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Long-term bank lending and the transfer of aggregate risk[☆]

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ABSTRACT

Long-term loan 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 rising default risk of existing contracts. The flip side is that firms benefit from not facing higher interest rates in recessions. If banks are highly leveraged, this can lead to financial instability with severe repercussions in the real economy. If banks are well capitalized, the risk transfer stabilizes the 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 in the US. We find that moving from Basel II to Basel III capital regulation eliminates banking crises, increases output in the long run and improves welfare.

1. Introduction

Which features make the financial sector prone to rare but severe crises? In the aftermath of the 2008 crisis and the Great Recession, this question has received renewed attention by academics and policymakers. One prominent explanation is that banks issue demandable debt to finance illiquid assets, which exposes them to runs, as in Gertler and Kiyotaki (2015). An equally well-established explanation invokes occasionally-binding market-based financing constraints which force banks to deleverage in bad times and set off a financial accelerator, as in Brunnermeier and Sannikov (2014). For both of these mechanisms to work, it is only necessary that banks are leveraged investors in long-lived assets. The nature of bank assets, whether equity or debt, is not crucial.

We propose a new and complementary explanation, the *risk transfer* mechanism, which fundamentally depends on the fact that the bulk of bank assets are long-term loans. The return on a loan portfolio is highly nonlinear and asymmetric.

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Net loss rates on commercial loans in the US were below 0.2 percent in 2006, offering little upside. The potential downside was large, as losses rose more than tenfold, peaking close to 3 percent in late 2009. Loans thus transfer macroeconomic tail risk from ultimate borrowers to intermediaries.[1] This risk transfer is quantitatively only important for long-term loans. When the economy enters a recession, the expected borrower default rate increases for several years. Banks that lend short-term suffer from immediate defaults, but since their portfolio is rolled over quickly, they can raise the interest rate on new loans to compensate the higher expected losses from defaults. If banks lend at long maturities, however, the interest on continuing loans does not adjust to reflect these expected defaults, so that the fundamental value of the portfolio declines. Banks therefore bear the cost not only of current defaults, but also of a large part of future defaults. That the return structure of debt finance is asymmetric and highly nonlinear helps to explain why financial crises are rare but severe. In contrast, if intermediaries hold equity portfolios, they fully participate in the risk, which is symmetric and linear in the value of firms.[2]

We study the role of the risk transfer for macroeconomic dynamics in a quantitative model which is designed to highlight this mechanism and is purposefully kept simple in other dimensions. Banks collect deposits from households and invest in well-diversified portfolios of long-term loans to firms owned by financially constrained entrepreneurs.[3] Banks are subject to regulatory capital requirements in the spirit of the Basel II regulations in place before 2010, and entrepreneurs are subject to financing frictions as in Bernanke et al. (1999). Following Christiano et al. (2014), the economy is hit by risk shocks, i.e. time varying dispersion in firms' idiosyncratic returns, which have been shown to be important drivers of macroeconomic fluctuations. To minimize unnecessary frictions, we introduce loan covenants as in Hatchondo et al. (2016), which eliminate the debt-overhang problem of long-term contracts. Firm and bank defaults are smoothed out in the aggregate by idiosyncratic shocks, which allows us to solve the model by standard higher-order perturbation techniques. While we only model corporate loans for simplicity, the same mechanisms apply equally to other types of loans, mortgages in particular, which typically have very long maturities.

Establishing the risk transfer as a conceptually separate mechanism is important for several reasons.[4] First, it helps to understand economic dynamics by showing that long-term loans actually *transfer* risk compared to short-term loans. While they expose banks to more aggregate risk, the flip side is a reduction in the risk for borrowers who are shielded from rising interest rates in bad times. Whether this transfer enhances macroeconomic stability depends on who can better handle the risk. If banks are highly levered, the result can be a financial crisis. If, on the other hand, banks are well capitalized, or can easily re-capitalize, long-term lending might actually stabilize the economy. Second, the risk transfers makes it clear that financial crises can arise even in the absence of bank runs or a financial accelerator mechanism triggered by constraints based on market prices. Third, it clarifies why it is important to model bank assets as long-term loans rather than equity or short-term loans. Only long-term loans correctly capture the exposure of the financial sector to aggregate risk which is crucial, for example, for a quantitative analysis of banking regulation.

To study the quantitative predictions of the model, we calibrate it to recent US data. In our baseline model economy, banks issue long-term loans with a maturity of five years in line with the average maturity of corporate debt. The model economy successfully matches a wide range of business cycle moments of output, investment, loan losses, interest rate spreads and bank default rates. In contrast, an economy with counterfactual short-term loans (one quarter maturity) fails to match many of these moments. Most importantly, this economy does not generate realistic variation in the excess interest rate spread, which is a measure of financing frictions in the banking sector, because the short-term portfolios are not exposed to much aggregate risk.

We explore the risk transfer mechanism through a number of experiments in the long-term and short-term loan economies. Our numerical analysis confirms that, in the presence of shocks to the dispersion of borrower's idiosyncratic returns, the financial sector is exposed to much larger aggregate risk under long-term loans than under short-term loans. Long-term loans amplify the response of the main macroeconomic variables, because banks are highly leveraged and not well equipped to take on the risk. This amplification only appears in a non-linear solution of the model. The linearized solution generates very little amplification, because firm and bank defaults increase significantly only in response to large adverse shocks. While long-term loans create instability in the financial sector, they insure borrowing firms against fluctuations in interest rate spreads. In counterfactual economies where banks are not subject to financing frictions, the risk transfer from firms to banks is beneficial for financial stability, and long-term loans tend to dampen economic fluctuations. In a next step we analyze news shocks, which make the risk transfer even more transparent.

In our baseline model, long-term loans not only expose banks to firm default risk, they also introduce a well-known financial accelerator. Banks are subject to capital requirements which depend on the market value of their assets. Falling asset prices reduce regulatory bank equity and force banks to deleverage, which further depresses asset prices and creating an amplification loop. To separate the risk transfer from the financial accelerator effect, we also analyze a version of the

[1] As is common in the literature, we use the terms banks and intermediaries interchangeably to refer to the entire leveraged financial sector. Our concept of lending includes not only loans but also corporate bonds, which have the same risk transfer property and a large share of which are held by the leveraged intermediary sector. See Elenev et al. (2021) for a discussion.

[2] Another important difference is that the riskiness of equity finance would make high leverage practically impossible.

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

[4] We are not the first to write down a model with long-term, defaultable loans. As we explain in detail in the literature section, no other paper has identified the importance of the risk transfer mechanism.

model where financial regulation and bankruptcy rules are based on the book value rather than the market value of assets. This case is also empirically relevant insofar as not all bank assets need to be marked to market. We find that the risk transfer alone, without the financial accelerator effect, generates a smaller effect on bank defaults, but the transmission to the non-financial aggregates is almost as large as in the baseline model.

Next we show that a regulatory reform in the spirit of Basel III improves financial stability and raises social welfare in our baseline long-term loan economy. These positive effects result from the elimination of costly bank defaults, which makes the intermediation process more efficient. The new regulatory regime is close to optimal in our calibrated model. This conclusion aligns with some earlier studies such as Mendicino et al. (2018) and Benes and Kumhof (2015), but is opposite to the findings in Elenev et al. (2021). They develop a model with long-term loan contracts between firms and banks that appears to be very similar to ours, but find that moving from the Basel II to Basel III regulatory regime reduces social welfare. We explain in detail where the different conclusions come from.

As a further check on the empirical relevance of the model, we explore to what extent it can explain a financial crisis similar to the Great Recession. For this exercise, we extend our baseline model with nominal frictions, to allow for stronger amplification of shocks through demand effects. We then create a shock sequence to replicate the macroeconomic dynamics of 2008-10 in our long-term loan economy. The economy with long-term loans matches the paths for a number of macroeconomic and financial variables well. We then feed the same shock sequence into an economy under Basel III regulation and into an economy with short-term loans. Both economies experience a milder recession and no financial crisis.

The main message of our paper is that loan maturity is a key determinant of the risk transfer between borrowers and lenders. Given that there are many different types of loan contracts in the real world, the effective maturity may not be the same as the formal maturity, and it is necessary to clarify which concept of maturity is relevant here. What matters for the risk transfer is the time it takes for an increase in aggregate borrower default risk to raise the interest rate paid on outstanding debt. Therefore, the risk transfer is not necessarily reduced when loans pay a floating interest rate. The fact that interest rate payments are often tied to an index of the riskless rate (see Ippolito et al. (2018)), even amplifies the destabilizing effect of long-term loans on the financial sector. The reason is that the riskless rate declines in a recession, which means banks receive lower interest rates, exactly when they already face losses from borrower defaults.[5] Our assumption of fixed rate contracts is thus conservative. A second possible reason why the effective maturity of a loan may be shorter than the formal maturity are renegotiations which occur frequently for bank loans and are often triggered by covenant violations.[6] To the extent that banks can negotiate interest increases on their existing loan portfolio in response to adverse aggregate shocks, this might weaken the risk transfer. While it is difficult to quantify the aggregate importance of this channel, its effect on our results is probably limited for two reasons. First, Roberts and Sufi (2009) find that a deterioration in bank balance sheets leads to more frequent renegotiations but does not raise the probability of an unfavorable outcome for borrowers. Second, our measure of lending includes not only loans, but also corporate bonds for which covenants are much less common (see Jungherr and Schott, 2022).

The rest of the paper proceeds as follows. Section 2 discusses the relationship of our paper to the existing literature. Section 3 presents the model, which is calibrated in Section 4. We analyze the quantitative role of loan maturity in macroeconomic dynamics in Section 5 and the implications for macroprudential policy in Section 6. In Section 7, we replicate the Great Recession in the model. Section 8 concludes.

2. Relationship to the existing literature

2.1. Empirical literature

The empirical relevance of banks' long portfolio maturities is well established. Our key mechanism, the transfer of aggregate default risk from firms to banks is measured empirically in Begenau et al. (2015). They study the risk exposure of various bank asset and maturity classes in a factor model with aggregate interest and default factors and find that the exposure to both types of risk increases steeply in maturity. In this paper, we explore theoretically the consequences of this risk transfer for business cycle fluctuations and bank regulation.

A related recent literature has focused on banks' exposure to interest rate risk that comes from the fact that their assets have long maturities with fixed interest rate, while their debt is short-term at variable rates. English et al. (2018) and Gomez et al. (2021) find that this exposure is indeed large. Gomez et al. (2021) further show that banks' exposure to interest rate risk is important for their responses to monetary policy. Drechsler et al. (2021) 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. We offer a new, model based view of this issue. Interest risk also reduces the total risk exposure of banks, but for a different reason from Drechsler et al. (2021): borrower default rates increase and the risk free rate falls in a recession. The cheaper financing rate partially compensates the banks for the increased default risk of their portfolio. The negative correlation of the two forms of risk thus provides a reason why it might be desirable for banks, not to hedge their interest rate risk exposure.

[5] Jermann (2019) shows that the choice of interest rate index (LIBOR, SOFR etc.) is important to the aggregate risk exposure of banks. In our model, however, indexing debt to any safe interest rate would make banks even more vulnerable in a crisis.

[6] See Roberts and Sufi (2009) and Chodorow-Reich and Falato (2022).

2.2. Theoretical literature

Given their empirical importance, a number of recent contributions have developed business cycle models with long-term bank lending and borrower defaults. Our analysis is complementary to the existing papers. The risk transfer associated with long-term loans applies generally. It is therefore also present in other models, but due to differences in the numerical solution method and/or the analytical focus, it is not coming to the forefront. Our contribution is to show the central role that this risk transfer plays in macroeconomic dynamics.

Our paper is closest to Elenev et al. (2021), who also solve a model with long-term loans in which both firms and banks are subject to default risk. The main role of loan maturity in their model is to generate liquidity-based firm default. The transfer of risk from firms to banks is not analyzed by Elenev et al. (2021).

Paul (2020) 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. Faria-e Castro (2021) introduces bank runs as in Gertler and Kiyotaki (2015) in a model with long-term loans and shows the benefits of Basel III-style macroprudential regulation. The mechanism triggering financial crises in these contributions is very different to our paper where they emerge from fundamental insolvency in the banking sector. 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 piecewise linear solution, taking into account the zero lower bound. This solution method does not capture the asymmetric and non-linear return of long-term loan portfolios, which is at the core of our analysis. 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 debt 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.

An alternative mechanism how borrower defaults can generate banking crises even with short-term loans is modeled in Mendicino et al. (2020). Bank failures are not driven by a transfer of aggregate risk, which is minimal, but they occur because banks' loan portfolios are imperfectly diversified. As the corporate default rate rises, some banks face much larger losses than others, which leads to defaults. In our model, banking crises can arise even if bank portfolios are perfectly diversified. Key is a realistic calibration of corporate default rates, bank leverage and loan maturity. Boissay et al. (2016) provide a further mechanism unrelated to asset maturity, 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. Brunnermeier and Sannikov (2014), show in an analytical framework that an economy with an intermediary sector can appear stable close to the steady state and yet experience severe financial crises due to occasionally binding borrowing constraints.

In finding that long loan maturity amplifies the effect of macroeconomic shocks, our results appear similar to Gomes et al. (2016) and Jungherr and Schott (2022), where long-term debt distorts firm incentives towards lower investment and higher leverage in aggregate downturns because of debt overhang. In fact, the mechanism generating this result is completely different in our paper: the distortion is eliminated through loan covenants, and amplification occurs because of banking sector losses.

Finally, we want to stress again that the risk-transfer channel analyzed here is complementary to all these mechanisms explored in the literature. In reality, these mechanisms coexist and reinforce each other.

3. The model

Our model builds on the well-established literature on business cycle consequences of firm financing frictions along the lines of Bernanke et al. (1999) and follows Christiano et al. (2014) by introducing fluctuations in idiosyncratic uncertainty. In this framework we introduce an explicit banking sector. An early contribution with this structure is Chen (2001), the three most closely related models are Benes and Kumhof (2015); Elenev et al. (2021) and Mendicino et al. (2018). Our model differs from them in the design of the long-term lending contract and the ownership structure of firms and banks.

To focus attention on the economic mechanisms associated with the presence of long-term loan contracts, we abstract from a number of features common in the business cycle literature, such as nominal rigidities, habit formation in consumption and investment adjustment costs. However, the model is designed so that the numerical solution can be computed by standard perturbation techniques. The essential mechanism of this paper can therefore be easily incorporated into larger models that replicate the business cycle among many dimensions.

3.1. Households

Households choose consumption c_t^h 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 Δ_t^B on aggregate. Households have a linear preference for safe and liquid deposits which is captured by ξ. This assumption is common in the literature to generate the low observed interest on deposits. We follow Stein (2012) by assuming linear utility in deposits. T_t is a lump-sum transfer related to the deposit insurance scheme. Households solve the following optimization problem:

$$\max_{\{c_t^h, d_t, s_t, l_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \mathbb{E}_0 \beta^t \left(log(c_t^h) - \eta \frac{l_t^{1+\nu} - 1}{1+\nu} + \frac{\xi}{100} \frac{d_t}{R_t} \right) \tag{1}$$

s.t.

$$d_t / R_t = d_{t-1} + w_t l_t - c_t^h + s_{t-1}^B \Delta_t^B + T_t + P_t^B (s_{t-1}^B - s_t^B).$$

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

$$\frac{1}{c_t^h} = \frac{\xi}{100} + \beta R_t \mathbb{E}_t \frac{1}{c_{t+1}^h}. \tag{2}$$

The liquidity premium creates a wedge of ξ percentage points between the discount factor β and the risk free interest rate in steady state which gives banks an incentive to use deposit financing. Labor supply is determined by the static first order condition $w_t = \eta l_t^\nu c_t^h$.

3.2. Firms

The final output good is produced by a continuum of competitive firms in a competitive sector with a constant-returns-to-scale Cobb-Douglas technology using capital K and labor L, with the capital share denoted by α. Total factor productivity Z_t is the same for all firms and follows the AR-1 process in logs

$$\log(Z_t) = \rho^Z \log(Z_{t-1}) + s_z \epsilon_t^Z, \tag{3}$$

where ϵ_t^Z is an i.i.d. innovation with standard normal distribution. The wage w_t is determined on a competitive spot market. Each firm owns its capital stock. At the end of each period, the firm sells its old capital used in production at the price q_t^o and buys new capital at the price q_t. The prices $q_t = \frac{1}{\Phi_I(K_{t-1}, I_t)}$ and $q_t^o = q_t \Phi_K(K_{t-1}, I_t)$ are determined in a competitive capital-goods sector which produces new capital from old capital with the constant-returns-to-scale production function $K_t = \Phi(K_{t-1}, I_t)$ and generates no profit. The function Φ captures standard quadratic capital adjustment costs at the aggregate level.

3.2.1. Ownership and financing

At the beginning of a period an existing firm f is described by its capital stock k_{t-1}^f and outstanding loans b_{t-1}^f from a bank. Firms are owned by a representative entrepreneur who is more impatient than the saver/worker household, i.e. $\beta^E < \beta$. Assuming that firms cannot issue equity to the saver household, this gives firms an incentive to use debt financing in equilibrium rather than accumulating internal equity to outgrow their financing constraints. Entrepreneurs have logarithmic utility and only consume firm dividends which implies the stochastic discount factor for firms:

$$\Lambda_{t,t+1}^E = \beta^E \frac{\Delta_t^F}{\Delta_{t+1}^F}$$

where Δ_t^F are aggregate firm dividends which equal entrepreneurial consumption C_t^e. There is free entry and new firms can be set up at no cost by entrepreneurs at the end of each period.

To keep the model simple, we assume that households do not directly lend to firms but only through intermediaries. This assumption is somewhat restrictive, since corporate borrowing in our model includes both loans and bonds, and in the data a fraction of the bonds are held by households. Elenev et al. (2021) report that these holdings are relatively small, as intermediaries hold 86.3% of corporate debt on average. Including household participation in the bond market would be a straightforward extension to the model. From now on we use the term loans to refer to both, corporate loans and bonds.

3.2.2. Idiosyncratic risk and default

As in Bernanke et al. (1999), each firm faces idiosyncratic risk in the form of shocks to the quality of its capital. Each period, firm f draws an idiosyncratic shock ω_t^f, which transforms its initial capital k_{t-1}^f into $\omega_t^f k_{t-1}^f$ of capital. After observing the shock, the firm decides whether to default on its outstanding debt. If the firm defaults, it is closed down and its assets are seized by its creditors. In default, only a share δ^F of the firm's output and capital is recovered, while the rest is lost. Idiosyncratic risk in combination with default costs creates a financial friction, which ties firm borrowing to net worth.

The shock ω_t^f is independent across firms and time, and is normally distributed with expectation $\mathbb{E}_t \omega_t^f = 1$ and standard deviation σ_t^F. The standard deviation of idiosyncratic uncertainty σ_t^F is the same for all firms but is subject to aggregate *risk shocks* which follow

$$\log(\sigma_t^F) = (1-\rho_V)\log(\bar{\sigma}^F) + \rho_V \log(\sigma_{t-1}^F) + s_v \epsilon_t^V \tag{4}$$

Again the innovation ϵ_t^V is i.i.d. and standard normal. This *risk shock* is found to be an important driver of macroeconomic dynamics for example in Bloom (2009) and Christiano et al. (2014).

3.2.3. The lending contract

A central feature of our model is that firm borrowing is long term, i.e., loans have a maturity exceeding one model period. In general the introduction of multi-period contracts leads to a distribution of loans with different residual maturities. To maintain tractability, we follow a well-established literature and introduce long-term loans with a geometrically declining repayment structure.[7] In particular, a loan issued in period t with principal of one has a repayment of $(\mu + \tilde{R}_t)(1-\mu)^{i-1}$ in period $t+i$. The remaining principal in period $t+i$ then is $(1-\mu)^{i-1}$. The parameter μ determines the average maturity of the loan which is given by $\frac{1}{\mu}$.

We assume that $\tilde{R}_t$ is fixed at the beginning of the contract and kept constant throughout the lifetime of the loan. This is the realistic assumption for corporate bonds, but in the real world the interest rate on loans is often (partially) indexed to the risk free interest rate. In this paper, we nevertheless stick to the assumption of fixed rate contracts, because it is conservative in the sense that it reduces the risk transfer from firms to banks. The reason is that floating rate contracts tie the interest rate only to the risk free rate, not to changes in the riskiness of borrowers, and the riskless rate typically goes down in a recession. Indexing the borrowing rate would imply that banks obtain a lower return on their loans when the default probability has gone up. The mechanisms that we describe would then become even stronger.

Choosing the level of $\tilde{R}_t$ is then purely a normalization as it scales the entire repayment stream. For simplicity we choose to fix the interest rate component of repayment at the steady state risk free rate $\tilde{R}_t = \bar{R}$.[8] Since agents in the model only care about the fundamental value of assets, dynamics in the model are not affected by this assumption. By assuming equal seniority independently of the issuance date, loans can be aggregated over time, by converting one unit of outstanding loans into $(1-\mu)$ units of new loans.

The interest on a loan is determined by a time-varying price schedule for loans. Banks set this schedule taking into account the ability of the firm to repay the loan in the future. Since firm operations are constant returns to scale, the loan price schedule $p_t(cl_t^f)$ is a function of the firm's debt to asset ratio $cl_t^f = \frac{b_t^f}{k_t^f}$. From now on we refer to cl_t^f as corporate leverage. In particular $p_t(cl_t^f)$ is decreasing in leverage, as more debt relative to capital reduces the probability of the loan being repaid.

Covenants Long-term loans distort firm incentives due to debt overhang and dilution. These distortions render the dynamic optimization problem time-inconsistent. For classical references see Jensen and Meckling (1976) and Myers (1977). Gomes et al. (2016) and Jungherr and Schott (2022) investigate their consequences in a macroeconomic context without a financial sector. Ferrante (2019) studies a model where banks issue long-term loans subject to debt overhang.

These distortions are not central to the focus of this paper, which lies on understanding the transfer of aggregate risk from firms to banks inherent in long-term contracts. What matters for this risk transfer are business cycle properties of firm default rates, not firm level investment and financing decisions. For conceptual clarity and tractability, we therefore assume a lending contract that eliminates the incentive to dilute the value of outstanding debt through excessive future risk taking. We do so by introducing loan covenants.[9] Covenants are common in corporate loans and have appealing efficiency properties as discussed by Demiroglu and James (2010) and Smith (1993) as well as Tirole (2010). In the design of the contract we follow Hatchondo et al. (2016), who use a similar approach in a model of sovereign default: The covenant stipulates that the firm has to make a compensation payment $CP(cl_t^f)$ to the bank for every outstanding loan if it deviates from the contracted leverage ratio. We assume this contracted leverage to be equal to the average corporate leverage ratio CL_t in the economy. The compensation payment is set as

$$CP_t(cl_t^f) = p_t - p_t(cl_t^f) \qquad \text{where} \quad p_t = p_t(CL_t), \tag{5}$$

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 all firms choose the same leverage ratio, so no compensation payments are made.

Three things should be noted. First, the effect of the covenant is that firms fully bear the effect of their actions on the value of their liabilities. Without a covenant, firms only bear the effect on newly issued liabilities, as for example in the

[7] This type of contract has been widely used to model long-term loans since Leland (1994). See Andreasen et al. (2013); Paul (2020) and Elenev et al. (2021)

[8] This normalization implies that the value of a loan in the steady state of a frictionless model would be equal to 1.

[9] As an alternative, Gomes et al. (2016) and Ferrante (2019) have used a tractable way to solve the firm problem taking into account the incentive distortions by making parametric assumptions about future policy functions.

setups of Gomes et al. (2016) and Ferrante (2019). The covenant thus fully eliminates the debt dilution effect and thus the debt overhang problem present in these two papers. As we explain in detail in Appendix B, this is the property that simplifies the solution of the model. Second, limited liability still applies, so owners can refuse to make payments and let the firm default. Third, banks are only compensated for individual firm risk taking. If the firm default rate rises due to a change in macroeconomic conditions, banks are not compensated and bear the losses. This is exactly the risk transfer we study in this paper.

3.2.4. The firm problem

After observing its draw ω_t^f the firm decides whether to default. If the firm does not default, it optimally chooses dividends Δ_t^f, productive capital k_t^f and loans b_t^f. Denoting by $G_t^F(\omega^f)$ and $g_t^F(\omega^f)$ the CDF and PDF of the idiosyncratic shock, respectively, the firm problem can be written in recursive form as

$$
\begin{aligned}
V^F\left(k_{t-1}^f, b_{t-1}^f, \omega_t^f\right) = \max_{b_t^f, k_t^f, \Delta_t^f} \Delta_t^f + \mathbb{E}_t \Lambda_{t,t+1}^E \int_{\omega_{t+1}^f \in \mathbb{R}} &max(V^F(k_t^f, b_t^f, \omega_{t+1}^f), 0) dG_{t+1}^F(\omega_{t+1}^f) \\
\text{s.t.} & \\
q_t k_t^f &= n_t^f + p_t(cl_t^f) b_t^f - \Delta_t^f, \\
n_t^f &= \omega_t^f k_{t-1}^f q_t^o + R_t^k k_{t-1}^f - [p_t(cl_t^f) + CP_t(cl_t^f)](1-\mu) b_{t-1}^f - (\mu + \bar{R}) b_{t-1}^f, \\
cl_t^f &= \frac{b_t^f}{k_t^f}.
\end{aligned} \tag{6}
$$

The firm's net worth n_t^f at the beginning of the period is the difference between the market value of assets and the market value of liabilities, net of any compensation payments made to the bank. Importantly, 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. Capital, debt and the current efficiency shock only affect the decision problem through their effect on net worth. By substituting out Δ_t^f, using the budget constraint, it is straightforward to see that the value of a continuing firm is linear in n_t^f. Due to free entry, the value of a firm with zero net worth is equal to zero which implies that the default threshold is given by:

$$
\omega_t^F(cl_{t-1}^f) = \frac{(1-\mu)p_t + \mu + \bar{R}}{q_t^o} cl_{t-1}^f - \frac{R_t^k}{q_t^o}. \tag{7}
$$

The default probability before the idiosyncratic shock is realized is then $\pi_t^F(cl_{t-1}^f) = G_t^F(\omega_t^F(cl_{t-1}^f))$. Since π_t^F depends only on the debt-to-capital ratio, the firm problem is constant returns to scale in k_t^f and b_t^f. 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.

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

$$
p_t(cl_t^f) + cl_t^f \frac{\partial p_t(cl_t^f)}{\partial cl_t^f} = \mathbb{E}_t \Lambda_{t,t+1}^E [p_{t+1}(1-\mu) + \mu + \bar{R}][1 - \pi_{t+1}^F(cl_t^f)]. \tag{8}
$$

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 investment in capital is given by:

$$
q_t + \left(cl_t^f\right)^2 \frac{\partial p_t(cl_t^f)}{\partial cl_t^f} = \mathbb{E} \Lambda_{t,t+1}^E \{R_t^k + q_{t+1}^o \mathbb{E}_{G_{t+1}^F}(\omega_{t+1}^f | \omega_{t+1}^f > \omega_{t+1}^F)\}[1 - \pi_{t+1}^F(cl_t^f)]. \tag{9}
$$

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. Since all firms chose the same debt-to-asset ratio, we can aggregate their decisions at the end of each period. This means the default rate π_t^F on a well-diversified portfolio of loans equals the individual default probability $\pi_t^F = \pi_t^F(CL_{t-1})$ and the return on a diversified loan portfolio is the repayment and continuation value of loans to non-defaulting firms plus the recovery rate on defaulting loans:

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

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

$$
RR_t = \delta^F [R_t^k + q_t^o \mathbb{E}_{G_t^F}(\omega_t | \omega_t < \omega_t^F)] \frac{1}{cl_{t-1}}.
$$

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, the value of future compensation payments of deviating firms would be included in the loan return.

To understand the role of the two financial frictions in the model, we define the lending rate, total interest rate spread and the excess interest rate spread:

$$R_t^l = \mathbb{E}_t\left(\frac{p_{t+1}(1-\mu)+\mu+\bar{R}}{p_t}\right), \quad isp_t = R_t^l - R_t, \quad eisp_t = \mathbb{E}_t\left(\frac{R_{t+1}^B}{p_t} - R_t\right). \tag{10}$$

The variable isp_t is the spread over the risk free rate paid by a borrowing firm and measures the combined effect of bank and firm financing frictions. The variable $eisp_t$ is the return that banks demand in excess of the compensation for expected firm defaults and therefore isolates the effect of the bank financing friction. To take the model to the data, we also define the net charge-off rate on loans as

$$Ch\_Off f_t = \pi_t^F(1 - RR_t) \tag{11}$$

which reflects the net losses banks incur on their loan portfolio because of firm defaults in a period. Since the face value of a loan is equal to one, the charge-off rate can be understood as a share of the loan portfolio that is written off.

3.3. The banking sector

There is a continuum of banks indexed by b which are owned by households. Bank b enters period t with liabilities in the form of one-period deposits d_{t-1}^b and assets in the form of a loan portfolio b_{t-1}^b. We define bank leverage as the debt to asset ratio $bl_t^b = \frac{d_t^b}{b_t^b}$. The structure of the banks' problem is similar to that of production firms. In contrast to firms, however, banks are subject to regulatory capital requirements and their liabilities are insured.[10]

3.3.1. Regulation

We adapt the setup of bank regulation of Benes and Kumhof (2015) to our model. Regulatory capital $\tilde{n}_t^b$ at the beginning of each period is required to exceed a fraction ψ of total bank assets, i.e., $\tilde{n}_t^b \geq \psi b_{t-1}^b R_t^B$. Banks violating the capital requirement have to pay a regulatory fine of κ of their market value to the regulator. Like firms, banks are exposed to idiosyncratic shocks. These shocks create a distribution of regulatory capital ratios across banks where a small fraction of banks violates the capital requirement in every period. The idiosyncratic risk is assumed to capture differences in management efficiency or returns on trading activities unrelated to lending.[11] The effect of the idiosyncratic shock is therefore proportional to bank size, captured by assets, but is unrelated to the performance of these assets. Specifically, the return of bank b is given by $R_t^b = R_t^B + \omega_t^b$ where ω_t^b is independent across banks and normally distributed with mean zero and standard deviation σ^B.

As pointed out in Benes and Kumhof (2015), 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. Violations of the regulatory capital requirement are already rare events and only a much larger shock would turn bank equity negative. To address this issue, we deviate from Benes and Kumhof (2015) by assuming that banks can hide some of their losses from the eyes of the regulator. Therefore, only a fraction γ of idiosyncratic returns is reported on the balance sheet.[12] Thus regulatory capital is defined as $\tilde{n}_t^b = (R_t^B + \gamma\omega_t^b)b_{t-1}^b - d_{t-1}^b$ while true net worth is $n_t^b = (R_t^B + \omega_t^b)b_{t-1}^b - d_{t-1}^b$. This simple assumption allows us to generate the observed level of the bank default rate, even though banks are required by the regulator to hold substantial amounts of equity. This is not unrealistic given that Lehman failed with book equity of $28 billion on its balance sheet in 2008. Ball (2016) notes that some of their assets were overvalued by as much as $30 billion relative to their true market value. Begenau et al. (2020) find large differences between book and market capital ratios for banks, especially around the financial crisis. They argue that this is due to “slow loss accounting”, as banks report losses on their portfolios with delay. In this paper, we do not attempt to model these dynamics in detail. See Begenau et al. (2020) for a study of the effects of this practice in a theoretical model.

We set up the model to capture important features of the regulatory framework in place before 2008, in particular Basel II. Clearly, our model is stylized compared to the complex real world regulatory frameworks which include different risk weights and rules for how expected losses are treated.[13] As in Elenev et al. (2021), we assume that the regulatory regime evaluates all assets on bank balance sheets at market values, while in reality many assets are evaluated at book

[10] Given that our definition of the intermediary sector also includes institutions, the deposit insurance should be interpreted as a combination of explicit (insurance) and implicit (expected bailouts) guarantees. Of course also the regulatory regime differs somewhat across the various levered financial institutions.

[11] This risk should not be interpreted as imperfect diversification of bank portfolios, which is assumed in Mendicino et al. (2020) and has different implications.

[12] Strictly speaking, this assumption implies that banks do not fully report high idiosyncratic returns either. From the perspective of the bank, there is no incentive to report these returns, because they do not get fined by the regulator anyway. Since shocks have mean zero, actual bank equity is identical to regulatory equity in the aggregate.

[13] Basel III also contains an adjustment for asset maturity. These regulations, however, became relevant only after 2010.

value. We maintain this assumption for theoretical consistency, as market value is the relevant statistic for all other bank decisions, including default. In Appendix C, we show that a model where regulation is based on book instead of market values generates similar dynamics.

3.3.2. Dividend adjustment costs

A second difference between banks and firms in our model is that banks have access to capital markets while firms do not. However, capital market access is not frictionless. A well known cause of concern for regulators is that banks are reluctant to issue equity or cut dividends sufficiently during times of crisis. In a recent ESRB document, published in the Covid-19 crisis, the authors argue that "*Leaving it to individual banks to decide to cancel pay-outs might create a stigma effect for banks that go ahead with such decisions. If banks were keen to avoid this stigma pay-outs could exceed the optimal level.*"[14] We use a well-established short-cut to capture this friction and impose convex costs h for banks that deviate from the their target dividend to equity ratio:[15]

$$h(\Delta^b, n^b) = \Delta^b + \frac{100\omega}{2} n^b \left(\frac{\Delta^b}{n^b} - \frac{\bar{\Delta}^B}{\bar{N}^B} \right)^2, \tag{12}$$

Here Δ^b are bank dividends, n^b is the net worth, and $\bar{\Delta}^B$ and $\bar{N}^B$ are their respective aggregate steady state values. We denote the derivatives of h with respect to Δ^b and n^b as h_Δ and h_n respectively.

The functional form implies that banks target their steady state dividend-equity ratio. When deviating from this optimal ratio, banks incur quadratic costs, scaled by their current equity. We model 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 costs in our framework slightly differ from the form used in Jermann and Quadrini (2012) and other papers in that we set a target dividend to equity ratio, rather than a dividend level. In this way, the bank problem stays constant-returns to scale.

3.3.3. The bank problem

As for firms, we formulate the bank problem recursively. At the beginning of a period, every bank is supervised by the regulator. Banks with negative net worth are liquidated and their assets are seized by the regulator who fully repays the depositors. Banks which violate the regulatory capital requirement pay the fine to the regulator. If it does not default, bank b solves the following problem:

$$\begin{aligned}
V^B(b^b_{t-1}, d^b_{t-1}, \omega^b_t) &= \max_{\Delta^b_t, d^b_t, b^b_t} \quad \Delta^b_t + \mathbb{E}_t \Lambda^H_{t,t+1} \int_{\omega^B(bl^b_t)}^{\infty} V^B(b^b_t, d^b_t, \omega^b_{t+1}) dG^B(\omega^b_{t+1}) \\
&\text{s.t.} \\
b^b_t p_t &= n^b_t - h(\Delta^b_t, n^b_t) + d^b_t / R_t, \\
n^b_t &= (R^B_t + \omega^b_t) b^b_{t-1} - d^b_{t-1} - \kappa \mathbb{1}_{\omega^B_t(bl^b_{t-1}) < \omega^b_t < \omega^R_t(bl^b_{t-1})} [(R^B_t + \omega^b_t) b^b_{t-1} - d^b_{t-1}], \\
bl^b_t &= \frac{d^b_t}{b^b_t},
\end{aligned} \tag{13}$$

where $\omega^B_t = bl^b_{t-1} - R^B_t$ and $\omega^R_t = \frac{bl^b_{t-1} - R^B_t(1-\psi)}{\gamma}$ are the thresholds for default and violation the capital requirement, respectively, and $G^B(\omega^b)$ and $g^B(\omega^b)$ denote the CDF and PDF of the idiosyncratic shock.

In order to describe optimal bank behavior, it is useful to define some expected values at the beginning of the period, before the idiosyncratic shock is observed. The probabilities of default and regulatory violation are $\pi^B_t = G^B(\omega^B_t)$ and $\pi^R_t = G^B(\omega^R_t)$. The expected cost of regulatory violation is $RC_t = \int_{\omega^B_t}^{\omega^R_t} [(R^B_t + \omega^b_t) b^b_{t-1} - d^b_{t-1}] \kappa \, dG^B(\omega^b_t)$. Even though the realized cost jumps at the threshold, this expected cost is a smooth function, which allows us to differentiate the bank's objective function. Taking first order conditions, we derive the Euler equations for deposits and loans.[16] Deposits are chosen according to

$$\frac{1}{R_t} = \mathbb{E}_t \left\{ \Lambda^H_{t,t+1} \frac{h_\Delta(\Delta^b_t, n^b_t)(1 - h_n(\Delta^b_{t+1}, n^b_{t+1}))}{h_\Delta(\Delta^b_{t+1}, n^b_{t+1})} \left[(1 - \pi^B_{t+1}) + \frac{1}{\gamma} g^B(\omega^R_{t+1})(R^B_{t+1} + \omega^R_{t+1} - bl^b_t)\kappa - (\pi^R_{t+1} - \pi^B_{t+1})\kappa \right] \right\}. \tag{14}$$

Equation (14) 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

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[14] See European Systemic Risk Board (2020, p. 3). The idea that equity issuance can be considered as a bad signal to the market goes back to Myers and Majluf (1984).

[15] It is common in the literature to fix the dividend payouts of banks to a fraction of their equity and to rule out equity issuance. See for example Benes and Kumhof (2015) and Mendicino et al. (2018). We see this assumption as too restrictive, because banks do cut dividends and issue equity in bad times as shown in Baron (2020).

[16] In Appendix B the optimality condition for loans is derived formally. The optimality condition for deposits can be derived analogously.

repaying, if the bank does not default, plus the expected increase in costs arising from potential violation of the capital requirement.

Lending is chosen according to

$$p_t = \mathbb{E}_t \left\{ \Lambda^H_{t,t+1} \frac{h_\Delta(\Delta^b_t, n^b_t)(1 - h_n(\Delta^b_{t+1}, n^b_{t+1}))}{h_\Delta(\Delta^b_{t+1}, n^b_{t+1})} \Big[\left(R^B_{t+1} + \mathbb{E}_{G^B}(\omega^b_{t+1} | \omega^b_{t+1} \geq \omega^B_{t+1})\right)(1 - \pi^B_{t+1}) \right.$$
$$\left. - \left(R^B_{t+1} + \mathbb{E}_{G^B}(\omega^b_{t+1} | \omega^R_{t+1} \geq \omega^b_{t+1} \geq \omega^B_{t+1})\right)(\pi^R_{t+1} - \pi^B_{t+1})\kappa + \frac{1}{\gamma} g^B(\omega^R_{t+1})(R^B_{t+1} + \omega^R_{t+1} - bl^b_t)\kappa\, bl^b_t \Big] \right\}. \tag{15}$$

The left hand side of Eq. (15) is the marginal cost of giving out an extra loan, 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.

Equation (15) 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 which is given by the partial derivative of Eq. (15) with respect to cl^f_t. The derivation is given in Appendix B but the intuition is straightforward.[17] If a firm adjusts its leverage, the bank will set a loan price that compensates it for the changes in expected, discounted returns. Since higher leverage lowers the probability of repayment, the offered price is decreasing in firm leverage.

The first order conditions (14) and (15) are invariant to the scale of Δ^b_t and n^b_t, so the beginning of period value of a bank is linear in net worth. Since the optimization problem yields the same optimal leverage ratio for all continuing banks, we can aggregate all bank decisions at the end of each period.[18]

3.4. Aggregation

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

$$T_t = RC_t + \delta^B(R^B_t + \mathbb{E}_{G^B}(\omega_t | \omega_t \leq \omega^B_t))\pi^B_t B_{t-1} - D_{t-1}\pi^B_t \tag{16}$$

which is slightly positive in steady state. As is common, we use capital letters to denote aggregate variables, so C^h_t is aggregate household consumption, L_t is aggregate hours worked, et cetera. The aggregate resource constraint then reads

$$Y_t = I_t + TC_t + DWL_t. \tag{17}$$

Here $TC_t = C^h_t + C^h_t$ is total consumption, which is the sum of aggregate household and entrepreneur consumption. DWL_t is the sum of dead-weight losses stemming from bank and firm defaults. In Appendix A we explicitly perform this aggregation from the agents' budget constraints.

4. Data and calibration

Let us first substantiate quantitatively the three facts that are central to the main mechanism we study. First, banks are highly leveraged. Prior to the crisis in 2008 banks insured by the Federal Deposit Insurance Corporation (FDIC) had regulatory capital of 13% of their risk weighted assets on average. Second, they extend long-term loans. Bradley and Roberts (2015) report an average maturity for commercial loans of 3.5 years, while Elenev et al. (2021) find and average maturity of corporate bonds of 10 years. Third, borrowers are subject to cyclical default risk. The annualized charge-off rate (default rate net of recovery rate) on corporate loans spiked at 2.7% in Q4 2009, while it had been at only 0.2% in Q1 2006. Similarly, the credit losses rates for all rated bonds reported by Moody's Investors Service (2011) were 0.3% in 2007 and 3.4% in 2009.

4.1. The economy with long-term debt

Table 1 shows the baseline calibration of our model. A number of parameters 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. We use data from Q1 1990 to Q4 2010 for all variables, since banking regulations changed strongly with the transition from

[17] Gomes et al. (2016) use the same approach to determine the long-term loan price schedule in a model without a banking sector. In Bernanke et al. (1999) and Christiano et al. (2014) the derivation of the one period loan price schedule is simpler since ex-post interest payments adjust to guarantee a constant return. Therefore a zero profit condition can be used instead of taking derivatives of the Euler equation.

[18] 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.

Table 1
Calibration. **Bold** values are set matching moments of model simulations to empirical counterparts.

Parameter		Value
Household discount factor	β^H	0.990
Labor supply elasticity	ν	0.250
Entrepreneur discount factor	β^E	**0.984**
Capital depreciation rate	δ	0.025
Capital share in production	α	0.300
Capital adjustment cost	ι	**0.288**
Liquidity preference	ξ	0.382
Firm default cost	δ^F	0.700
Bank default cost	δ^B	0.900
Capital requirement	ψ	0.080
Penalty for regulatory violation	κ	**0.065**
Sd firm specific shock	$\bar{\sigma}^F$	**0.251**
Sd bank specific shock	σ^B	**0.037**
Share of bank shock observed by regulator	γ	**0.505**
Loan maturity	μ	0.050
Dividend adjustment cost	ω	**2.440**

Table 2
Stochastic processes. **Bold** values are set matching moments of model simulations to empirical counterparts.

Parameter		Value
Sd of TFP	σ_z	0.007
Persistence of TFP	ρ_z	0.950
Sd of risk shock	σ_ν	**0.010**
Persistence of risk shock	ρ_ν	**0.909**

Table 3
Model moments for different model versions and targets. The columns LT-BL and ST-BL refer to the baseline long-term and short-term debt economies with the same fundamental parameters. ST-RC refers to the re-calibrated economy with short-term debt. Model moments are computed from a simulation of 1,000,000 periods; for quantity variables logarithms are taken and HP-filter ($\lambda = 1600$) applied for both data and model; for interest and default rates unfiltered data was used.

Variable	Target	LT-BL	ST-RC	ST-BL
Mean (Corporate debt/assets)	0.38	0.38	0.39	0.38
Mean (Charge-off)	0.95	0.95	0.95	0.96
Mean (Bank default)	0.20	0.20	0.20	0.24
Mean (Bank equity/assets)	0.13	0.13	0.11	0.13
Std (Investment)/Std (GDP)	4.06	3.95	3.72	3.31
Std (Excess interest rate spread)	0.64	0.60	0.11	0.09
AC (Excess Interest Rate Spread)	0.83	0.80	0.91	0.90
Std (Charge-off)	0.69	0.68	0.78	0.76
AC (Charge-off)	0.87	0.87	0.78	0.87

Basel II to Basel III after the Great Recession.[19] We use national accounts data from the Federal Reserve Database and data on the financial sector from the FDIC. For the excess interest rate spread we use the excess bond spread as a measure developed by Gilchrist and Zakrajšek (2012). We follow their interpretation of the spread as a measure of intermediation frictions.

In line with most of the literature, we refer to interest rates and spreads in annualized terms, while we report default rates as quarterly rates. We provide information on the exact construction of the data in Appendix E. 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 charge-off rates on bank loans and interest rate spreads.

The household discount factor β^H of 0.99, the capital share α of 0.3 and the depreciation rate δ 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.[20] 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 match the business

[19] Of course, several regulatory changes occur within our sample, in particular the transition from Basel I to Basel II. For the questions that we focus on, these were less drastic than the change from Basel II to Basel III.

[20] See Chetty et al. (2011) for a discussion. Like in other RBC models without labor market frictions, labor input in the model is still not as volatile as in the data.

Table 4
Selected standard deviations. 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.

	Absolute		Relative	
Variable	Model	Data	Model	Data
GDP	1.21	1.16	1.00	1.00
Investment	4.79	4.71	**3.95**	**4.06**
Consumption	0.77	0.84	0.63	0.72
Risk free rate	0.36	0.85	0.29	0.73

cycle standard deviation of investment. Following the evidence in Krishnamurthy and Vissing-Jorgensen (2012), we calibrate ξ to match an annualized liquidity premium of 73 bps. In combination with the discount factor, this implies a steady state deposit rate of 3.2%.

Default costs for non-financial firms $(1-\delta^F)$ and banks $(1-\delta^B)$ 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). A deadweight cost of 30% may be high, and is difficult to measure, but what matters for the risk to banks is the net loan charge-off rate, which we target in the calibration. The net charge-off rate reflects actual losses on loans (net of recovery) faced by banks, and is well measured in the data. Lowering the default cost and recalibrating average firm defaults so as to match net charge-offs would not significantly change model dynamics. As a further robustness check, we solve a model version where defaults do not cause resource losses but are redistributed lump-sum to the owners of the respective firms. Dynamics in this economy are similar to the baseline, cf. Online Appendix I. We set the entrepreneurial discount factor β^E to 0.985 and the steady state standard deviation of idiosyncratic firm returns $\bar{\sigma}^F$ to 23% to target steady state values for corporate leverage of 38% and an annualized average charge-off rate on corporate loans of 0.95%. For our baseline calibration we set $\mu = 0.05$ which implies an average loan maturity of 5 years. Here we follow Gomes et al. (2016), who point out that this is a conservative choice given the long average maturity of corporate bonds.

The next set of parameters are related to the banking sector. We choose a regulatory capital requirement ψ of 8% in line with Basel II regulations. The standard deviation of idiosyncratic bank returns σ^B is set to match a mean of the quarterly bank default rate of 0.2%. The share of idiosyncratic returns observed by the regulator γ of 0.511 is calibrated to match the average regulatory capital ratio of 13%. The cost of regulatory intervention coupled with idiosyncratic risk, induces banks to hold significant capital buffers above the regulatory requirement.[21]

The severity of bank financing frictions is crucial for the working of our model. We calibrate the regulatory penalty for violating the capital requirement κ and the dividend adjustment cost ω to jointly match the standard deviation and the serial correlation of the excess interest rate spread, defined in Equation (10). This spread is zero in a world without financial frictions, and its serial correlation is an indicator for how long it takes banks to adjust their balance sheet after a shock.[22]

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.[23] To capture the business cycle risk that banks are exposed to, we calibrate the magnitude and persistence of the risk shock to match the fluctuations in loan charge-off rates.[24] While we state individual targets for each moment for the purpose of exposition, it should be clear that all target moments depend on all parameters. To calibrate the parameters, we minimize squared relative distances with equal weights for all moments. Columns one and two of Table 3 show the model moments and their targets. The model matches empirical moments very well.

Table 4 compares the standard deviations of common macroeconomic aggregates in the model to their data counterparts. The relative standard deviation of investment to output was targeted and is close to the data. The fluctuations in the interest rate are smaller than in the data, but similar to most other RBC models. Business cycle correlations are reported in Table 5.

[21] The share of banks which violate the capital requirement is not a target in our calibration. As reported by Begenau et al. (2020), in the data it fluctuates between zero and 0.5% in the years before 2008 and peaks at 5% during the Great recession. In comparison, the stochastic steady state is 0.24% and the 95th percentile is 5% in a simulation of 1,000,000 periods, showing that the model produces similar dynamics to the data.

[22] We argue that observed net equity issuance is not a suitable target since it affected by many factors not captured by the model. These include: mergers and acquisitions, changes in regulations and their implementation, government interventions (TARP; CAP). For example, the government interventions in 2008 and 2009 account for most of the volatility of net bank equity issuance between 2000 and 2010.

[23] Since productivity is homogeneous across firms and factor markets are competitive, the model variable Z_t can be mapped to the Solow residual directly.

[24] For the lack of quarterly data on credit loss rates for bonds, we only use data loan charge off rates here. However, the average corporate loan and bond portfolios seem to have very similar risk characteristics. The long run mean loan charge of rate is 0.95%, which is close to Moody's Investors Service (2011) long run mean credit loss rate of 1%, implying a similar borrower quality. Moreover, the trough and peak in the boom and bust cycle around the great recession are quite close, which means that the cyclical fluctuations are of similar magnitude. We therefore conclude that the loan charge-off rate is a good proxy for overall exposure of the financial sector to corporate default risk.

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.

Variable	Model	Data
Investment	0.84	0.83
Consumption	0.83	0.94
Risk free rate	0.30	0.28
Charge-offs	−0.32	−0.66
Excess interest rate spread	−0.57	−0.18
Excess interest rate spread(t-1)	−0.42	−0.42
Excess interest rate spread(t-2)	−0.30	−0.55
Excess interest rate spread(t-3)	−0.19	−0.59

The model matches the correlation of investment with output well, while the correlation of consumption and output is somewhat too low in the model.

The results for variables related to financial frictions are the most relevant ones for the mechanisms we study. Loan charge-offs are negatively correlated with output in both model and data, however, the correlation is stronger in the data. The interest rate spread is of particular importance, since it captures the combined effect of corporate and banking sector frictions. The model predicts a negative contemporaneous correlation with output, which decreases in absolute value if the interest rate spread is lagged. The overall magnitude is similar in the data, but the contemporaneous correlation is smaller in absolute value and increasing at higher lags. While there is no mechanism in the present model that could capture this pattern, we discuss news shocks as a potential candidate in Section 5.2.

4.2. The economy with short-term debt

In the Online-Appendix G we repeat our calibration exercise, now setting the maturity of bank loans to one quarter. It turns out that there is no empirically successful calibration of our model with short-term loans. Since banks are exposed to very little aggregate risk if they lend short-term, the model fails to generate the observed fluctuations in the bank default rate and excess interest rate spread. This provides some additional, model-based evidence of the empirical relevance of long-term loans, which has been established in the literature reviewed in Section 2.1.

5. Aggregate consequences of long-term loans

5.1. Long-term loans and financial stability

To analyze how long-term lending affects macroeconomic dynamics, we compare our baseline economy to an economy with one-period loans ($\mu = 1$) but otherwise identical parameterization. We start by looking at the response to a large risk shock,[25] where each economy is initialized at its stochastic steady state, i.e., the fixed point of the policy functions under zero shocks. We then consider a sequence of three 1.5-standard-deviation shocks to idiosyncratic firm risk σ^E. Beyond that point we set all shocks to zero. This shock sequence generates a financial disruption similar to the Great Recession; we perform a more detailed crisis experiment in Section 7.

Figure 1 shows the responses of the two economies. The direct impact of the rise in idiosyncratic uncertainty is a similar increase in the corporate default rate π^F by around 1.0 percentage points in both economies. However, the banking sector is affected very differently. The bank default rate π^B increases by 0.5 percentage point with long-term loans, compared to 0.06 percentage points with short-term loans. Banks contract credit supply more strongly, as the excess interest rate spread *eisp* rises by 1.6 percentage points compared to 0.2 percentage points. The contraction in credit supply leads to a larger decline in loans B and investment I and a deeper recession overall.

Total consumption TC in both economies 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 7 quarters. This feature of risk shocks is well known and is the reason for the low correlation between consumption and GDP. The issue can partially be resolved by adding nominal rigidities to the model as we do in Online Appendix K following Christiano et al. (2014). As we discuss in the appendix, the impact of the risk shock on output is amplified much more in the economy with nominal rigidities and long-term loans, because of the demand effect. To isolate the risk transfer mechanism, we use the simplest model version without nominal frictions in the main part of the paper.

The financial crisis in the long-term loan economy arises from the interaction of two mechanisms. First, the risk transfer inherent in long-term loans leads to a strong decline in the fundamental value of bank assets. Second, a well-known financial accelerator emerges as banks are forced to deleverage in a ”fire sale”, so the market value of assets p falls even more. Falling

[25] Productivity shocks have little effect on default and interest rates, so little risk is transferred through long-term contracts. The impulse responses are almost identical for economies with different loan maturity. For details see the working paper version Reiter and Zessner-Spitzenberg (2020).

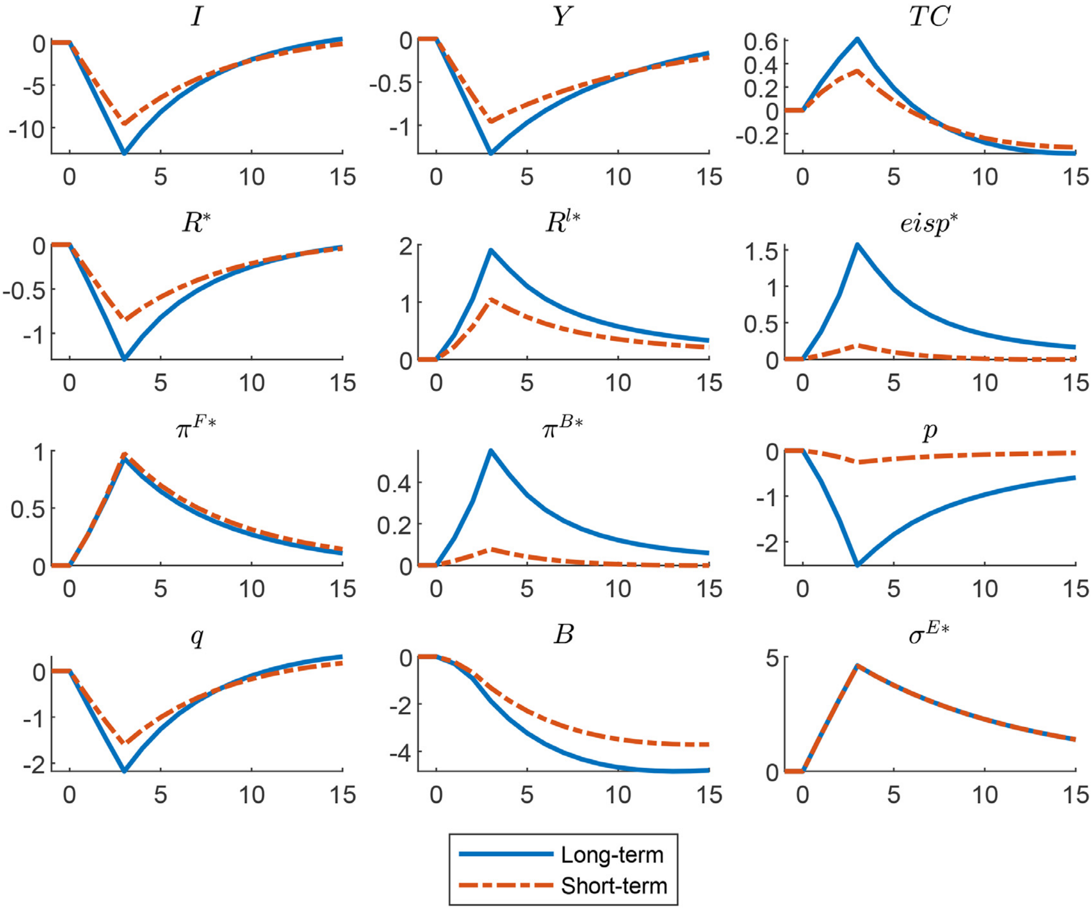

Fig. 1. Response to an increase in the in the standard deviation of idiosyncratic capital quality in economies with dividend adjustment costs. Time: Quarters. Values: Deviations from stochastic steady state in percent, except (*): deviations from stochastic steady state in percentage points.

market values and deleveraging amplify each other, making the crisis more severe. In Section 5.3 we decompose the overall effect in these two parts.

The amplification of the risk shock in the long-term loan economy is entirely driven by the crisis in the banking sector. To see this, we compare our baseline economies to alternative economies in which the dividend adjustment cost ω is set to zero in Fig. 2. In contrast to Fig. 1, the effect of the risk shock on investment and output is now dampened in the long-term loan economy. This dampening happens although the increase in the lending rate R^l is almost identical with long-term and short-term debt. To explain this, it is useful to interpret the Euler Eq. (8) as determining firm leverage cl_t^f by the lending rate R_t^l via the loan price schedule $p_t(cl_t^f)$.[26] For a given lending rate, firms choose the same *leverage*. For given leverage, the level of borrowing and investment is increasing in net worth. Long-term contracts cushion the fall in firm net worth relative to the case of short-term loans, and thereby dampen the contraction in investment and output, because only a small part of the loans is refinanced at the higher interest rate.

This mechanism highlights the central result of this paper: long-term lending *transfers* risk. That is, it exposes the financial sector to more risk but *insures* borrowers. The effect of this transfer depends on who is better equipped to bear the risk. If banks can issue equity to households without friction, they can absorb losses more easily than financially constrained entrepreneurs. Long-term lending thus mitigates the effect of the risk shock. If banks face dividend adjustment costs, their equity erodes quickly because of high leverage and the risk transfer leads to financial instability and amplification of shocks.

Comparing the economies with short-term loans (red lines) across Figs. 1 and 2, we see that the banking friction plays almost no role, because bank equity is sufficient to bear the risk. Comparing the economies with long-term loans (blue

[26] Dividing by $p_t(cl_t^f)$ and using the definition of R_t^l in (10), the Euler Eq. (8) can be written as

$$1 + \frac{\partial p_t(cl_t^f)/p_t(cl_t^f)}{\partial cl_t^f/cl_t^f} = R_t^l \cdot \mathbb{E}_t \Lambda_{t,t+1}^E [1 - \pi_{t+1}^F(cl_t^f)] + \text{CovarianceTerm}$$

.

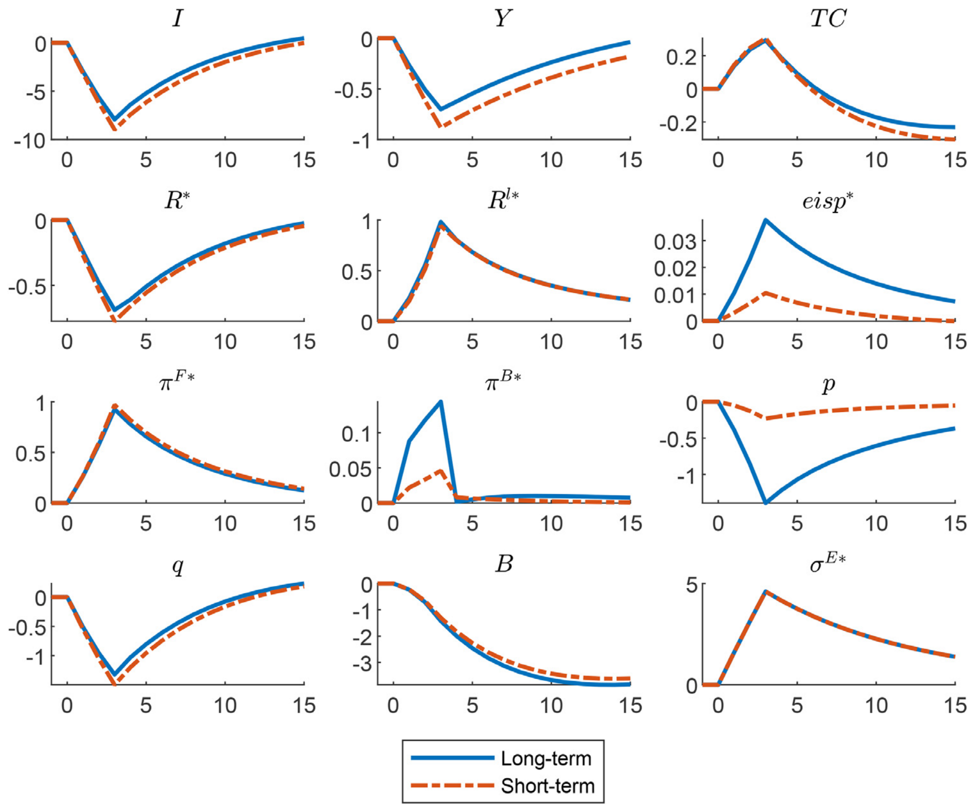

Fig. 2. Response to an increase in the in the standard deviation of idiosyncratic capital quality in economies without dividend adjustment costs. Time: Quarters. Values: Deviations from stochastic steady state in percent, except (*): deviations from stochastic steady state in percentage points.

lines), we see that the banking friction leads to much larger bank defaults and larger aggregate fluctuations. Interestingly, the financial crisis and rising credit spreads do not spill back into a larger increase in firm defaults in the economy with the bank financing frictions. This is again the consequence of the risk transfer: while the value of firm assets (capital) q goes down, the market value of their liabilities p drops as well. The two effects approximately offset each other, cf. the condition for firm defaults (7).

The response of financial variables such as bank defaults and interest rate spreads to risk shocks is highly nonlinear. The importance of both banking frictions and loan maturity only appears when shocks are large, because both, borrower and bank defaults are highly asymmetric and rise sharply only in response to large shocks. The reason for this non-linearity is that, in normal times, firm and bank defaults only occur in the left tail of the distribution of idiosyncratic shocks. The shocks being normally distributed, the probability density at the default thresholds is then low and default rates respond little to changes in macroeconomic conditions. Large shocks move the default threshold towards the center of the distribution, where the density is rapidly increasing. To capture these dynamics, we solve the model by third-order perturbation, which is possible because we have formulated the model such that all model equilibrium conditions are differentiable to higher orders. We document these nonlinearities and motivate our solution method in the Online Appendix F.

5.2. News shocks: transferring the risk of expected defaults

An even sharper picture of the risk transfer to the financial sector through long-term loans is provided by the analysis of news shocks, i.e. shocks which become known before they realize. Figure 3 shows the responses to news arriving in period 1, saying that σ^E will rise by a two-and-a-half standard deviation shock in period 2. To highlight the pure 'news' effect, the shock does not actually materialize. That is, the expected shock is offset by a realized shock in the opposite direction in the following period.

With short-term debt the financial sector is not exposed to the shock on impact. Expected firm defaults in period 2 increase, but banks raise the lending rate in period 1 which protects them from possible losses in period 2. This increase only reflects future expected defaults and the excess interest rate spread remains at zero. Since the lending rate rises in period 1, firm borrowing and investment decline. The reduction in credit supply also leads to a noticeable (but too small to affect banks) increase in firm defaults in period 1, even though no shock has occurred. Since the risk shock does not realize in period 2, bank default rates even decrease.

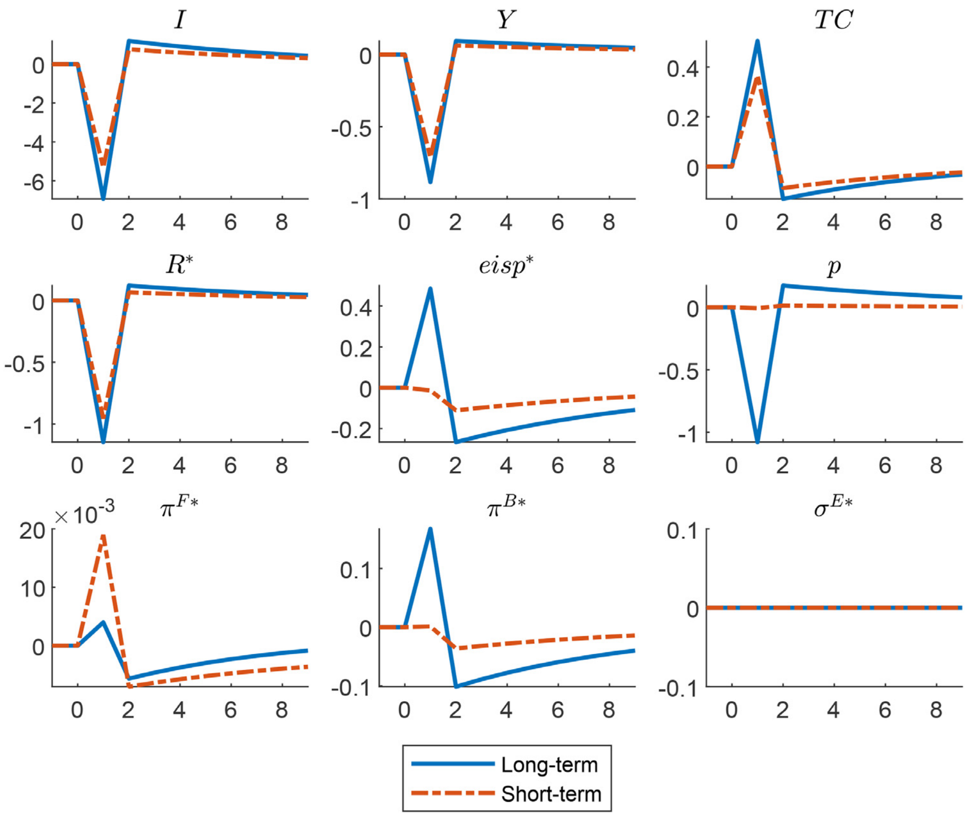

Fig. 3. Response to an increase in the standard deviation of idiosyncratic capital quality, in economies with short-term loans. Time: Quarters. Values: Deviations from stochastic steady state in percent, except (*): deviations from stochastic steady state in percentage points.

With long-term debt, the expectation of future firm defaults lowers the value of bank loans immediately, causing an increase in bank defaults. Moreover, the expectation of losses on the outstanding loan portfolio increases the probability for banks to violate the regulatory requirement in period 2. Banks therefore raise the lending rate by more than what is warranted by the expected defaults (*eisp* increases). As a result, all variables contract more in the economy with the long-term than with short-term loans.[27] The risk transfer, in contrast to the financial accelerator effect, is clearly visible here in that far fewer firms default in the long-term debt economy in spite of the increase in the interest rate. This is because these firms only face the higher interest rate on the newly issued debt, while most debt does not have to be rolled over at the higher interest rate.

In this paper, we only use news shocks as a device to highlight the risk transfer mechanism. As shown by Christiano et al. (2014), news shocks can be important in their own right for macroeconomic models to explain business cycle dynamics. We believe that this is also the case for financial crises in our model. In the data, the excess interest rate spread peaks early and bank defaults are concentrated at the beginning of the financial crisis. Firm defaults peak only after the trough of the following recession (cf. Fig. 6 below). The model economy could replicate this pattern, if news about future firm defaults arrive already at the beginning of the downturn, triggering a financial crisis and spiking interest rates immediately, before the defaults even realize. Such dynamics are only possible with long-term loans, as the news of future firm defaults, no matter how bad, cannot cause a financial crisis with short-term debt. Studying the interaction of the risk transfer with news shocks in more detail is left for future work with a richer model.

5.3. Book-based regulation: risk transfer vs. financial accelerator

To understand the relative importance of the risk transfer and the financial accelerator mechanism, we shut down the accelerator in this section. That is, we consider a model version in which bank regulation and default are not based on the market but on the book value of loans $\tilde{p}$ (cf. Appendix C for the model equations). This exercise has also some empirical relevance, because in reality not all bank assets are priced to market.

[27] Notice that this amplification is somewhat smaller than the amplification in response to the realized news shocks, both because shocks are larger and because they actually realize.

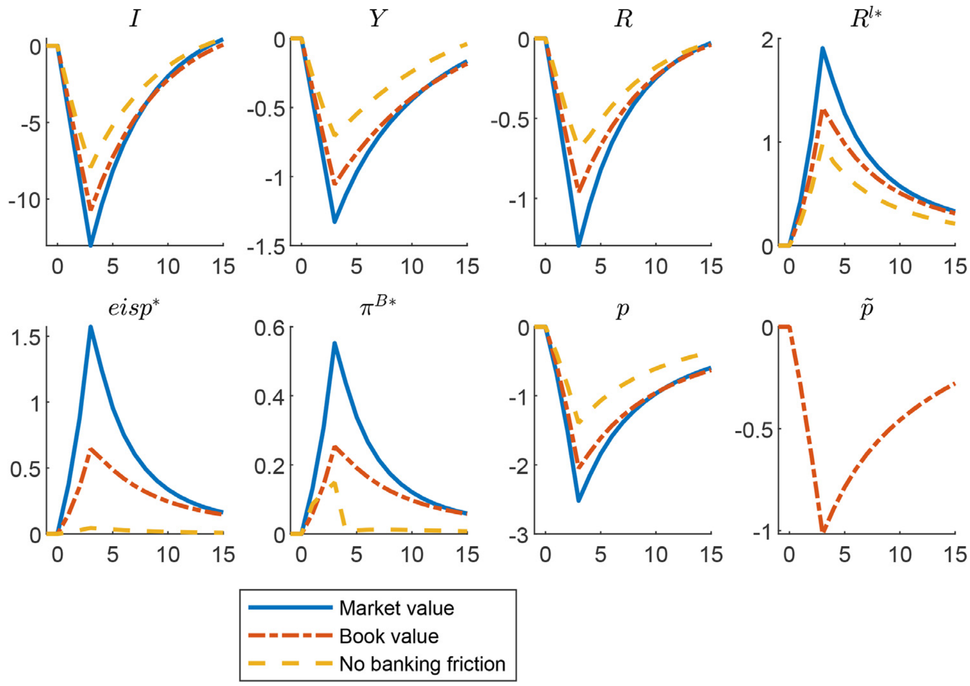

Fig. 4. Response to an increase in the standard deviation of idiosyncratic capital quality in economies with long-term loans with book versus market based regulation Time: Quarters. Values: Deviations from stochastic steady state in percent, except (*): deviations from stochastic steady state in percentage points.

Figure 4 compares the economy with book-based regulation to our baseline economy with and without dividend adjustment costs.[28] The instantaneous response of bank defaults and other financial series is cut by about half if the accelerator effect is eliminated, but a few quarters after the shock, the reaction is very similar in both cases. The response of investment, consumption and output, being affected by current and future interest rates, is amplified almost as much with book values as with market values. This means that the financing friction in the banking sector is important even without a financial accelerator, the fundamental risk transfer inherent in long-term loans is enough for this result. One should stress that the model was not recalibrated for this exercise. With recalibration, the economy with book values would generate even larger increases in the excess interest rate spread and bank defaults.

6. Macroprudential policy

6.1. Stabilization effects of 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 10.5 percent. In addition, the new capital requirement contains a countercyclical buffer. In line with Basel III regulations, the bank capital ratio rises, if lending is above trend and declines if lending is below trend. Specifically, the capital requirement is given by:

$$\psi_t = \bar{\psi} + \psi_{CG}\left(\frac{B_t^n}{\bar{B}^n} - 1\right) \tag{18}$$

where $B_t^n = p_t(B_t - B_{t-1}(1-\pi_t^F)(1-\mu))$ are newly issued loans. We choose $\psi_{CG} = 0.15$, which results in a capital requirement that fluctuates between 13 percent in expansions and 8 percent in recessions.[29] With this setup we capture the 8 percent capital requirement, enhanced by a 2.5 percent capital conservation buffer (CCB) and a further 2.5 percent countercyclical buffer (CCyB) in a stylized manner. This experiment is not designed as a careful one-to-one translation of Basel III into the model, as we abstract from the various regulatory interventions that occur if the different thresholds are violated.

[28] Whether regulation is based on book or market values does not matter much if there are no dividend adjustment costs, so we do not show both economies.

[29] In about 0.3 percent of quarters the requirement falls below 8 percent and exceeds 13 percent. It never leaves the interval from 7 to 14 percent.

Table 6
Moments are computed from a simulation of 1,000,000 periods. Standard deviations in %, except (*) standard deviations in percentage points. BL: Baseline, MP: Macroprudential regulatory regime.

	Mean			Standard deviation		
Variable	BL	MP	Δ%	BL	MP	Δ%
GDP	0.719	0.721	0.3%	3.237	3.162	−2.3%
Investment	0.138	0.139	0.9%	7.786	6.906	−11.3%
Household consumption	0.522	0.523	0.2%	2.735	2.697	−1.4%
Entrepreneurial consumption	0.056	0.056	−0.1%	3.696	3.667	−0.8%
Deposits	1.791	1.764	−1.5%	6.220	4.967	−20.1%
Bank equity/assets	0.128	0.163	27.2%	6.475	7.712	19.1%
Bank defaults*	0.202	0.017	−91.5%	0.232	0.038	−83.5%
Excess interest rate spread*	0.376	0.239	−36.4%	0.639	0.274	−57.0%
Firm debt/assets*	0.383	0.389	1.7%	0.018	0.018	−1.7%
Firm defaults*	0.523	0.563	7.7%	0.333	0.355	6.7%
Dead weight loss/GDP*	0.391	0.383	−2.1%	0.185	0.157	−15.2%

Moreover, Basel III relies on the credit-to-GDP gap to determine if lending is above or below trend. It is defined as the deviation of the credit to GDP ratio from its one-sided HP-filtered trend. Since this measure can only be computed from the entire history of past values, it would be difficult to implement in a theoretical model and we see our measure as a reasonable approximation. Results are generally similar, if we condition the capital requirement on the stock of loans relative to GDP or GDP itself.

The stabilizing effect of the new policy can be seen in columns 4–6 of Table 6. Regulation is highly effective at improving the stability of the banking sector. The standard deviation of the bank default rate and excess interest rate decline by 83.5% and 57% respectively.[30] The standard deviations of all other variables are reduced as well, although the magnitudes of the decline are modest. The reason is that financial crises are rare and do not have large effects on business cycle moments in the first place. The only exception is the bank equity to asset ratio which becomes more volatile. This is a mechanical effect, as the regulatory capital ratio is now time varying.

6.2. Costs of macroprudential policy

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.[31] However, Admati and Hellwig (2014) argue that fundamental factors do not justify the high level of bank leverage observed under Basel II regulation. Higher capital requirements could offset moral hazard incentives created by implicit and explicit government guarantees without raising the cost of intermediation.

Our model predicts (small) increases in the long-run means of lending, capital stock and GDP, while the bank equity ratio rises from 12.8 to 16.3 percent (cf. columns 1–3 of Table 6), in line with the arguments put forth by Admati and Hellwig (2014). Although the fundamental liquidity premium of deposits contributes to bank leverage, high bank leverage is mostly a response to regulatory incentives in our calibration. Tighter capital requirements eliminate bank defaults which increases intermediation efficiency and raises output.

While there are no steady state efficiency losses of tighter regulation, there can be significant costs during their introduction. As banks are forced to adjust their capital positions, they reduce credit supply. Figure 5 shows an increase in the capital requirement to 10.5%, starting in the steady state of the baseline policy regime. The blue solid line shows an immediate increase, the red-dashed line a phasing in over 20 quarters. The fast and unanticipated introduction of higher capital requirements causes a strong, but short lived contraction. Investment falls by 15 percent and output by 2 percent. In a more realistic scenario, where capital requirements are phased in slowly and banks are informed in advance, the contraction is only half as strong but slightly more persistent. In either case, the short run disruptions caused by tightening regulation are nonnegligible.

It is possible, however, that our model overestimates the costs of equity issuance in a transition phase and thereby the reduction in credit supply. Following a well-established literature (see fore example Covas and Den Haan, 2012; Jermann and Quadrini, 2012), we introduce equity costs in reduced form to match the empirical importance of financing frictions. As discussed above, one interpretation of these costs is that banks are unwilling to cut dividends or issue new equity because it is considered a bad signal to the capital market. If this is the case, the costs do not exist if the capital increase is imposed on all banks at the same time by the regulator.

[30] In Online Appendix L we show that the same reform does not have a similar effect in the economy with short-term debt, because banking frictions are not important with short-term loans.
[31] See for example Van den Heuvel (2008) and De Nicolò (2015).

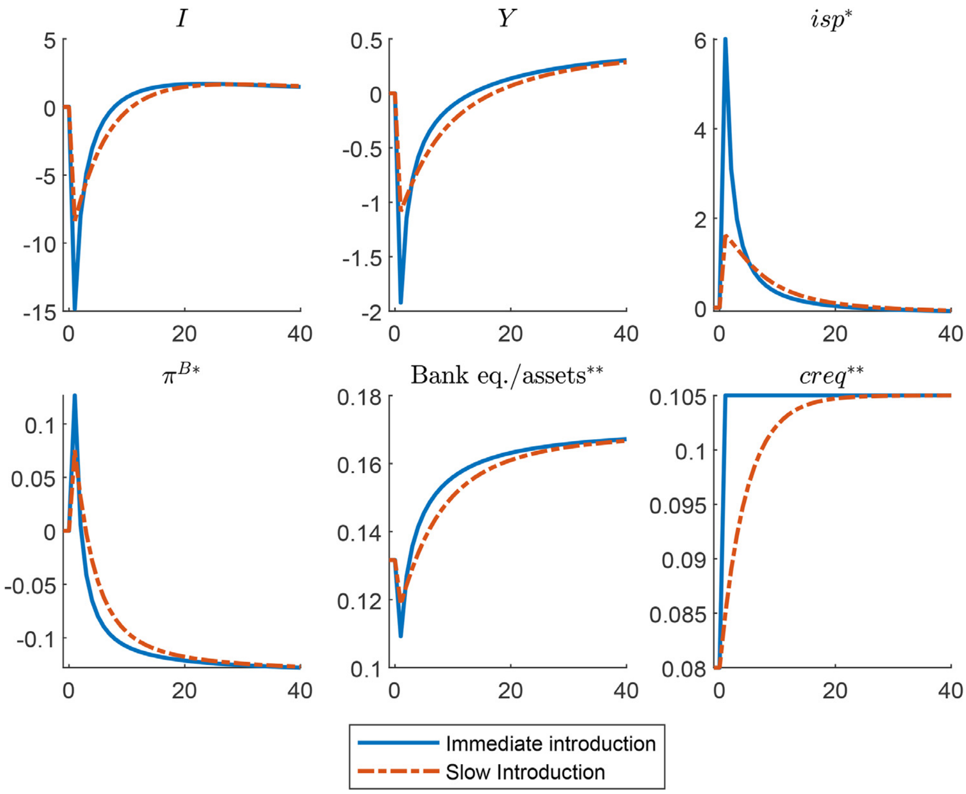

Fig. 5. Response to an increase in the bank capital requirement from 8% to 10.5% Time: Quarters. Values: Deviations from pre-introduction stochastic steady state in percent, except (*): deviations percentage points and (**) levels.

Table 7
Welfare measures in economies with different regulatory regimes, relative to baseline regulation. Values are in permanent consumption equivalent differences to the baseline regulation in percent. All regulatory regimes contain a time-varying component.

Welfare at regulation specific steady state						
Capital requirement	7%	9%	9.75%	10.5%	12%	14%
Household	−1.031	0.132	0.161	0.171	0.171	0.157
Entrepreneur	2.359	−0.088	−0.101	−0.105	−0.105	−0.103
Aggregate	−0.710	0.111	0.136	0.145	0.144	0.132
Aggregate ($\beta^E = \beta$)	−0.709	0.110	0.135	0.144	0.143	0.131
Welfare including transition						
Capital requirement	7%	9%	9.75%	10.5%	12%	14%
Household	−0.488	0.032	0.042	0.043	0.033	0.011
Entrepreneur	0.463	0.026	0.030	0.034	0.052	0.104
Aggregate	−0.397	0.031	0.040	0.042	0.035	0.020
Aggregate ($\beta^E = \beta$)	−0.352	0.028	0.038	0.039	0.033	0.018

6.3. Welfare effects of macroprudential policy

Changes in banking regulation have different short- and long-run effects, and affect entrepreneurs and households differently. We therefore investigate whether tighter capital regulation increases welfare, with and without accounting for transition costs, and whether a Pareto improvement is possible. Including transition costs, Table 7 shows a Pareto improvement for capital requirements for capital requirements up to 14%. The maximal increase in social welfare (for an exact definition see Appendix D) is equivalent to an increase of about 0.042% of permanent consumption and is achieved by the 10.5% capital requirement of Basel III. Excluding the transition phase, the increase in social welfare is higher at around 0.145% of consumption. This reflects the fact that tighter regulation is associated with a costly transition. Increasing capital requirements beyond the 10.5% of Basel III reduces welfare.

What is the source of the welfare gain? From Table 6 it can be seen that it is mainly caused by an increase in average aggregate consumption, not a reduction in second moments. The higher capital requirement lowers the bank default rate which improves lending efficiency. The mean excess interest rate spread declines, inducing entrepreneurs to borrow and in-

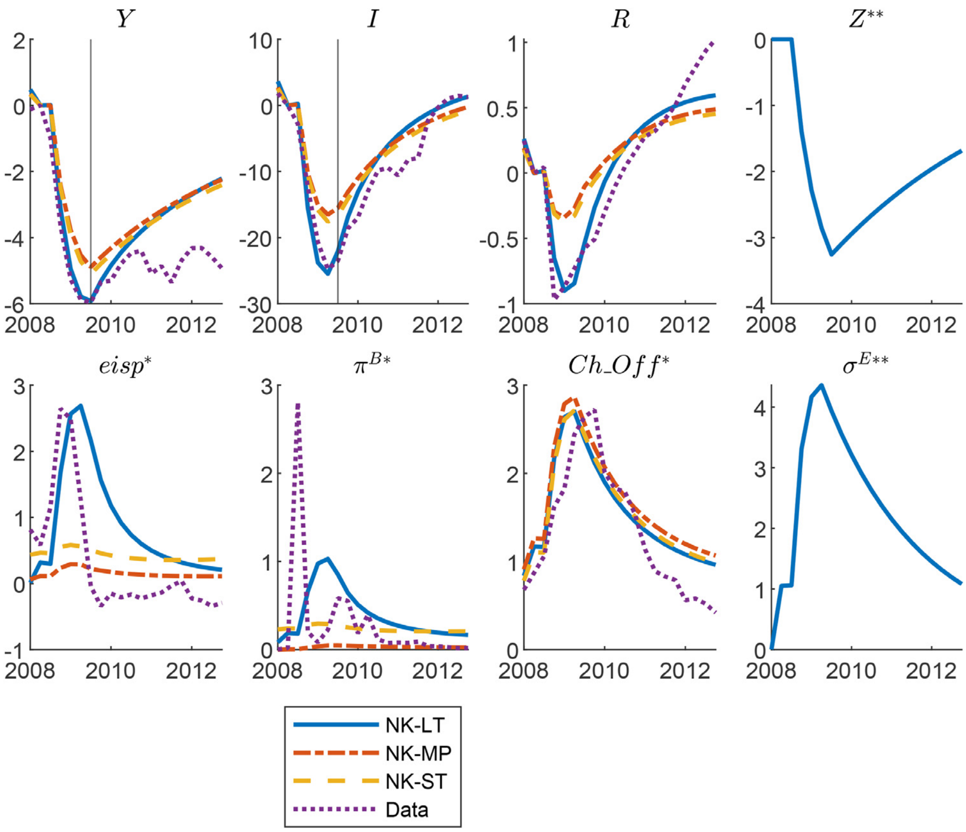

Fig. 6. Financial crisis experiment. Data: Y and I log-linearly detrended. NK: New Keynesian. LT: Long-term loans, MP: Macroprudential regulation (Basel III) and ST: Short-term loans. Values: Deviations from Q3 2008 in percent, except (*): percentage points (levels) and (**) percentage points (deviation from steady state).

vest more. Thus the firm default rate rises to almost fully offset the reduction in aggregate deadweight losses, which decline by only 0.008 percent of GDP. More investment raises output and consumption possibilities in the long run. The reduction of second moments is not a major source of welfare gains, which is a common finding. This is not because regulation would not reduce fluctuations, but because welfare gains from stabilization are generally low in macroeconomic models and that financial crises do not have large effects on business cycle moments as pointed out above.[32] In line with these results, we show in Online-Appendix K that the aggregate welfare gains come almost exclusively from the increase in the average capital requirement. Time variation benefits entrepreneurs at the expense of households, but leaves aggregate welfare almost unchanged.

Our findings are in line with Mendicino et al. (2018) and Benes and Kumhof (2015), but are in sharp contrast to Elenev et al. (2021), who find that tighter capital constraints reduce social welfare. Since the introduction of tighter capital requirements in Elenev et al. (2021) causes the mean of aggregate consumption to increase and the volatility of aggregate consumption to fall (cf. their Table IV), we argue that the main reason for their finding of a negative welfare effect is due to their use of a peculiar measure of social welfare. We discuss this in detail in Appendix D.2. In any case, the fact remains that the choice of welfare measure is to some degree arbitrary. We therefore want to stress that in our model, tighter capital regulation delivers a Pareto improvement for a range of parameters close to Basel III.

7. Financial crises and macroprudential policy

In our final exercise, we study the role of long-term loans as a cause of financial crises, by replicating the Great Recession in the model in a way similar to Ferrante (2019). We then ask whether macroprudential regulation could have prevented the crisis. Since the Great Recession was associated with a very large contraction in output, we use the economy with nominal

[32] As shown in Table 6, consumption standard deviations decline around 1% under macroprudential regulation for both agents. With log-utility, a back-of-the-envelope calculations as in Lucas (1987) shows that this reduction in consumption volatility brings a welfare gain of approximately 0.001 percent of consumption. See also the discussion in Mendicino et al. (2018).

rigidities described in Online Appendix K. As noted above, nominal rigidities lead to stronger shock amplification and give the model a better chance to match the output dynamics during the crisis.

The purple dotted line in Fig. 6 shows the data around the crisis episode. We log-linearly detrend the data for output and investment. Output, investment and the risk free interest rate are normalized to zero in Q3 2008, so their values can be understood as percent deviations from the pre-crisis values. The Great Recession is associated with a large contraction in output and investment, which reach troughs of 6% and 25% in late 2009 respectively. On the financial side, we show the levels of the excess interest rate spread, bank default rate and the net charge-off rate on commercial loans. The crisis starts in Q3 2008 with a spike in bank defaults. The excess interest rate spread peaks in Q4 2008. Loan charge-offs also start to rise, but reach their peak only at the end of 2009.

To replicate the crisis, we initialize our model economy at its stochastic steady state and feed in a shock sequence to match the paths of output and investment between Q3 2008 and Q3 2009. The blue solid line shows the result. We have not used any information on financial variables, but the model nevertheless matches the data surprisingly well. In particular fluctuations in the real interest rate, excess interest rate spread and loan charge-off rates are close to the data. The only exception are bank defaults, which are concentrated in the data in the third quarter of 2008, while they extend over a longer time period in the model. The concentration in the data could be a consequence of contagion effects in the financial sector, discrete events such as market freezes and sudden changes in expectations, all of which are not captured in the model. Nevertheless, the total number of bank defaults over the four years following the shock is approximately right, with 5.6 percent in the data and 7.2 percent in the model.

While the model successfully matches the financial data, it still requires a strong decline in TFP to generate a recession of this magnitude.[33] That is, the financial crisis does not have strong enough output effects. To fully explain the Great Recession, a bigger model model with stronger amplification mechanisms is needed, to generate the contraction by an endogenous decrease in employment rather than in TFP. Possible mechanisms are the zero lower bound on nominal interest rates, as in Ferrante (2019), or wage rigidity.

That financial crises are only a concern under long-term loans can be seen from the yellow lines in Fig. 6, showing results for the economy with short-term loans for the same shock sequence. There is almost no variation in bank defaults and the excess interest rate spread, despite a slightly larger increase in the charge-off rate. Since no financial crisis occurs, the short-term loan economy experiences a 40 percent smaller drop in investment, and a 25 percent smaller drop in output at the trough. This is in line with the finding in Section 5.1 that banking sector frictions play almost no role when loans are short-term. Still this economy experiences a severe recession, because of the adverse TFP shocks. Bigger differences could be found in a model where the recession is not caused by a large exogenous decline in TFP but endogenous amplification.

Lastly, we show that Basel III regulation is successful in fully eliminating the financial part of the recession (red lines in Fig. 6). Bank defaults are low and almost constant and no spike in the excess interest rate spread occurs. The dynamics of investment and output are almost identical to the short-term loan economy. While not shown in the figure, it is clear that Basel III could not have a similar effect in the economy with short-term loans, as there is no financial crisis to prevent.

8. 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.

Apart from a familiar financial accelerator mechanism, 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 facing financing frictions, long-term lending leads to considerable financial instability. With this we mean the occurrence of banking crises where a large fraction of intermediaries default leading to a contraction in credit supply and economic activity. These crises do not occur in the economy with short-term lending. A regulatory increase in bank capital requirements similar to the move from Basel II to Basel III puts banks in a position to absorb these risks, eliminates crises and improves welfare.

Our analysis should not be understood as an investigation of the optimal maturity structure in an economy or the effects of interventions that change the maturity of loans. Maturity is decided by market participants, here we treat it as a given parameter and study the effects of this parameter on the distribution of aggregate risks and macroeconomic dynamics more generally. The question of optimal loan maturity for aggregate welfare is relevant and interesting in its own right. To answer it, one would need a model that captures the trade-offs underlying maturity choice at firm level, such as idiosyncratic rollover risk and issuance costs. If banks price macroeconomic risk lower than a social planner because of regulatory distortions or pecuniary externalities (see for example Dávila and Korinek, 2018; Lorenzoni, 2008), loan maturity in competitive

[33] While the shock involved are large, they are not completely implausible. The largest shocks are around two standard deviations for both TFP and σ^F in Q4 2008. In all other quarters, shocks are one standard deviation or smaller.

equilibrium can be excessive. Whether this problem should be addressed by increasing bank capital or by macroprudential interventions to shorten loan maturities is an open question.

Appendix A. Aggregation and resource constraint

In this section we derive the aggregate resource constraint (17) from the aggregation of individual agent's budget constraints. In equilibrium, the household holds all bank shares, so $S_t^B = 1$. Aggregate bank and firm dividends are given by Δ_t^B and Δ_t^F, so the aggregate household budget constraint becomes

$$D_t/R_t = D_{t-1} + w_t L_t - C_t^h + \Delta_t^B + T_t.$$

The aggregate transfer has already been derived in the main text, cf. (16):

$$T_t = RC_t + \delta^B(R_t^l + \mathbb{E}_{G^B}(\omega_t|\omega_t \le \omega_t^B))\pi_t^B B_{t-1} - D_{t-1}\pi_t^B.$$

Aggregate bank dividends are computed from the budget constraint of non-defaulted banks as

$$\Delta_t^B = [B_{t-1}(R_t^l + \mathbb{E}_{G_t^B}(\omega_t|\omega_t \ge \omega_{t+1}^B)) - D_{t-1}](1-\pi_t^B) + D_t/R_t - p_t B_t - RC_t.$$

Notice that dividend adjustment costs do not enter the aggregate constraint, since they do not constitute real resource losses. Plugging the dividend payments of the bank into the household budget constraint gives

$$C_t^h = w_t L_t + B_{t-1}[(1-\pi_t^B)(R_t^l + \mathbb{E}_{G_t^B}(\omega_t|\omega_t \ge \omega_t^B)) + \pi_t^B\delta^B(R_t^l + \mathbb{E}_{G_t^B}(\omega_t|\omega_t \le \omega_t^B))] - p_t B_t.$$

Notice that financial flows between banks and households (deposits, dividends) are netted out, only real resource flows (default costs and lending to entrepreneurs) remain. From $\mathbb{E}_{G_t^B}(\omega_t) = 0$ it follows that $(1-\pi_t^B)\mathbb{E}_{G_t^B}(\omega_t|\omega_t \ge \omega_t^B)) = -\pi_t^B\mathbb{E}_{G_t^B}(\omega_t|\omega_t \le \omega_t^B))$. The household budget constraint then simplifies to

$$C_t^h = w_t L_t + B_{t-1}[R_t^l - \pi_t^B(1-\delta^B)(R_t^l + \mathbb{E}_{G_t^B}(\omega_t|\omega_t \le \omega_t^B))] - p_t B_t$$

It remains to aggregate the entrepreneur side, which can then be used to net out financial flows between households and entrepreneurs. Aggregating entrepreneurial budget constraints gives

$$C_t^e = (1-\pi_t^F)K_{t-1}[q_t^o\mathbb{E}_{G_t^F}(\omega_t|\omega_t > \omega_t^F) + R_t^K] - (1-\pi_t^F)[(1-\mu) + (\mu + \bar{R})]B_{t-1} + p_t B_t - q_t K_t.$$

Using $(1-\pi_t^F)\mathbb{E}_{G_t^F}(\omega_t|\omega_t > \omega_t^F) = 1 - \pi_t^F\mathbb{E}_{G_t^F}(\omega_t|\omega_t \le \omega_t^F)$, which follows from $\mathbb{E}_{G_t^F}(\omega_t) = 1$, and $I_t = q_t K_t - q_t^o K_{t-1}$ we get

$$C_t^e + I_t = (1-\pi_t^F)K_{t-1}R_t^K + p_t B_t - (1-\pi_t^F)B_{t-1}[(1-\mu) + (\mu+\bar{R})] - \pi_t^F\mathbb{E}_{G_t^F}(\omega_t|\omega_t \le \omega_t^F)K_{t-1}q_t^o.$$

Using that $R_t^l = (1-\pi_t^F)[\mu + \bar{R} + (1-\mu)p_t] + \pi_t^F\delta^F[R_t^K + q_t^o\mathbb{E}_{G_t^F}(\omega_t|\omega_t \le \omega_t^F)]\frac{K_{t-1}}{B_{t-1}}$, we write

$$\begin{aligned} C_t^e + I_t = {} & (1-\pi_t^F)K_{t-1}R_t^K - B_{t-1}R_t^l + p_t B_t \\ & - \pi_t^F\delta^F[R_t^k + q_t^o\mathbb{E}_{G_t^F}(\omega_t|\omega_t \le \omega_t^F)]K_{t-1} - \pi_t^F\mathbb{E}_{G_t^F}(\omega_t|\omega_t \le \omega_t^F)K_{t-1}q_t^o. \end{aligned}$$

Collecting terms gives:

$$\begin{aligned} C_t^e + I_t = {} & (1-\pi_t^F + \pi_t^F\delta^F)K_{t-1}R_t^K \\ & - \pi_t^F(1-\delta^F)q_t^o\mathbb{E}_{G_t^F}(\omega_t|\omega_t \le \omega_t^F)K_{t-1} - B_{t-1}R_t^l + p_t B_t. \end{aligned}$$

Adding up aggregate household and firm budget constraints delivers

$$\begin{aligned} C_t^h + C_t^e + I_t = {} & w_t L_t + K_{t-1}R_t^K \\ & - \pi_t^B B_{t-1}(1-\delta^B)[R_t^l + \mathbb{E}_{G_t^B}(\omega_t|\omega_t \le \omega_t^B)] - \pi_t^F K_{t-1}(1-\delta^F)[R_t^K + q_t^o\mathbb{E}_{G_t^F}(\omega_t|\omega_t \le \omega_t^F)]. \end{aligned}$$

Because of the constant returns to scale production function and competitive markets we have $Y_t = w_t L_t + K_{t-1}R_t^K$. The terms $DWL_t^B = \pi_t^B B_{t-1}(1-\delta^B)[R_t^l + \mathbb{E}_{G_t^B}(\omega_t|\omega_t \le \omega_t^B)]$ and $DWL_t^F = \pi_t^F K_{t-1}(1-\delta^F)[R_t^K + q_t^o\mathbb{E}_{G_t^F}(\omega_t|\omega_t \le \omega_t^F)]$ are the deadweight costs of firm and bank defaults respectively. Setting $DWL_t = DWL_t^B + DWL_t^F$, establishes that the budget constraints aggregate to the resource constraint

$$Y_t = I_t + TC_t + DWL_t.$$

Appendix B. Derivation of the loan-price schedule

In this section we derive the loan price schedule. The optimality condition for lending (15) is obtained as an intermediate step. Finding the derivative of the loan price schedule 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. Notice that this derivation is simpler in the framework of Bernanke et al. (1999) and Christiano et al. (2014) where banks offer state contingent one-period contracts which give them zero profits in any state.

Consider the problem of a bank that holds a portfolio of loans b to firms which choose the equilibrium level of leverage CL. For readability we omit the bank specific superscript here. Assume that the bank lends the additional amount b_t^j to an individual firm j, with leverage cl_t^j at loan price $p_t(cl_t^j)$. Let $R_{t+1}^l(cl_t^j)$ be the return on a loan next period (with the expectation taken with respect to idiosyncratic risk), depending on the leverage of firm j. We extend the definitions in the main text to reflect the (out-of-equilibrium) heterogeneous portfolio:

$$\omega_{t+1}^B = \frac{d_t - (1-\kappa)(R_{t+1}^l b_t + R_{t+1}^l(cl_t^j)b_t^j)}{(b_t + b_t^j)} \quad , \quad \omega_{t+1}^R = \frac{d_t - (1-\psi)(R_{t+1}^l b_t + R_{t+1}^l(cl_t^j)b_t^j)}{(b_t + b_t^j)\gamma} \tag{19}$$

and

$$R_{t+1}^l(cl_t^j) = (1-\pi_{t+1}^F(cl_t^j))[\mu + \bar{R} + (1-\mu)p_{t+1}] + \pi_{t+1}^F RR_{t+1}(cl_t^j), \tag{20}$$

where the default probability and recovery rate are evaluated for a firm with leverage cl_t^j.

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

$$\begin{aligned}
V_{N,t}^B n_t = max_{\Delta_t, d_t, b_t, b^j} \quad & \Delta_t + \mathbb{E}\Lambda_{t,t+1}^H \Bigg\{ \int_{\omega_{t+1}^B}^{\infty} \big[(R_{t+1}^l + \omega_{t+1})b_t + (R_{t+1}^l(cl_t^j) + \omega_{t+1})b_t^j - d_t\big] dG^B(\omega_{t+1}) \\
& -\kappa \int_{\omega_{t+1}^B}^{\omega_{t+1}^R} \big[(R_{t+1}^l + \omega_{t+1})b_t + (R_{t+1}^l(cl_t^j) + \omega_{t+1})b_t^j - d_t\big] dG^B(\omega_{t+1}) \Bigg\} V_{N,t+1}^B \\
\text{s.t.} \quad & \\
& b_t p_t + b_t^j p_t(cl_t^j) = n_t - h(\Delta_t, n_t) + d_t/R_t
\end{aligned}$$

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

$$\begin{aligned}
p_t(cl_t^j) = \mathbb{E}_t \Lambda_{t,t+1}^H \frac{h_\Delta(\Delta_t^b, n_t^b)(1 - h_n(\Delta_{t+1}^b, n_{t+1}^b))}{h_\Delta(\Delta_{t+1}^b, n_{t+1}^b)} & \Bigg\{ \int_{\omega_{t+1}^B(bl_t)}^{\infty} \big[R_{t+1}^l(cl_t^j) + \omega_{t+1}\big] dG^B(\omega_{t+1}) \\
& - \big(G^B(\omega_{t+1}^R) - G^B(\omega_{t+1}^B)\big)\kappa [R_{t+1}^l(cl_t^j) + \mathbb{E}_{G^B}(\omega_{t+1} | \omega_{t+1}^R \geq \omega_{t+1} \geq \omega_{t+1}^B)] \\
& - g_{t+1}^B(\omega_{t+1}^R) \Bigg[-\frac{(1-\psi)R_{t+1}^l(cl_t^j)}{(b_t + b_t^j)\gamma} - \frac{d - (1-\psi)(R_{t+1}^l b_t + R_{t+1}^l(cl_t^j)b_t^j)}{(b_t + b_t^j)^2\gamma} \Bigg] \\
& * [(R_{t+1}^l + \omega_{t+1}^R)b_t + (R_{t+1}^l(cl_t^j) + \omega_{t+1}^R)b_t^j - d_t]\kappa \Bigg\}
\end{aligned}$$

where the derivatives with respect to ω_{t+1}^B disappear, since bank value is zero at the default threshold. Since the loan to an individual firm is small relative to the bank balance sheet, we can evaluate this equation at $b^j = 0$:

$$\begin{aligned}
p_t(cl_t^j) = \mathbb{E}_t \Lambda_{t,t+1}^H \frac{h_\Delta(\Delta_t^b, n_t^b)(1 - h_n(\Delta_{t+1}^b, n_{t+1}^b))}{h_\Delta(\Delta_{t+1}^b, n_{t+1}^b)} & \Bigg\{ \int_{\omega_{t+1}^B}^{\infty} \big[R_{t+1}^l(cl_t^j) + \omega_{t+1}\big] dG^B(\omega_{t+1}) \\
& - \big(G_{t+1}^B(\omega_{t+1}^R) - G_{t+1}^B(\omega_{t+1}^B)\big)\kappa [R_{t+1}^l(cl_t^j) + \mathbb{E}_{G_{t+1}^B}(\omega | \omega_{t+1}^R \geq \omega_{t+1} \geq \omega_{t+1}^B)] \\
& - g_{t+1}^B(\omega_{t+1}^R) \Bigg[-\frac{(1-\psi)R_{t+1}^l(cl^j)}{b_t\gamma} - \frac{d_t - (1-\psi)(R_{t+1}^l b_t)}{b_t^2\gamma} \Bigg] [(R_{t+1}^l + \omega_{t+1}^R)b_t - d_t]\kappa \Bigg\}
\end{aligned} \tag{21}$$

Note that Eq. (21) yields Eq. (15) in the main text, if evaluated at equilibrium leverage $cl^j = CL_t$. This establishes the price of a loan in equilibrium.

Differentiating (21) with respect to individual firm leverage cl^j and plugging in further definitions yields the slope of the loan price schedule

$$\begin{aligned}
\frac{\partial p_t(cl_t^j)}{\partial cl_t^j} = \mathbb{E}_t \Lambda_{t,t+1}^H & \frac{h_\Delta(\Delta_t^b, n_t^b)(1 - h_n(\Delta_{t+1}^b, n_{t+1}^b))}{h_\Delta(\Delta_{t+1}^b, n_{t+1}^b)} \frac{\partial R_{t+1}^l(cl_t^j)}{\partial cl_t^j} \{1 - \pi_{t+1}^B \\
& - [\pi_{t+1}^R - \pi_{t+1}^B]\kappa + g^b(\omega_{t+1}^R)(1-\psi)\frac{\kappa}{\gamma}[(R_{t+1}^l + \omega_{t+1}^R) - bl_t]\}.
\end{aligned} \tag{22}$$

This differentiation is valid because cl_t^j only enters $R_{t+1}^l(cl_t^j)$, while all other variables on the right hand side are at bank and not firm level and are therefore unaffected by the firm's choice.

The point where our assumption of covenants simplifies the analysis relative to Gomes et al. (2016) lies in the computation of the derivative $\frac{\partial R^l_{t+1}(cl^j_t)}{\partial cl^j_t}$. Without covenant, the leverage choice of a firm next period depends on its own choice of leverage this period. If a firm were to choose a higher leverage in the current period, it would also choose higher leverage in the following period because of debt overhang.[34] This is exactly the debt overhang distortion at the center of Gomes et al. (2016). The current leverage choice thus affects default risk in periods $t+2$ and beyond, which enters the continuation value of the loan $p_{t+1}(cl^j_{t+1})$. That means, computing the equivalent of $\frac{\partial R^l_{t+1}(cl^j_t)}{\partial cl^j_t}$ in the model of Gomes et al. (2016), involves a derivative of the firm's own future leverage policy function cl^j_{t+1}, with respect to its choice in the current period cl^j_t.

This derivative is not necessary in our framework because of the covenant, which fully eliminates the debt overhang distortion. The firm can choose to deviate with its leverage from the level prescribed by the covenant and pay the compensation payment. This affects the probability that the firm defaults in the following period, which gives rise to an interest rate schedule.[35] However, if the firm does not default in period $t+1$, it will be optimal to again choose the level of leverage in line with the covenant. That is, the choice of future leverage is again independent of the choice of current leverage for each firm. This is understood both by the firm itself and by its creditors. Keep in mind that the firm is nevertheless aware how its choices affect its future returns and behaves fully optimally. No pooling of assets and liabilities across firms occurs.

Next, we show how the derivative $\frac{\partial R^l_{t+1}(cl^j_t)}{\partial cl^j_t}$ is computed in our model. The return on the loan next period is given in Equation (20). The crucial difference to Gomes et al. (2016), is that p_{t+1} does not depend on cl^j_t, because of the covenant as explained in the previous paragraph. We can thus compute the derivative as

$$\frac{\partial R^l_{t+1}(cl^j_t)}{\partial cl^j_t} = -\frac{\partial \pi^F_{t+1}(cl^j_t)}{\partial cl^j_t}[(1-\mu)p_{t+1}+\mu] + \frac{\partial \pi^F_{t+1}(cl^j_t)}{\partial cl^j_t} RR_{t+1}(cl^j_t) + \frac{\partial RR_{t+1}(cl^j_t)}{\partial cl^j_t}\pi^F_{t+1}(cl^j_t).$$

The remaining derivatives $\frac{\partial \pi^F_{t+1}(cl^j_t)}{\partial cl^j_t}$ and $\frac{\partial RR_{t+1}(cl^j_t)}{\partial cl^j_t}$ can be computed in a straightforward manner, as in models with one-period debt:

$$\frac{\partial \pi^F_{t+1}(cl^j_t)}{\partial cl^j_t} = g^F_t(\alpha^F_{t+1}(cl^j_t))\frac{\partial \alpha^F_{t+1}(cl^j_t)}{\partial cl^j_t},$$

with

$$\frac{\partial \alpha^F_{t+1}(cl^j_t)}{\partial cl^j_t} = \frac{(1-\mu)p^j_{t+1}+\mu+\bar{R}}{q^o_{t+1}}$$

and

$$\frac{\partial RR_{t+1}(cl^j_t)}{\partial cl^j_t} = \delta^F\left\{q^o_{t+1}\frac{\partial \mathbb{E}_{G^F_{t+1}}(\omega_{t+1}|\omega_{t+1}<\omega^F_{t+1}(cl^j))}{\partial cl^j_t}\frac{1}{cl^j_t} - \left[R^k_{t+1}+q^o_{t+1}\mathbb{E}_{G^F_{t+1}}(\omega_{t+1}|\omega_{t+1}<\omega^F_{t+1}(cl^j_t))\right]\left(\frac{1}{cl^j_t}\right)^2\right\}.$$

Appendix C. Model with book-based regulation

We define the book value of loans as

$$\tilde{p}_t = \frac{\tilde{R}}{R_t}\mathbb{E}_t\left\{(1-\pi^F_{t+1})[\mu+\bar{R}+(1-\mu)\tilde{p}_{t+1}] + \pi^F_{t+1}RR_{t+1}\right\},$$

where $\tilde{R}$ is a constant which offsets the steady state level of the excess interest rate spread charged by banks. That is, the non-stochastic steady state of this model is identical to the model in the main text. The book value of loans only responds to changes in the risk free rate and to changes in the firm default rate. This captures the fact that banks need to set aside provisions for expected losses. If market prices of loans fall because of a shortage in aggregate bank equity, the book value is unaffected.

Consequently, we define the book return on loans as

$$\tilde{R}^l_t = (1-\pi^F_t)[\mu+\bar{R}+(1-\mu)\tilde{p}_t] + \pi^F_t RR_t,$$

Regulatory bank equity is then given by $\tilde{n}^b_t = (\tilde{R}^l_t + \gamma\omega^b_t)b^b_t - d^b_t$, which is the relevant variable for the threshold for regulatory intervention in this model version. Additionally, banks default when the book value of their assets is below the book value of liabilities:

$$(\tilde{R}^l_t + \omega^b_t)b^b_t < d^b_t \tag{23}$$

[34] Notice that also in Gomes et al. (2016) these are only out-of-equilibrium deviations and no heterogeneity emerges in equilibrium.

[35] This out-of-equilibrium schedule can be computed even though no firm ever deviates from the contracted level of leverage.

The rest of the model equations are identical to the equations in the main text. We want to stress that this is a theoretical exercise to isolate the risk transfer mechanism. The default condition (23) is not consistent with optimal bank behavior.

Appendix D. Definition of social welfare

D1. Definition used in Section 6.3

The general form of the social value function is

$$\tilde{V}^A(C^h, L, C^e, D, \tilde{\beta}, \upsilon^E) = \mathbb{E}_0 \sum_{t=0}^{\infty} \left[\beta^t \left(u^H(C_t^h, L_t) + \frac{\xi}{100} D_t / R_t \right) + \upsilon^E \tilde{\beta}^t u^E(C_t^e) \right] \tag{24}$$

We allow for the possibility that the social planner discounts entrepreneurs' utility at a rate $\tilde{\beta}$ different from β^E, cf. Section 6.3. Separately for each value $\tilde{\beta}$ of the entrepreneur's discount factor, the value weight $\upsilon^E(\tilde{\beta})$ of entrepreneurs is chosen such that

$$\left. \frac{\partial \tilde{V}^A(C^{h*} - \tilde{C}^h, L^*, C^{E*}, D, \tilde{\beta}, \upsilon^E(\tilde{\beta}))}{\partial \tilde{C}^h} \right|_{\tilde{C}^h=0} = \left. \frac{\partial \tilde{V}^A(C^{h*}, L^*, C^{e*} - \tilde{C}^e, D, \tilde{\beta}, \upsilon^E(\tilde{\beta}))}{\partial \tilde{C}^e} \right|_{\tilde{C}^e=0} \frac{\bar{C}^h}{\bar{C}^e} \tag{25}$$

Here $\left(C^{h*}, L^*, C^{e*}, D^*\right)$ denotes the state-contingent allocation under the baseline regulation, starting from the stochastic steady under this policy. The definition (25) implies that a constant-over-time, budget neutral small redistribution undertaken at $\left(C^{h*}, L^*, C^{e*}, D^*\right)$ does not affect social welfare. We express the value gain of any allocation (C^h, L, C^e, D) over the baseline allocation $\left(C^{h*}, L^*, C^{e*}, D^*\right)$ as the value of λ such that

$$\begin{aligned} &\tilde{V}^A(C^{h*}(1+\lambda), L^*, C^{E*}(1+\lambda), D^*, \tilde{\beta}, \upsilon^E(\tilde{\beta})) - \tilde{V}^A(C^{h*}, L^*, C^{e*}, D^*, \tilde{\beta}, \upsilon^E(\tilde{\beta})) \\ &\qquad = \tilde{V}^A(C^h, L, C^e, D, \tilde{\beta}, \upsilon^E(\tilde{\beta})) - \tilde{V}^A(C^{h*}, L^*, C^{e*}, D^*, \tilde{\beta}, \upsilon^E(\tilde{\beta})) \end{aligned} \tag{26}$$

To isolate the steady state effect, we compute the welfare measure (24) starting from the stochastic steady state specific to this regulation. To account for the transition phase as well, we compute (24) starting from the stochastic steady state of the baseline regulation.

D2. Comparison to the welfare measure in Elenev et al. (2021)

Although the model in Elenev et al. (2021) appears to be very similar to ours, they come to the opposite conclusion in terms of the welfare effects of macroprudential policy. This difference seems to arise mainly because they aggregate welfare differently over household types. In Elenev et al. (2021)

- the only variable entering agents' utility is consumption
- transition effects are not included in their welfare measure
- after the introduction of tighter capital requirements
  - average aggregate consumption increases in the long run
  - the volatility of aggregate consumption falls (cf. their Table IV).

To understand how welfare can decline nevertheless, let us discuss social welfare in more detail. Aggregating the utility of different types of agents into one social welfare function always requires some arbitrary weighting of agents' utility, but it becomes particularly problematic if agents have different discount factors. For example, Jackson and Yariv (2015) show that in this case every Pareto efficient and non-dictatorial method of aggregating utility functions must be time-inconsistent. In Elenev et al. (2021), households discount the future with the factor 0.982, impatient entrepreneurs with the factor 0.94 in annual terms. They normalize utility streams such that a small redistribution at time $t = 0$ leaves social welfare unchanged. If time preferences are homogeneous, this choice is justified by the fact that purely redistributive policies do not affect welfare up to first order. However, with heterogeneous discount factors, this implies that a redistribution from patient to impatient agents at any time $t > 0$ decreases welfare. This is what happens in Elenev et al. (2021) after a tightening of capital requirements. The specific redistribution from patient to impatient agents after the regulatory reform makes the welfare function decrease. This happens despite an increase in aggregate consumption which suggests an increase in efficiency.

As an alternative, we choose welfare weights such that a marginal *permanent* redistribution between the two types has no effect on social welfare (for the exact definition of the welfare function, cf. Appendix D). This is arguably more natural, because it aligns better with the concept of long-run efficiency, whereas putting special weight on $t = 0$ raises the issue of time consistency. Using our welfare weights, it appears that both our model and Elenev et al. (2021) deliver the same policy conclusion: Basel III improves aggregate welfare over Basel II.

Another advantage of our welfare weights is that aggregate welfare is much less affected by the heterogeneity in discount factors. In Table 7 we also report aggregate welfare using the same time preference to discount the utility of entrepreneurs and households, and the results are very similar. This near-independence of discount factors is important for the following reason. As in many other models with financial frictions, the low discount factor of entrepreneurs in our model and in

Elenev et al. (2021) is calibrated to match the observed leverage of firms. A common understanding in the literature is that the difference in discount factors should not be literally interpreted as a high level of impatience, but rather stands in for financial frictions not made explicit in the model, such as restricted access to capital market for small and young firms. Using those discount factors for welfare calculations then falls victim to a version of the Lucas critique: while the parameters serve to fit some aspects of the data, they are not really preference fundamentals, and it is dangerous to use them for policy evaluation.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jedc.2023.104651.

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