Standard Deviations
Model moments are computed from a simulation of 1 000 000 periods; For nonstationary variables logarithms are taken, all variables are HP-filtered($\lambda = 1600$), the same procedure is applied to both model and data;**bold** values are targeted

Variable	Model	Data
Investment	0.88	0.83
Consumption	**0.77**	**0.77**
Risk free rate	0.40	0.20
Charge-offs	-0.36	-0.63
Bank defaults	-0.24	0.00
Bank defaults(t-1)	-0.17	-0.12
Bank defaults(t-2)	-0.10	-0.19
Bank defaults(t-3)	-0.06	-0.24
Interest rate spread	-0.39	-0.31
Interest rate spread(t-1)	-0.27	-0.44
Interest rate spread(t-2)	-0.17	-0.49
Interest rate spread(t-3)	-0.09	-0.47

Table 5: Selected Correlations with GDP
Model moments are computed from a simulation of 1 000 000 periods; For non-stationary variables logarithms are taken, all variables are HP-filtered($\lambda = 1600$), the same procedure is applied to both model and data; **bold** values are targeted

matched quite well in terms of magnitude. For interest rate spread and bank default rate, the model predicts a negative contemporaneous correlation with output, which decreases in absolute value if the variable is lagged. In the data, however, these variables are more negatively correlated with output at higher lags. This suggest that in reality it takes some time for disruptions in financial markets to affect aggregate output. In the model there is no mechanism that could capture such a delay, so the dynamic pattern of correlations is off, but overall their magnitude is close to the data.

5 Results

We use the calibrated model above to study the roles of loan maturity and the financial sector for economic dynamics. To highlight the role of long-term debt, we compare our calibrated economy to an economy where loans have a maturity of one quarter ($\mu = 1$), but with the same parameterization otherwise. Notice that the two economies have the same non-stochastic steady state, but some parameters were set to match first and second moments of model simulations for the economy with long-term loans. To understand the full effects of debt maturity, we consider it more informative to compare two economies with the same structural parameters rather than to recalibrate the economy with short-term debt to match the same moments.[27]

[27]Note that even in the economy with long-term loans we found it difficult to match the risk exposure of the financial sector for an otherwise reasonable calibration. With short-term debt banks are exposed to less business cycle risk, so the bank default rate becomes even less volatile. Recalibrating the model

To study the role of bank financing frictions in detail, we compare the two economies to counterparts where the dividend adjustment cost ω is set close to zero, which means that banks can freely adjust their equity in every period.[28] Banks still have limited liability and face costly default in these economies, so bank financing is not frictionless in a strict sense. However, with freely adjustable dividends, bank lending is never constrained by a lack of equity, and as we show below, bank defaults play basically no role in this case. Quantitatively, these economies therefore behave as if bank financing was frictionless.

We structure the discussion of the result as follows. In Section 5.1 we highlight the economic mechanisms in our model by studying linear and nonlinear impulse responses to uncertainty shocks. In Section 5.2 we investigate the effect of long-term loans on business cycle moments. In Section 5.3 we look specifically at crises periods. We develop the policy implications of our model in Section 5.4. Finally, we provide a somewhat broader discussion of the costs and benefits of long-term loans in Section 5.5.

5.1 The response to uncertainty shocks

The key mechanism driving our results is the transfer of aggregate risk from the firm sector to the banking sector. In our model, aggregate risk is mostly coming from the risk shock, while productivity shocks have little effect on default and interest rates, and little risk is transferred through long-term contracts (cf. Figure 2). In this section, we therefore focus on the risk shock, and we compare the responses to a large initial increase in idiosyncratic uncertainty at firm level for all four parameterizations above. We initialize the economies at their respective stochastic steady states, i.e., the fixed point of the policy functions under zero shocks. The scenario we consider is an increase in the dispersion of idiosyncratic firm capital quality from its mean of 23 percent to 33 percent over the course of three quarters. Beyond that point we set all shocks to zero. Impulse responses are drawn starting in the period before the shock sequence begins.

Figure 3 compares the impulse responses of the economies with and without banking sector friction, if loans are short-term.[29] The direct impact of the rise in idiosyncratic uncertainty is an increase in the corporate default rate, which peaks at 3.1 percentage points over the steady state. Banks face some losses due to the unexpected increase in

with short-term debt to improve the fit in this dimension would therefore require us further increase the volatility of firm defaults and loan write-offs. Comparisons across such different calibrations would then not be informative about the underlying economic mechanisms.

[28] For technical reasons we set $\omega = 2 * 10^{-4}$, rather than exactly zero. If ω is exactly zero, the distribution of household wealth and deposits is not well defined any more and the dividend process becomes unstable. We verify, however, that in this range ω only affects dividends, but has essentially no consequences for other dynamics in the model.

[29] Note that the economy with short-term loans and no banking sector friction is very similar to the well studied model of Bernanke, Gertler, and Gilchrist (1999), except for the presence of the risk shock.

borrower defaults, which leads to an increase in the bank default rate by 0.1 percentage points . They also react by raising the lending rate by 0.7 percentage points , which compensates them for higher expected future borrower defaults. Investment and output both fall, reaching troughs of 23 percent and 2.2 percent below steady state respectively. Total consumption in the economy increases on impact, since the financial friction in the corporate sector prevents resources to be used for investment, but falls below steady state persistently after around 6 quarters. This feature of risk shocks is well known in the literature and is the reason for introducing a negative correlation between TFP and risk shocks. The most important conclusion for us is that the financial sector friction plays very little role for the main economic aggregates here. Without financial frictions, banks quickly re-capitalize, and the default rate returns to its steady state level. With dividend adjustment costs in place, banks cannot easily react to the losses on their loan portfolio. As a result the bank default rate peaks at 0.2 percentage points over steady state and remains elevated for some time. However, bank failures are not frequent enough to make a big difference for credit supply. All real variables therefore behave very similarly to the economy without the banking friction. In the economy with short-term debt, the risk that banks are exposed to is too small to seriously affect economic dynamics.

Compare this to the dynamics in the economies with long-term loans in Figure 4. Without a banking sector friction it is clear that the long-term contract provides insurance to borrowers: as firms become more risky, they only have to roll over a small part of their outstanding debt at higher interest rates. This reduces the incentive to default, resulting in a peak corporate default rate of slightly below 3 percent above steady state. Moreover, consumption by entrepreneurs falls by less than 1 percent compared to 3 percent in the economies with short-term debt. The banking sector is hit by the losses on its long-term loan portfolio, as it holds a large portfolio of outstanding loans, which are now much less likely to be repaid in full. The bank default rate reaches 0.25 percentage points above steady state at its peak. Since equity can be freely adjusted, the default rate quickly returns to 0. In this economy entrepreneurs are insured through the long-term lending contract and the financial sector can absorb the additional risk well. This means that the contractions in output and investment are also less severe at 20 percent and 1.8 percent below steady state respectively.

These results reverse in the presence of the banking sector friction. Even though slightly fewer borrowers default than in the economies with short-term loans, banks are hit much harder in this economy. As the value of the loan portfolio falls, bank defaults increase dramatically, reaching 0.8 percent in the peak quarter. Banks have to reduce lending and further raise interest rates, in order to satisfy capital requirements. This sets off a financial accelerator, as the higher interest rate further reduces the value of outstanding loans. Moreover, since banks expect to fail with a higher probability, they value assets even less. The result is a persistent increase in the lending rate.[30] While the initial increase in the lending rate is about the same as in the economy without the banking friction, the higher persistence discourages investment today, as firms anticipate that they will have to refinance their loans at high interest rates. Investment and output decline by 30 percent and 3 percent below their steady state values in this economy.

We conclude that the financial sector plays a much larger role for the real economy, if debt is long-term. Comparing the troughs of the recession, the response in output is amplified by a factor of 2, due to the presence of bank financing frictions. With short-term debt the amplification is negligible.

That bank balance sheets affect equilibrium outcomes is the consequence of large shocks in combination with strong nonlinearities in the model. To demonstrate this, Figure 5 shows the impulse responses to the same shock sequence in the two economies with long-term debt, but obtained from a linearized solution. The effect of the financial sector on the main real aggregates, in particular output, investment and consumption, disappears after linearization. Banking crises only arise through a combination of two non-linearities. First, the default decision of firms is strongly non-linear: the firm default rate increases by 3 percent in the non-linear solution, compared to 1.3 percent in the linearized solution. Second, close to the steady state, financing frictions have little bite, in the sense that the probability of facing penalties is low. This probability rises nonlinearly when banks come closer to the regulatory threshold. Banks can therefore absorb some losses without restricting credit supply, and the financial accelerator described above does not arise. This reasoning explains why bank balance sheets have little influence on economic dynamics in normal times, i.e., with small shocks, where the linear solution captures economic dynamics well.

Using nonlinear solution methods is therefore essential to understand model dynamics. Just looking at a linearized version of the model, there would be no reason to be concerned about financial stability and no role for macroprudential regulation. Moreover, we would find that long-term credit plays a stabilizing role as it allows firms to transfer aggregate risk to the financial sector, which in the following we will show is not true in the nonlinear solution.

[30] Note that our definition of the lending rate contains the ratio of future price of loans to current price. Here both fall drastically, which partly offset each other. As a result the lending rate does not increase more sharply, but more persistently in this economy, as it takes longer for prices to return to their steady state value.

5.2 The de-stabilizing effects of long-term credit

In this section we take a closer look at how long-term credit affects bank behavior and the stability of the economy.

The strong nonlinearities documented in the last section generate precautionary behavior on the side of firms and banks, which affects both averages and fluctuations in the economy. We therefore look at how the maturity of assets affects first and second moments of macroeconomic aggregates. Table 6 shows the deterministic steady state as well as moments from a non-linear solution of the economy with a banking sector friction, both under short-term and long-term loans. The table also contains statistics for economies where a macroprudential policy has been implemented, but these will be discussed in a later section.

The table reveals the precautionary behavior of banks under long-term loans, being exposed to more aggregate risk. With long-term loans they target an asset-to-equity ratio[31] of 6.52 compared to 7.03, if precautionary behavior is not taken into account. In comparison, banks have a much smaller precautionary motive when lending is short-term, as their target average leverage remains at 6.85. Even though banks target lower leverage with long-term loans, they default slightly more often. As we show below, this happens because the economy experiences rare banking crises where many intermediaries default. The nonlinearities of the model are also apparent in average firm default rates, where simulation means exceed the non-stochastic steady state under both debt maturities. Their debt to asset ratio, however, always remains close to 38 percent.

The effects of risk transfer from borrowers to lenders are reflected in business cycle volatilities, which are reported in Table 7. Long-term debt insures the borrowers, whose consumption volatility is reduced by 10 percent, at the expense of savers, whose consumption volatility is increased by around 1 percent. Overall the economy appears to be more volatile. The additional risk faced by banks can be seen from the standard deviation of bank defaults, which is larger by a factor of 5 in the presence of long-term loans. Higher risk in the financial sector raises the standard deviation of the risk free rate from 0.37 percentage points to 0.39 percentage points and the standard deviation of the interest rate spread from 0.65 percentage points to 0.74 percentage points . Higher interest rate volatility translates into an increase in the standard deviations of investment and output by 5 percent and 1 percent, respectively. The magnitude of these differences in real variables might appear to be modest. Note, however, that debt maturity only plays a role for output and investment during times of financial stress, when firm and bank financing

[31]For bank leverage we show the stochastic steady state rather than a simulation mean. We think it captures precautionary motives better, since this value can be considered as the target leverage banks aim for in the absence of shocks. The asset-to-equity ratio is used because it is a more common measure for bank leverage, than debt-to-asset.

		Long-term		Short-term	
Variable	Non-St. StSt	BL	MP	BL	MP
GDP	0.732	0.732	0.731	0.732	0.731
Capital	5.862	5.845	5.835	5.845	5.833
Labor	0.300	0.300	0.300	0.300	0.300
Total Consumption	0.582	0.582	0.582	0.582	0.582
Deposits	1.925	1.881	1.784	1.883	1.780
Bank equity to assets*	7.037	6.523	5.123	6.854	5.263
Bank default %	0.134	0.150	0.008	0.143	0.004
Corporate debt to assets	0.385	0.383	0.383	0.383	0.382
Corporate default %	0.418	0.475	0.477	0.478	0.477

Table 6: First Moments
Means computed from a simulation of 1 000 000 model periods; *: for bank equity to assets we report the fixed point of nonlinear policy functions (stochastic steady state). BL: Baseline, MP: Macroprudential regulatory regime

constraints are tight. Such episodes are rare, in our model as in reality, and therefore do not affect average business cycle moments very much. This fact is also discussed, for example, in Khan and Thomas (2013). Financial sector variables, like the bank default rate and interest rate spread, are relatively stable in normal times, and their volatility is mainly driven by large spikes in financial crises. This explains the bigger difference between the standard deviations for these variables.

Our results are in stark contrast to Andreasen, Ferman, and Zabczyk (2013), who find that business cycles fluctuations are dampened by the introduction of long-term lending. In their model, borrowing firms do not default on their outstanding debt, and the interest payment on a loan is fixed, while the repayment on the principal depends on the value of capital. This makes shorter maturity loans more risky. As a result long-term loans carry less business cycle risk than short term loans. Since banks are exposed to less risk, long-term lending stabilizes credit supply and output. In our model, the presence of borrower default makes long-term lending much more risky for banks, as shown above. Since banks are highly levered, they are not well equipped to take on this risk, and investment and output become more volatile.

5.3 The anatomy of financial crises

Because banking crises happen infrequently, they have a moderate effect on the conventional business cycle statistics that we have reported above. To study the role of bank financing frictions, we now take a detailed look at the behavior of our economies during financial crisis episodes. For this purpose, we simulate all four economies with the same

	Long-term		Short-term	
Variable	BL	MP	BL	MP
GDP	1.351	1.317	1.335	1.319
Investment	5.569	5.048	5.315	5.145
Household Consumption	0.776	0.770	0.771	0.771
Entrepreneurial Consumption	0.794	0.744	0.885	0.859
Risk free rate*	0.389	0.349	0.365	0.350
Interest rate spread*	0.741	0.625	0.652	0.627
Bank defaults*	0.246	0.080	0.048	0.002

Table 7: Standard deviations in %, *:ppt, 1 000 000 periods, Quantity variables: logarithms taken and HP-filtered(lambda = 1600), BL: Baseline, MP: Macroprudential regulatory regime

exogenous shock processes for 1 000 000 quarters and define a banking crisis by an event where the bank default rate exceeds its mean by 2.5 standard deviations in the baseline economy.[32] This leaves us with crises that occur roughly once in 100 years. We then average over the simulated paths starting 10 quarters before the crisis and ending 20 quarters after the crisis. All graphs are shown relative to the pre-crisis mean. Note that we identify crisis events in the baseline economy and look at the identified episodes for all four economies. Therefore all economies are exposed to the same shocks during the time window we consider.

Figure 6 establishes the importance of the bank financing friction during crisis episodes in the economy with long-term credit, by comparing it to the economy without the friction. The episodes that cause banking crises feature low productivity (0.8 percent below pre-crisis mean) and high idiosyncratic risk (6 percentage points above pre-crisis mean). In the baseline economy, 0.8 percent of banks default in the peak quarter of a crisis on average, which is lower than the peak during the Great Recession at 2.8 percent in the fourth quarter of 2008, but bank defaults are more persistent in our model. In the absence of the dividend friction, banks issue new equity amounting to 7 times their average pre-crisis dividends at the peak of the crisis so that the increase in their default rate is minimal. The role of bank financing frictions in the investment contraction is sizeable: investment falls by 18 percent, compared to 11 percent in the absence of bank financing frictions. As a result output and labor reach a trough of 2.7 percent and 2 percent, respectively, compared to 2.0 percent and 0.8 percent if banks can freely issue equity. The output loss is limited due to the simple RBC structure of our model, but highly persistent. Ten quarters after the crisis, the difference in output between the two economies remains at 0.5 percentage points .

[32] If we find such a quarter, we drop the next 20 observations in order to avoid counting the same episode twice.

In contrast, Figure 7 shows that neither of the economies with short-term loans, if subject to the same shocks, experiences banking crises. The average paths for the economies with and without banking sector frictions are almost indistinguishable, except for the bank default rate, which rises by 0.09 percentage points compared to 0.04 percentage points . Investment falls by 13 percent, while the output reaches a trough of 2.4 percent.

We conclude that the friction in the banking sector has almost no relevance in an economy with short-term credit, even when the economy is hit by severe adverse shocks. As explained above, this is due to the fact that short-term contracts expose banks to very little risk. This result is consistent with Aikman and Paustian (2006), who find that adding a banking friction into the model of Bernanke, Gertler, and Gilchrist (1999) affects dynamics very little.

Figure 6 also illustrates the role of interest rate risk in our model. The lending contract in our model specifies a fixed interest rate, while banks are financed through short-term demand deposits. The maturity mismatch between bank assets and liabilities exposes banks to fluctuations in the risk free rate, in addition to the fluctuations of the firm default rate. If deposit and lending rate both increase, keeping the spread constant, banks potentially face large losses since their funding costs increase, while the interest on their outstanding debt is fixed. To what extent banks are actually exposed to interest rate risk is subject to debate in the empirical literature. Floating rate contracts that index interest payments to the short-run risk free rate are very common, particularly for mortgage lending. However, banks can potentially hedge interest rate risk through instruments traded on financial markets. Of course this only reduces the aggregate exposure if the risk can be transferred to institutions outside of the intermediary sector. In recent contributions English, Van den Heuvel, and Zakrajšek (2018) find that banks are exposed to large amounts of interest rate risk, while Drechsler, Savov, and Schnabl (2018) find they are hedged well against this risk.

In our model, it turns out that taking on the interest rate risk reduces the total exposure of banks to aggregate risk, because the firm default rate and the risk free rate are negatively correlated. When the economy enters a crisis, the default rate rises and the risk free rate falls (cf. Figure 6). Indexing outstanding debt to the risk free rate would only cause further losses for banks in this situation. We therefore find that modeling loans with a fixed interest rate is a conservative choice for analyzing the transfer of aggregate risk.

5.4 Macroprudential policy

The destabilizing effects of long-term loans arise because a highly leveraged banking sector is not well equipped to absorb the risk of higher firm defaults in severe recessions.

Does this change if a macroprudential policy in the spirit of Basel III is implemented? We implement such a policy in our model as an increase in the capital requirement from 8 percent to 12 percent. In addition, the new capital requirement contains a countercyclical buffer: banks are allowed to lower their capital whenever the corporate default rate increases, so that losses do not affect their lending capacity. We find that it is important to make the capital requirement somewhat slow moving, as otherwise tightening capital requirements during the recovery can severely prolong recessions. We therefore introduce an auto-regressive component in the capital requirement:

$$\psi_t = \bar{\psi}(1 - \rho_\psi) + \rho_\psi \psi_{t-1} + \psi_\pi(\pi_t^F - \bar{\pi}^F) \tag{40}$$

We choose $\rho_\psi = .92$ and $\psi_\pi = .3$, which results in a capital requirement that fluctuates between 13 percent in expansions and 10 percent in recessions. In about 2 percent of quarters the requirement falls below 10 percent, while it exceeds 13 percent in less than 1 percent of quarters. It never leaves the interval from 8 to 14 percent. This is roughly in line with an 8 percent capital requirement, enhanced by a 2.5 percent capital conservation buffer (CCB) and a further 2.5 percent counter-cyclical buffer (CCyB). We condition the capital requirement on the corporate default rate, as is best captures losses faced by banks. Results are generally similar if the capital requirement is contingent on, for example, output.

Figures 6 and 7 show the time paths of these economies around banking crises. In the economy with short-term debt (Figure 7), macroprudential policy has little effect. This is not surprising, since we have already established that banking frictions do not matter much in this case. The higher capital ratio helps to avoid a small increase in bank defaults, but other variables are hardly affected. Since banks are not strongly constrained in their lending due to a shortage of equity, the implementation of countercyclical capital requirements stimulates lending only very little in a recession. This can also be seen in the business cycle standard deviations.

Macroprudential policy matters when debt is long-term, where it is very effective in preventing financial crises (Figure 6). When hit by a severe adverse shock, the economy with macroprudential regulation responds on impact similarly to an economy without banking friction. In particular, there is almost no rise in bank defaults, although the recession is somewhat more persistent with macroprudential policy. This is mainly because banks are still under-capitalized when the regulatory regime begins to tighten again. The stabilizing effect of the new policy can also be seen in the business cycle standard deviation in table 7. The standard deviations of all variables are reduced, most notably the volatility of bank defaults, which falls by a factor of three. Interest rates, investment and consumption all become less volatile.

While the stabilizing effects of macroprudential policies are clear, it is often argued that higher capital requirements raise the cost of intermediation and adversely affect investment and output during their introduction and in the long run.[33] Table 6 shows that the second effect exists in our model, but that it is small. Average output is 0.1 percent lower in the economies with the higher capital requirement, while bank leverage falls from 6.52 to 5.12 and bank defaults are essentially eliminated. Moreover, the smaller gross steady state output does not necessarily reflect an efficiency loss, for two reasons. First, average bank defaults are significantly reduced by the higher capital requirement, reducing the dead-weight loss in the economy. Second, the higher steady state output in the economy with lower capital requirements is the result of a 0.1 percent higher stock of physical capital, which must be built up by delaying consumption and maintained by a higher level of investment and labor. We find that total consumption is only 0.05% lower, which is offset by a 0.07% decrease in labor under the macroprudential regime. Deposits, which also provide utility due to their liquidity value, shrink by 6% under the new regulatory regime, but the impact on utility is small. Evaluating the utility function at the long run means, we find that utility is 0.025% lower in consumption equivalent terms.[34]

While the steady state effects of the change in regulatory policy are small, during the implementation phase output losses are nontrivial. As banks are forced to adjust their capital positions, they significantly reduce lending. Figure 8 shows an economy that is in the steady state of the baseline policy regime and raises the capital requirement from 8 percent to 12 percent in period 1. The fast and unanticipated introduction of higher capital requirements causes a massive, but short lived contraction. Investment falls by 40 percent while output contracts by 5 percent. However, the economy recovers quickly once banks have accumulated enough equity to satisfy the new regulation. We are obviously looking at a drastic and unrealistic policy measure here, as banks have to increase their capital ratio within one quarter. In reality banks are informed well in advance over future increases in regulatory capital ratios and have time to build up the necessary equity. We therefore also consider a slow introduction of the capital requirement. In particular Figure 9 shows an economy, where an increase in capital requirements from 8 percent to 12 percent is announced in period 1 and the slowly phased in over the next 20 quarters. The slower introduction causes a much less severe contraction on impact. Output falls by only 1.8 percent. The recession, however, also lasts longer: after 10 quarters output is

[33] See for example Van den Heuvel (2008) and De Nicolò (2015)

[34] Note that this is simply an illustration of the magnitudes of effects and not a relevant measure of welfare. We simply aggregate entrepreneurial and household consumption in the utility function, so that potential redistribution effects do not affect this result.

still more than 1 percent below its pre-regulatory intervention level. These results suggest that even if long-run costs of tighter financial regulation might be low, the transition to a new policy regime can be associated with non-trivial output losses.

Although our model appears to be very close to Landvoigt, Elenev, and Nieuwerburgh (2018), some of our results are in stark contrast to theirs. Common to both papers is the finding that a time-varying capital requirement can be very useful to stabilize credit supply. However, Landvoigt, Elenev, and Nieuwerburgh (2018) come to exactly opposite results on the output effect of increasing the capital requirements. They find large negative long-run effects of higher capital requirements, but in their model the economy transits smoothly to its new output level, without a severe recession, when the requirements are raised. The reason why Landvoigt, Elenev, and Nieuwerburgh (2018) find no output contraction in the transition is because labor supply is fixed in their model, productivity is unaffected by the policy, and capital moves slowly. In our model, labor supply is endogenous and falls jointly with investment, causing a strong contraction in output.

To explain the differences in long-run effects between our model and (Landvoigt, Elenev, and Nieuwerburgh 2018), the key factor is the different ownership structure of banks and firms between the two models. In our model, banks can issue equity to patient saver households, while firms are owned by impatient entrepreneurs. These assumptions are meant to capture the fact that small and medium-sized firms, which rely on bank credit, do not have access to equity markets, while banks do. That the output costs of higher capital requirements are so low in our model is because high bank leverage is a response to regulatory incentives, not to fundamental factors such as agency costs, and only to a small extent to the fundamental liquidity premium of deposits. In this respect, our model follows Admati and Hellwig (2014) who argue that the fundamental factors do not justify the high level of bank leverage observed before the crisis. In Landvoigt, Elenev, and Nieuwerburgh (2018), banks and firms are owned by the same impatient entrepreneur households. Requiring banks to increase their equity capital is more costly in terms of output in their model, as the impatient agents prefer to contract lending rather than increase the equity position of their banks, leading to a long-run decline in lending and capital formation.

Since the precise reasons for high bank leverage and slow speed of adjustment of equity remain a point of discussion in the literature, the estimates of the transition costs should be interpreted with caution. We follow the literature (Jermann and Quadrini (2012),Covas and Den Haan (2012)) in using a reduced form approach to the cost of equity issuance, and calibrate this cost so as to match the business cycle facts of bank equity and dividends. It is not clear that the same costs apply to a transition phase due to a regulatory change. If the reason that banks are unwilling to cut dividends or issue new equity is that this is considered a bad signal to the capital market, this cost would disappear if the capital increase is imposed by the regulator to all banks at the same time. Our estimate of the cost may then be considered as an upper bound. For the long-run costs, our model implies that they are very small, but we recognize that other studies come to different conclusions. Our analysis highlights the sensitivity of policy implications regarding regulatory capital requirements with respect to the assumptions made. However, a clear policy implication of our model is that accurately capturing business cycle risks is essential for assessing the potential benefits of capital requirements. While macroprudential capital requirements do not improve financial stability in a model with short-term loans, they are highly effective at preventing severe banking crises in a model with long-term loans.

5.5 The costs and benefits of long-term loans

Long-term defaultable debt transfers risk from borrowers, typically firms, to lenders, typically banks. In the benchmark calibration of our model, this reduces bankruptcy risk of firms, but destabilizes the economy by causing infrequent but severe banking crisis. A key result of our analysis (cf. Table 7) is that this trade-off disappears once banks are adequately capitalized, so that they can easily absorb the risk. In this case, the role of debt maturity is reversed, and long-term loans increase financial stability. The economy features slightly smoother cycles compared to the one with short-term debt, while borrowers are insured much better against fluctuations.

If one is concerned that raising capital requirements can have large costs in terms of output losses, the question arises if there are cheaper ways to improve financial stability. We find it important to point out that our results should not be understood as evidence that a reduction of loan maturities through regulatory intervention is a good policy in this regard. For a number of reasons long-term loans are probably more important for firms in reality than in our model. The "Maturity Matching Principle", saying that a firm should finance current assets with short-term liabilities and fixed assets with long-term liabilities, is a standard concept in corporate financing. In a survey, Graham and Harvey (2002) find that 65 percent of CFOs cite maturity matching of debt and assets as the reason for long-term issuance. Financing fixed assets with short-term debt exposes firms to a roll-over risk that is not properly captured in our model, where capital is subject to adjustment costs in the aggregate, but liquid at firm level. In addition, refinancing all outstanding debt each quarter is costly, because of contracting costs.[35] As a result

[35]See Poeschl (2017) and Crouzet (2016) for examples of debt maturity choice with firm level investment irreversibility.

the cost and risk associated with short-term debt might be severely understated in our model.

An interesting alternative to shortening loan maturities would be to encourage long-term contracts that eliminate roll-over risk at firm level without transferring so much aggregate risk to the bank, by making the interest rate state-contingent. As we have argued above, floating rate contracts tied to the risk free interest rate do not help in this regard, as the risk free rate falls during times of financial stress. To reduce the aggregate risk to the banking sector, loan rates would have to be tied to overall corporate default rates in the economy. This could be easily done in our model, we are not aware that this type of contract is applied in practice.

It is well recognized that long-term debt not only has positive effects but can cause distortions of firms' incentives. As pointed out in Gomes, Jermann, and Schmid (2016) and Jungherr and Schott (2019), debt overhang associated with long-term debt becomes worse in aggregate downturns. As a result long-term debt reduces firm incentives to invest in a recession and amplifies cyclical fluctuations. This result is in contrast to our findings that long-term contracts stabilize firm investment. The difference arises, because in our framework, debt overhang is eliminated through covenants in the contract. We take the stand here that this problem can be handled by the private sector without regulatory intervention. In Gomes, Jermann, and Schmid (2016) and Jungherr and Schott (2019) on the other hand firms can frictionlessly issue equity, so long-term debt loses its hedging value.

In follow up work (Zessner-Spitzenberg (2019)) we develop a macroeconomic model with heterogeneous firms which optimally choose the maturity of their debt trading-off costs of debt overhang against the hedging benefit of long-term debt. A central finding of this paper is that since debt maturity is chosen optimally by the firm, the insurance benefit of long-term debt likely dominates the debt overhang distortion. This result provides support for our focus on the stabilizing role of long-term debt at firm level.

6 Conclusions

In this paper we develop a macroeconomic model, where banks provide long-term defaultable loans to productive non-financial firms. Both borrowing firms and banks are subject to financing frictions and as a result their respective equity positions determine credit demand and supply in equilibrium. In this environment, we study the effects of loan maturity on economic dynamics.

We find that long-term loans lead to a significant aggregate risk transfer from borrowers to lenders. The reduction in risk allows borrowers to smooth their consumption, while savers' consumption becomes more volatile. Long-term lending can either stabilize or destabilize the economy, depending on whether lenders or borrowers are in the better position to absorb aggregate risk.

If lending is done by highly leveraged banks, long-term lending leads to considerable financial instability. With this we mean the occurrence of severe banking crises, where a large fraction of intermediaries default. In the case of adverse aggregate shocks, high leverage implies that bank equity erodes quickly, leading to defaults and a severe contraction in credit supply and economic activity. These crises do not occur in the economy with short-term lending, so that the unconditional variance of output is lower than in the economy with long-term lending. This result is reversed if a regulatory increase in bank capital requirements puts banks in a position to absorb these risks. In this case, long-term loans stabilize the economy because they help productive firms to manage their own risks.

If it is true that long-term credit is important for the liquidity management of firms, the transfer of risk to banks requires bank regulators to impose high enough capital constraints. While higher capital requirements reduce aggregate fluctuations in the long run, the transition to a state with higher bank equity may be accompanied with significant output losses. To avoid or reduce those, it is necessary to give the private sector enough time to build up bank equity. Furthermore, the government may help with transitory capital injections, a policy that was widely used in the US in response to the losses faced by banks during the recent crisis.

There are multiple interesting directions for future research. Currently we are developing a model with heterogeneous firms, which optimally choose the maturity of their debt to hedge against refinancing risk. Another direction is to build a richer quantitative framework, with nominal rigidities that give a role to monetary policy. In a more stylized model with short-term debt Collard, Dellas, Diba, and Loisel (2017) find that monetary policy does not have to be concerned with financial stability, as long as an optimal macroprudential policy is implemented. It would be highly interesting to investigate whether this finding is still true in a framework, where interest rate changes can have strong balance sheet effects on banks through affecting the value of their long-term claims.

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A Derivation of the loan-price schedule

The goal of this section is deriving the loan price schedule in equation 35 in the main text. Additionally the optimality condition for lending 34 is obtained as an intermediate step. Finding the derivative of the loan price schedule in equation 35 is complicated by the fact that each individual firm makes up a zero measure of the banks' total loan portfolio. Deriving the effect of an individual firm on the expected regulatory costs paid by the bank therefore requires some care.

Consider the problem of a bank that holds a portfolio of loans b, to firms which choose the equilibrium level of leverage CL. In addition the bank lends b^j to an individual firm j, with leverage cl^j. Let $R^b_{t+1}(cl^j)$ be the return on a loan next period, depending on the leverage of firm j. More over we define:

$$\alpha^B = \frac{d - (1-\kappa)(R^b_{t+1}b_t + R^b_{t+1}(cl^j)b^j_t)}{(b_t + b^j_t)}$$

$$\alpha^R = \frac{d - (1-\psi)(R^b_{t+1}b_t + R^b_{t+1}(cl^j)b^j_t)}{(b_t + b^j_t)\gamma}$$

Using the linearity of bank value in net worth, we can write the problem as:

$$\begin{aligned}
V^B_{N,t}n_t = max_{f_t,d_t,b_t,b^j} \quad & f^i_t + \mathbb{E}\Lambda^H_{t,t+1}\int_{\alpha^B}^{\infty}\{(R^b_{t+1}+\alpha_{t+1})b_t + (R^b_{t+1}(cl^j)b^j_t + \alpha_{t+1})b^j_t - d_t dG^B_t(\alpha) \\
& - [G^B(\alpha^R) - G^B(\alpha^B)]\kappa(R^b_{t+1}b_t + R^b_{t+1}(cl^j)b^j_t)\}V^B_{N,t+1} \\
& \text{s.t.} \\
b_t p_t + b^j_t p_t(cl^j) = {} & n_t - h(f_t, n_t) + d^i_t/R_t
\end{aligned} \tag{41}$$

The bank optimality condition with respect to b^j is given by:

$$\begin{aligned}
p_t(cl^j) = {} & \mathbb{E}_t\Lambda^H_{t,t+1}\frac{h_f(f^i_t,n^i_t)(1-h_n(f^i_{t+1},n^i_{t+1}))}{h_f(f^i_{t+1},n^i_{t+1})}\int_{\alpha^B(bl^i_t)}^{\infty} RB^j_{t+1}(cl^j) + \alpha G^B_t(\alpha) \\
& - g(\alpha^B)\frac{\partial\alpha^B}{\partial bj}((R^b_{t+1} + \alpha^B_{t+1})b_t + (R^b_{t+1}(cl^j) + \alpha_{t+1})b^j_t - d_t) \\
& - [G^B(\alpha^R) - G^B(\alpha^B)]\kappa R^b_{t+1}(cl^j) \\
& - g(\alpha^R)[-\frac{(1-\psi)R^b_{t+1}(cl^j)}{(b_t+b^j_t)\gamma} - \frac{d-(1-\psi)(R^b_{t+1}b_t + R^b_{t+1}(cl^j)b^j_t)}{(b_t+b^j_t)^2\gamma}] \\
& * (R^b_{t+1}b_t + R^b_{t+1}(cl^j)b^j_t)\kappa \\
& + g(\alpha^B)\frac{\partial\alpha^B}{\partial bj}\kappa(R^b_{t+1}b_t + R^b_{t+1}(cl^j)b^j_t)
\end{aligned} \tag{42}$$

Using the definition of α^B it can be seen that the second an fifth lines of this equation cancel out. This is intuitively clear, since the value of the bank is 0 at the point where it defaults, so the change in the default probability does not show up in the first order condition. Since the loan to an individual firm is small relative to the bank balance sheet, we can evaluate this equation at $b^j = 0$:

$$\begin{aligned} p_t(cl^j) = \mathbb{E}_t\Lambda^H_{t,t+1}\frac{h_f(f^i_t, n^i_t)(1 - h_n(f^i_{t+1}, n^i_{t+1}))}{h_f(f^i_{t+1}, n^i_{t+1})}\int_{\alpha^B}^{\infty} RB^j_{t+1}(cl^j) + \alpha G^B_t(\alpha) \\ - [G^B(\alpha^R) - G^B(\alpha^B)]\kappa R^b_{t+1}(cl^j) \\ - g(\alpha^R)[-\frac{(1-\psi)R^b_{t+1}(cl^j)}{b_t\gamma} - \frac{d - (1-\psi)(R^b_{t+1}b_t)}{b_t^2\gamma}](R^b_{t+1}b_t)\kappa \end{aligned} \tag{43}$$

Note that equation 43 is equivalent to equation 34, if evaluated at equilibrium leverage $cl^j_t = CL_t$. This establishes the price of a loan in equilibrium. Finally differentiating 43 with respect to individual firm leverage cl and plugging in further definitions, yields equation 35 from the main text:

$$\begin{aligned} \frac{\partial p_t(cl^j_t)}{\partial cl} = \mathbb{E}_t\Lambda^H_{t,t+1}\frac{h_f(f^i_t, n^i_t)(1 - h_n(f^i_{t+1}, n^i_{t+1}))}{h_f(f^i_{t+1}, n^i_{t+1})}\frac{\partial R^b_{t+1}(cl)}{\partial cl}\{1 - \pi^B_{t+1} \\ + g^b(\alpha^R_{t+1})(1-\psi)\frac{\kappa}{\gamma}R^b_{t+1} - [\pi^R_t(bl) - \pi^B_t(bl)]\kappa\} \end{aligned} \tag{44}$$

B Figures

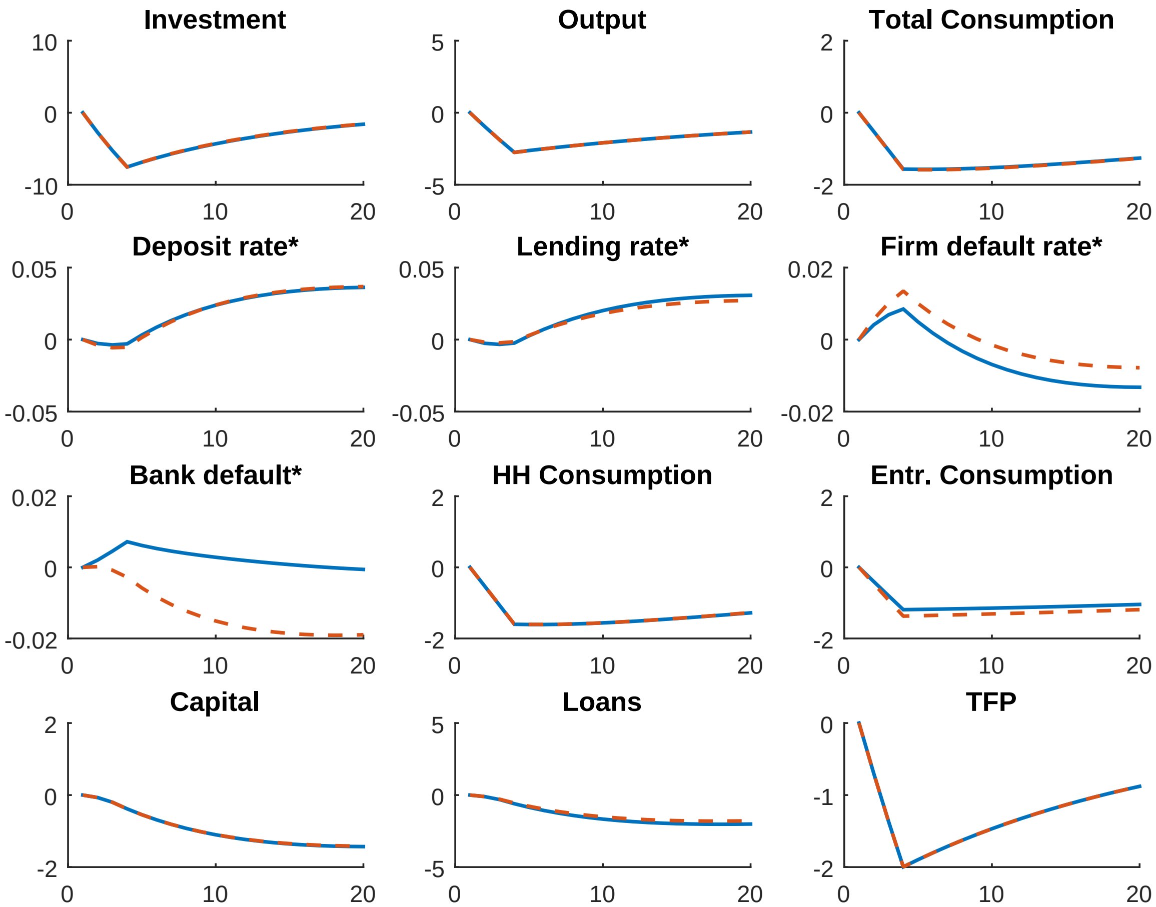

Figure 2: **Response to an decrease in aggregate TFP, in economies with dividend adjustment costs.**
The blue solid line corresponds to an economy with long-term loans, the red dashed line to an economy with short-term loans.
Time: Quarters. Deviations from stochastic steady state in %, except *: ppt deviations.
Solution Method: 3rd order perturbation

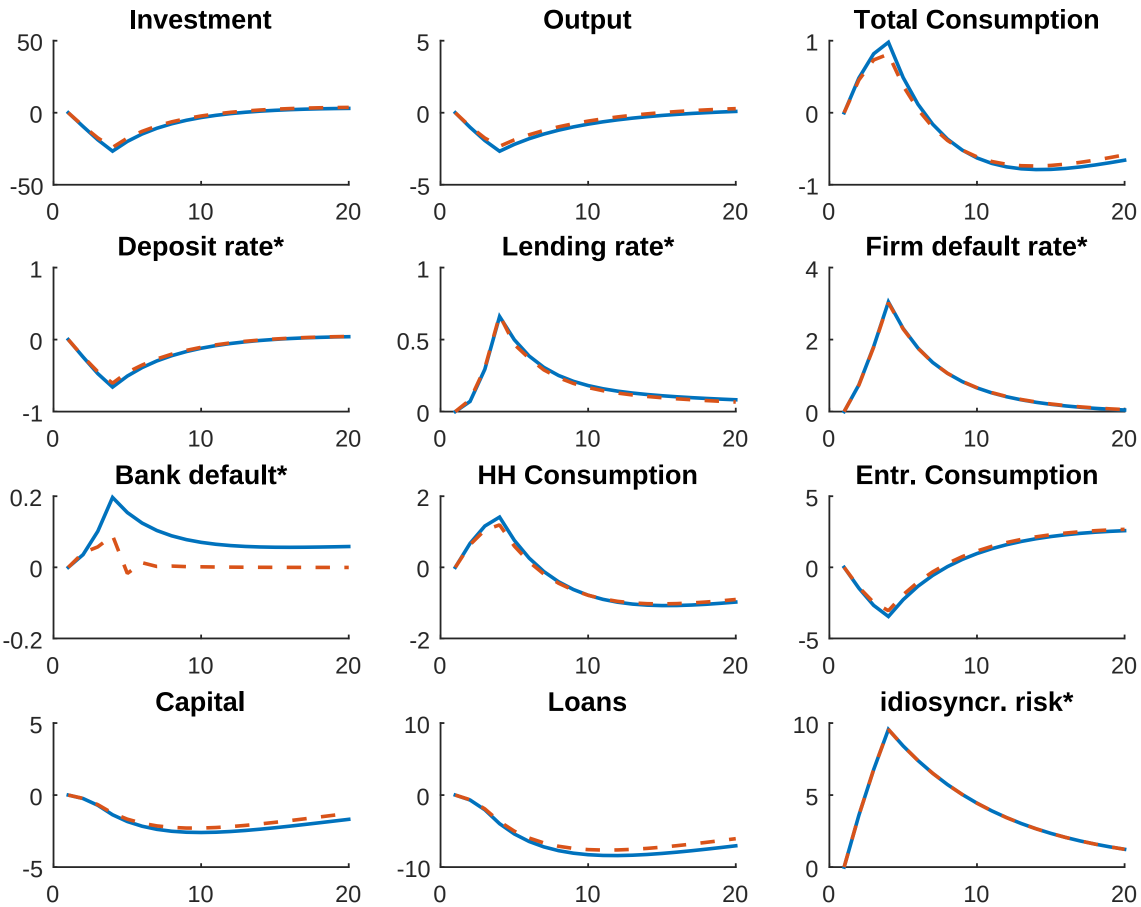

Figure 3: **Response to an increase in the standard deviation of idiosyncratic capital quality, in economies with short-term loans.**
The blue solid line corresponds to an economy with dividend adjustment costs, the red dashed line to an economy without dividend adjustment costs.
Time: Quarters. Deviations from stochastic steady state in %, except *: ppt deviations.
Solution Method: 3rd order perturbation

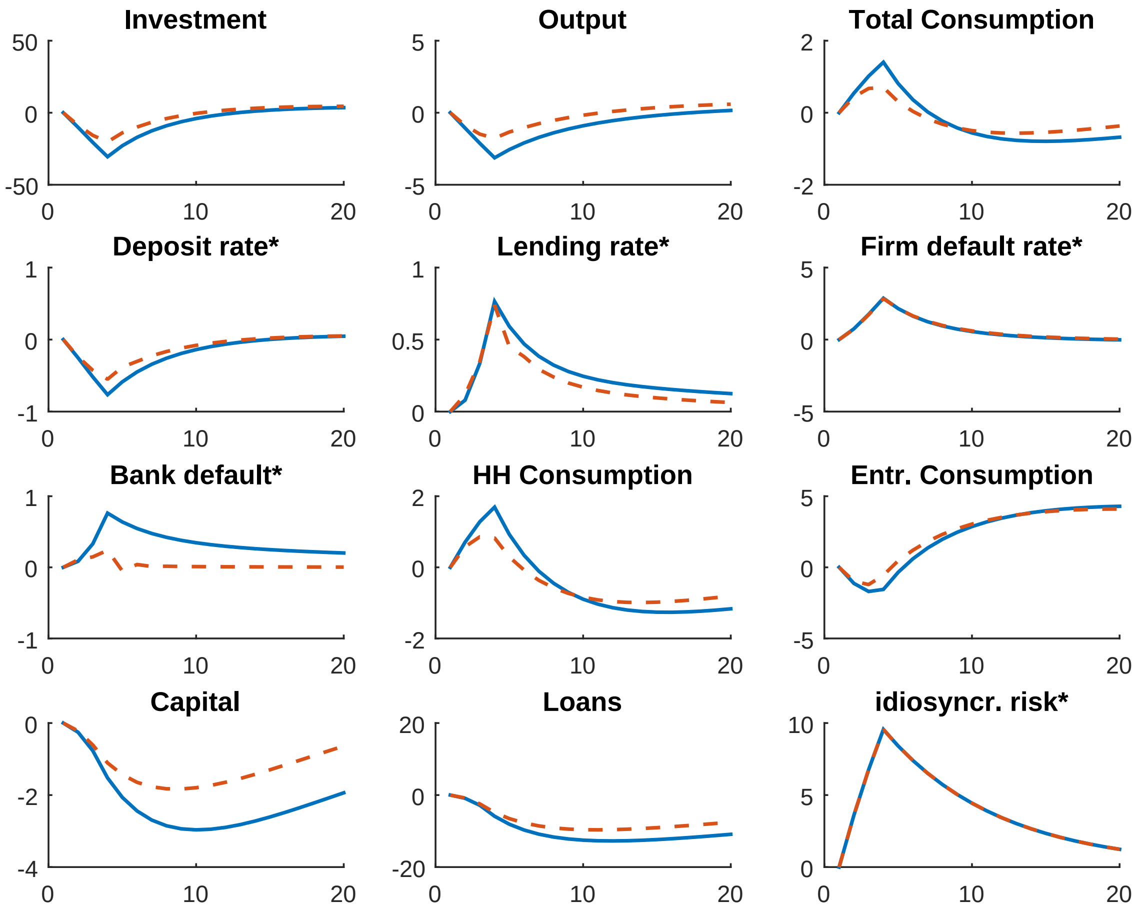

Figure 4: **Response to an increase in the in the standard deviation of idiosyncratic capital quality, in economies with long-term loans.**
The blue solid line corresponds to an economy with dividend adjustment costs, the red dashed line to an economy without dividend adjustment costs.
Time: Quarters. Deviations from stochastic steady state in %, except *: ppt deviations.
Solution Method: 3rd order perturbation

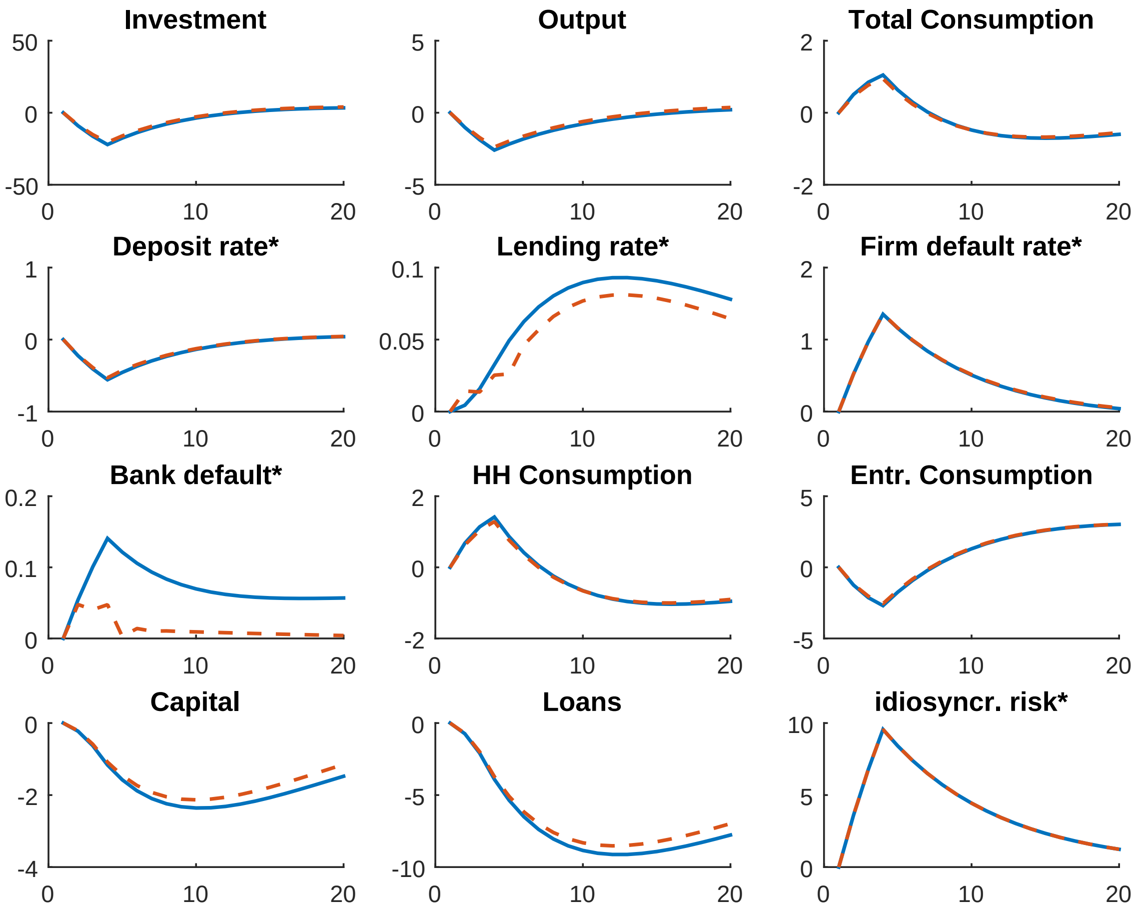

Figure 5: **Linearized response to an increase in the in the standard deviation of idiosyncratic capital quality, in economies with long-term loans.**
The blue solid line corresponds to an economy with dividend adjustment costs, the red dashed line to an economy without dividend adjustment costs.
Time: Quarters. Deviations from stochastic steady state in %, except *: ppt deviations.
Solution Method: Linearization

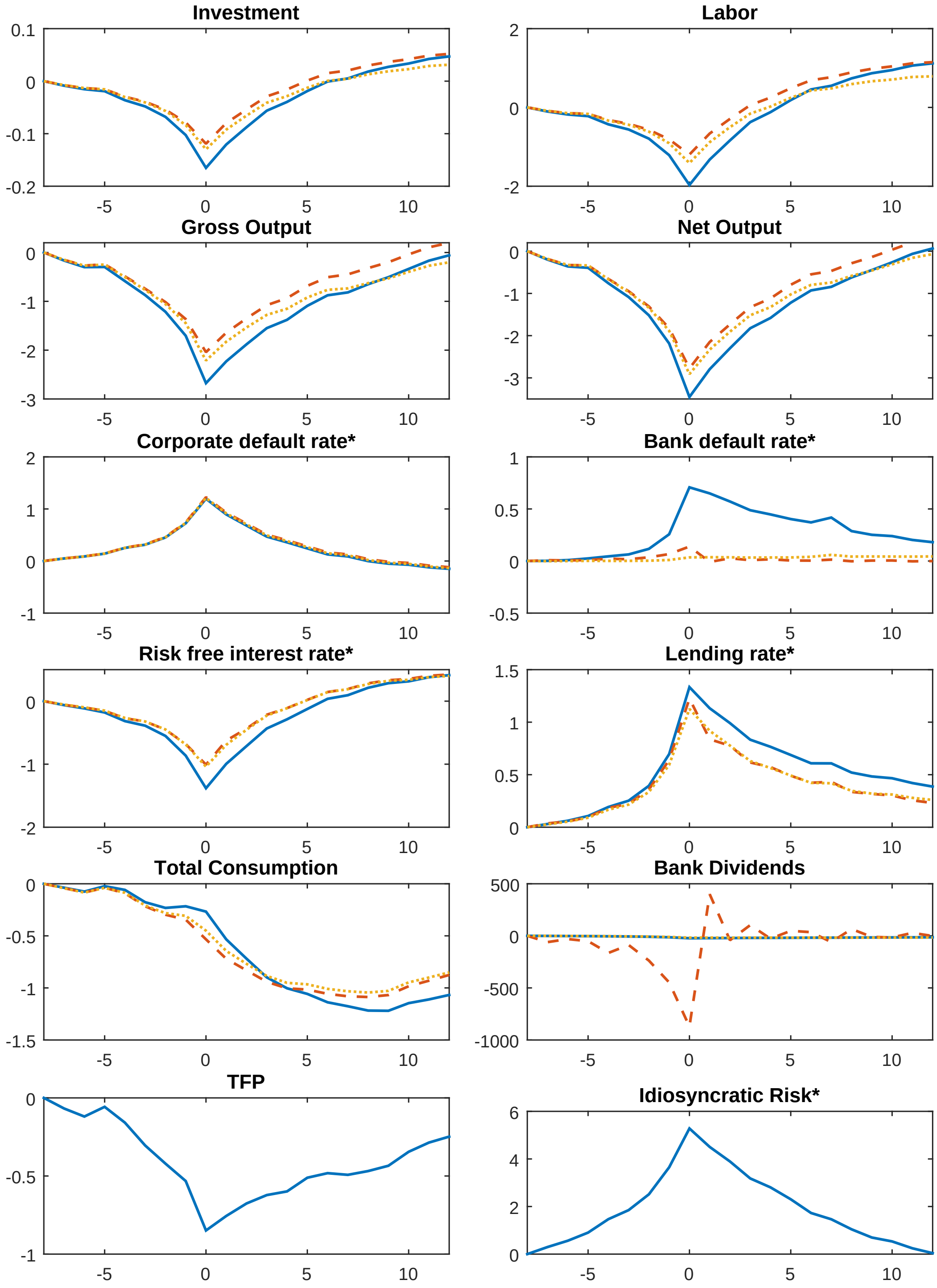

Figure 6: **Average paths around banking crises in economies with long-term loans.**
The blue solid line corresponds to an economy with dividend adjustment costs, the red dashed line to an economy without dividend adjustment costs and the yellow dotted line to an economy where macroprudential banking regulations have been introduced.
Time: Quarters relative to occurrence of the crisis. Deviations from pre-crisis mean in %, except *: ppt deviations.

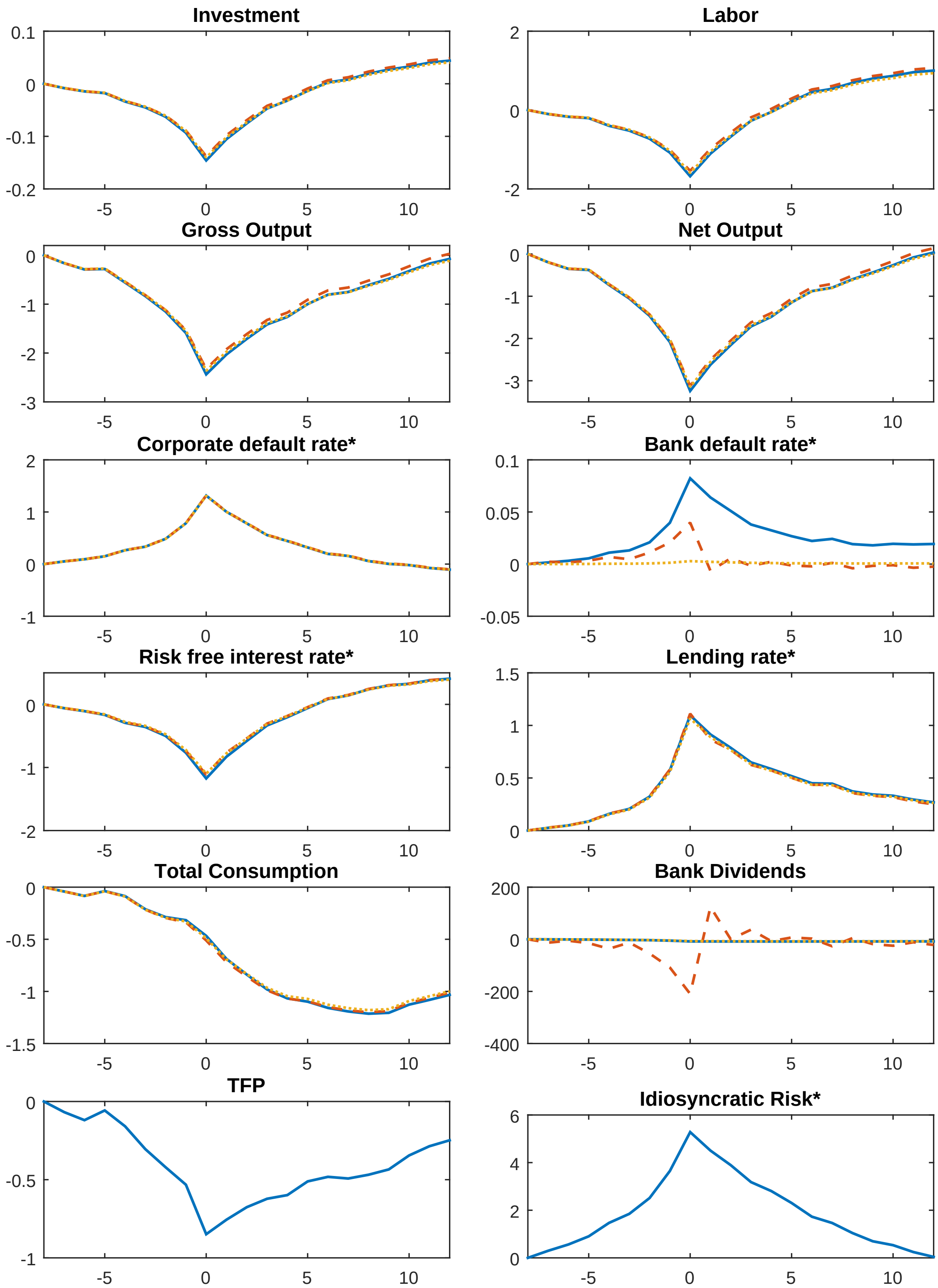

Figure 7: **Average paths around banking crises in economies with short-term loans.**
The blue solid line corresponds to an economy with dividend adjustment costs, the red dashed line to an economy without dividend adjustment costs and the yellow dotted line to an economy where macroprudential banking regulations have been introduced.
Time: Quarters relative to occurrence of the crisis. Deviations from pre-crisis mean in %, except *: ppt deviations.

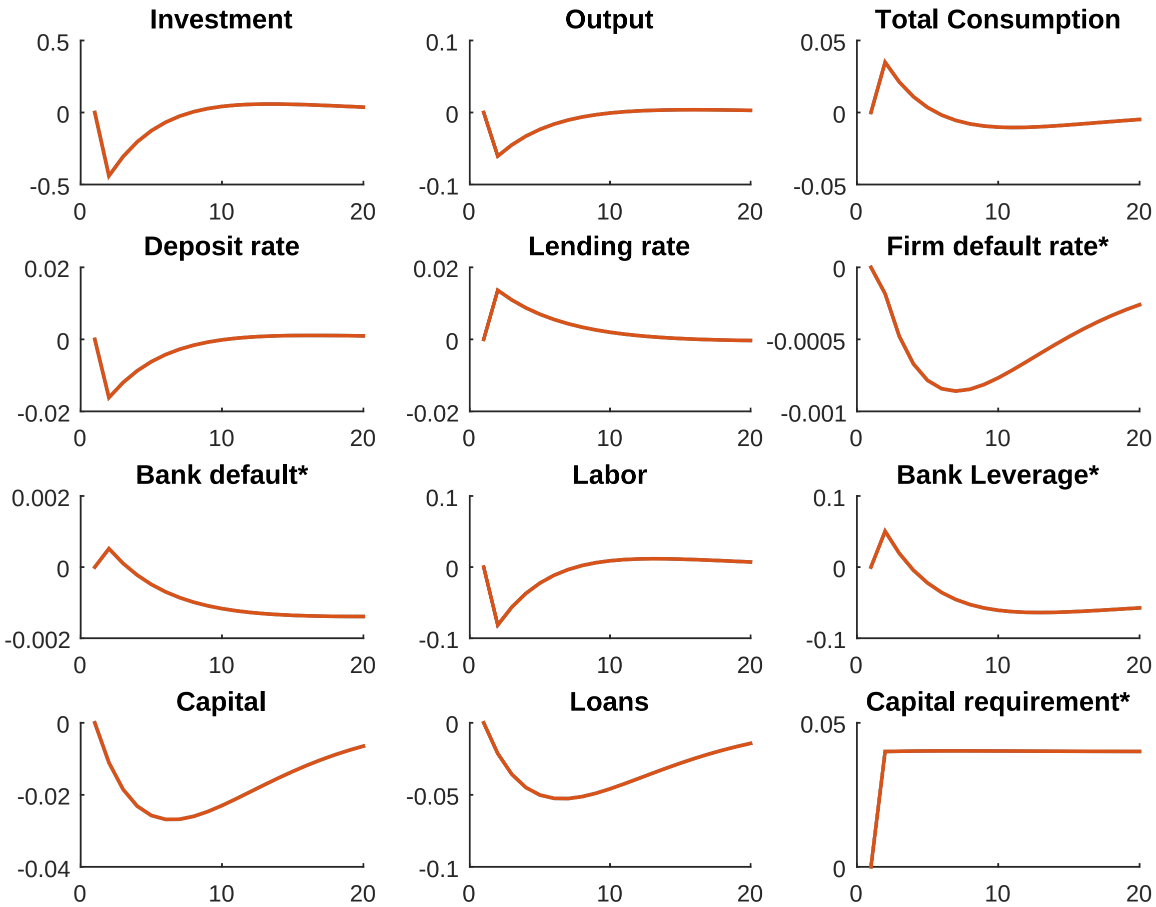

Figure 8: **Response to an instant increase in the bank capital requirement from 8% to 12%**
Economy with long-term loans and dividend adjustment costs.
Time: Quarters. Relative deviations from pre-introduction stochastic steady state, except *: absolute deviations.

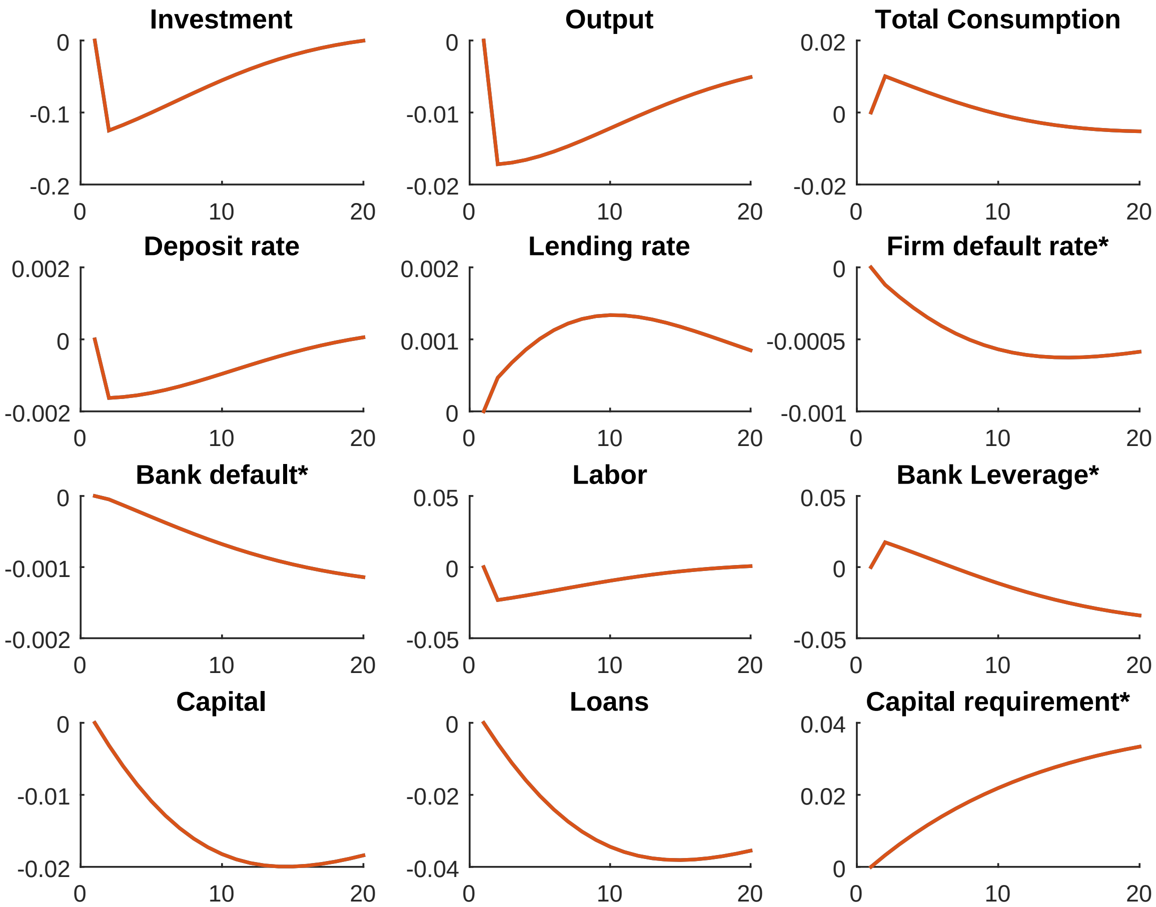

Figure 9: **Response to a slow increase in the bank capital requirement from 8% to 12%**
Economy with long-term loans and dividend adjustment costs.
Time: Quarters. Deviations from pre-introduction stochastic steady state in %, except *: ppt deviations.