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RISKY FIRMS AND FRAGILE BANKS: IMPLICATIONS FOR MACROPRUDENTIAL POLICY

by Tommaso Gasparini*, Vivien Lewis**, Stéphane Moyen*** and Stefania Villa****

Abstract

Based on US data, increases in firm default risk raise the probability of bank default while decreasing output and prices. To rationalize the empirical evidence, we analyze firm risk shocks using a New Keynesian model in which entrepreneurs and banks enter into a loan contract and both are subject to default risk. Corporate defaults lead to losses on banks' balance sheets. A highly leveraged banking sector exacerbates the contractionary effects of firm defaults. We estimate the parameters of the model by matching the VAR impulse responses of firm and bank risk, output, prices and the policy rate to a range of shocks -- firm risk, demand, technology and monetary policy. Our model performs well at replicating the observed dynamics, making it suitable for policy analysis. We show that high minimum capital requirements jointly implemented with a countercyclical capital buffer are effective in dampening the adverse consequences of firm risk shocks.

JEL Classification: E44, E52, E58, E61, G28.

Keywords: bank default, capital buffer, firm risk, macroprudential policy.

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1 Introduction[1]

As a result of the Covid-19 pandemic and the lockdown measures that followed, many firms were faced with a heightened risk of default. Crane et al. (2022) document elevated exit rates in some sectors and especially among small firms in the United States. In a similar vein, Greenwood et al. (2020) show that in late 2020 various indicators pointed to an increase in expected corporate defaults. Macroprudential regulators identified corporate insolvencies as a major threat to financial stability.[2] Indeed, a wave of corporate defaults may trigger asset sales and a reduction in credit provision, which in turn exacerbates the recession. For instance, Gourinchas et al. (2025) suggest that, without government support during the pandemic, failure rates of small and medium-sized enterprises would have increased by 6 percentage points. From a policy perspective, there has been an extensive debate on how regulation can stabilize economic activity by supporting a sound financial system (e.g. Mizen et al., 2018; Buch et al., 2021; De Guindos, 2021).

This paper analyzes the role of the banking sector in the transmission of risk shocks and how macroprudential policy can dampen the adverse effects of these shocks on the real economy. First, we empirically quantify the impact of firm risk shocks on the real economy and the banking sector in the United States in a VAR analysis with multiple shocks (firm risk, demand, technology and monetary policy shocks), using a combination of zero and sign restrictions. We find that risk shocks are transmitted to the financial sector in the form of greater bank default risk, and that they decrease output and inflation. In addition, firm risk shocks dominate other disturbances in accounting for business cycle fluctuations in output. Second, we capture this transmission in a model that combines New Keynesian price setting frictions with financial market imperfections. We estimate the dynamic parameters via impulse response matching and find that the model replicates reasonably the observed dynamics. A wave of corporate defaults induced by a risk shock results in losses on bank balance sheets and in a rise in bank defaults. The economy goes through a demand-driven recession, with both output and prices falling. This transmission is exacerbated by a highly leveraged banking sector. The joint activation of a high capital requirement and a countercyclical capital buffer can help to safeguard financial stability without unduly restricting credit and investment.

Credit demand and financial intermediation are modeled as follows. Similarly to Bernanke et al. (1999), henceforth BGG, entrepreneurs have insufficient net worth to buy capital and

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[2] See, e.g., the 8^{th} Report of the Financial Stability Committee to the German parliament, AFS (2021).

therefore they borrow from banks. Entrepreneurs are subject to idiosyncratic default risk, which gives rise to a costly state verification problem. When an entrepreneur declares default, banks incur monitoring costs in order to observe the entrepreneur's realized return on capital. As in Zhang (2009), Benes and Kumhof (2015) and Clerc et al. (2015), we depart from BGG by stipulating a default threshold that is contingent on the aggregate return to capital. In BGG, debt contracts do not have this contingency, such that the entrepreneur's net worth varies together with aggregate risk. Since the financial intermediary is then perfectly insulated from such risk, its balance sheet plays no role. Here, in contrast, banks suffer balance sheet losses if entrepreneurial defaults are higher than expected.

Banks have limited liability. Similarly to Clerc et al. (2015) and van der Kwaak et al. (2023), when a bank fails, it is monitored by a bank resolution authority, an action which reduces the bank's remaining assets by a certain fraction. Bank defaults do not, however, affect the return on deposits. Full deposit insurance - financed through lump sum taxes - removes any incentive for depositors to monitor the banks' activities. Thus, the deposit rate equals the policy rate. At the same time, bank equity is limited to the accumulated wealth of bankers, who are the only agents allowed to invest in banks. This results in a high equity return per unit invested. As a consequence of expensive equity and cheap deposit funding, banks have an incentive to maximize leverage. Due to limited liability, banks do not internalize the cost of increased banking sector fragility. Macroprudential policy imposes a time-varying minimum capital requirement on banks. Banks incur a cost if they deviate from the capital requirement, giving rise to an endogenous capital buffer above the latter.

In this setup, a highly leveraged banking sector exacerbates the adverse demand effects of firm risk shocks. Imposing higher *minimum capital requirements* affects the transmission of risk shocks through two channels, a default risk channel and a bank equity channel. On the one hand, such a policy reduces bank and firm leverage, thereby decreasing the impact of risk shocks on borrower defaults. The stabilization of bank default rates helps to mitigate the fall in investment and, consequently, output. On the other hand, due to the finite amount of bank equity, higher capital requirements decrease banks' lending capacity. Following a firm risk shock, banks experience a surge in non-performing loans and a decline in their equity, which constrains their ability to provide credit and support investment.

We show that the release of a *countercyclical capital buffer* (CCyB) can mitigate the adverse consequences of a firm risk shock on investment and output by attenuating the decline in credit caused by the reduction in bank equity. Our contribution consists in showing that high steady state capital requirements and countercyclical capital buffers are complementary for macroeconomic stabilization. The joint implementation of these two policies can effectively dampen the negative effects of firm risk shocks on output.

This paper focuses on the interplay between firm and bank defaults and examines the stabilization properties of macroprudential policies.[3] It fits into the literature on bank

[3] Here, we study lender-based macroprudential instruments. Millard et al. (2023) focus on the macroeconomic implications of borrower-based macroprudential policies.

regulation in dynamic stochastic general equilibrium (DSGE) models. Our model shares several features with Clerc et al. (2015), e.g. the prediction that economies with better-capitalized banks exhibit smaller responses to shocks. Moreover, releasing a countercyclical capital buffer could lead to a significant increase in bank defaults only in the case in which initial capital requirements are low. However, our main focus lies on the analysis of firm risk shocks, which are absent in Clerc et al. (2015).[4] We show in a VAR analysis that this type of shock explains a substantial proportion of business cycle fluctuations in the US. Our main policy insight is that introducing a CCyB alongside high capital requirements stabilizes output; this is due to strong complementarities between the two policies in the presence of firm risk shocks.

In line with Elenev et al. (2021), we find that countercyclical capital buffers can mitigate the adverse effects of firm risk shocks, even with low capital requirements. The reason is that banks are incentivized to maintain an equity buffer above the minimum requirement, as they face costs if they deviate from the regulation. This buffer limits the increase in bank defaults following a risk shock. While our analysis is a positive one, Mendicino et al. (2018) study the welfare effects of cyclical capital requirements. Our study has similarities with van der Kwaak et al. (2023), who investigate how risk shocks affect macroeconomic outcomes. It is different in two respects. First, they define risk shocks as bank-specific shocks to their asset return, whereas we focus on second moment shocks to borrower productivity. Second, our emphasis is on the business cycle implications of banking sector regulation, while they study the long-run implications of deposit insurance. Our work is also related to Mendicino et al. (2020), who investigate optimal capital requirements when banks are exposed to non-diversifiable borrower risk. In this paper, we study the transmission of firm risk shocks, while they consider asymmetric bank loan portfolios as the key source of bank fragility. Their focus lies on optimal capital requirements, while we discuss the stabilization properties of macroprudential policies for the business cycle.

A key contribution of our work is to demonstrate the good empirical performance of a model à la Clerc et al. (2015), where monetary policy and bank capital requirements operate in a world with firm and bank default risk. We do so by matching the impulse responses of a multiple-shock vector autoregression that includes risk shocks. Our empirical findings complement the results presented by Galaasen et al. (2020). Similar to this paper, they study empirically how shocks that hit borrowers affect banks and the overall economy. However, our analysis diverges from theirs, as we identify risk shocks to a continuum of borrowers rather than granular credit risk at the borrower level.

The remainder of the paper is structured as follows. Our empirical evidence on firm risk shocks is presented in Section 2. Section 3 outlines the model, which we take to the data in Section 4. Section 5 shows how firm risk shocks are transmitted to the rest of the economy, including the financial sector, and investigates the role of bank leverage in this transmission.

[4] Other notable differences are that we consider monetary policy shocks in a sticky-price model, and that we abstract from household leverage.

In particular, the effectiveness of macroprudential policies is discussed. Finally, Section 6 concludes. Data details and alternative empirical specifications, the full model derivation, technical details and robustness checks are provided in the online appendix.[5]

2 VAR evidence on firm risk shocks

Risk shocks have been identified as an important driving force of business cycle fluctuations (Christiano et al., 2014). What do we mean by 'risk shocks'? A micro-based view of macroeconomics takes into consideration that individual producers with different levels of productivity coexist. At a given point in time, we might think of a productivity distribution across firms, whose standard deviation provides a measure of risk.[6] The idea behind this notion of firm risk is that a greater standard deviation implies greater uncertainty regarding firms' output. In that sense, heightened firm risk necessarily implies greater macroeconomic volatility and a contractionary effect on output. Indeed, Chugh (2016) shows that average productivity and the cross-sectional standard deviation of idiosyncratic productivity are inversely correlated. In line with this, Kehrig (2011) shows that the dispersion of productivity across US plants rises in recessions and Bloom et al. (2018) find that measures of the establishment-level dispersion both in TFP shocks and in output growth are strongly countercyclical.

In our empirical analysis, we measure firm risk as the option-implied cross-sectional firm volatility of Dew-Becker and Giglio (2023), consistently with the theoretical concept outlined above. Bank risk is proxied by the spot funding spread (SFS) from Jondeau et al. (2020). The spot funding spread is given by the three-month IBOR-OIS spread, where IBOR stands for Interbank Offered Rate and OIS for Overnight Interest Swap.

We estimate a five-variable vector autoregression (VAR) at the monthly frequency on US data. The variable vector contains firm risk, bank risk, the logarithm of real GDP, the logarithm of the price index (measured by the GDP deflator) and the policy interest rate. Data on real GDP are available only at the quarterly frequency, and thus we interpolate the series by means of the Chow and Lin (1971) method and using industrial production as the base series. The sample period is January 2005 to June 2020, and we set the VAR lag length to three.

In order to analyze the transmission of firm risk shocks and assess their relative importance compared to other shocks, we identify four structural shocks: firm risk, technology, demand, and monetary policy shocks. We employ a combination of sign and zero restrictions to identify these shocks within a structural VAR framework, a widely used methodology in the macroeconometric literature (e.g. Arias et al., 2018, 2019). Each shock is identified by theoretically motivated sign or zero restrictions imposed on the impulse responses of selected

[5] The online appendix is also available at `http://sites.google.com/view/vivienjlewis`.

[6] This notion of risk differs from e.g. Bloom (2009) and Basu and Bundick (2017), where 'uncertainty shocks' are defined as a time-varying variance of aggregate productivity.

variables. The restrictions are detailed in Table 1 and are applied over a six-month horizon.

Table 1: VAR identification restrictions

	Risk	Technology	Demand	Monetary Policy
Firm risk	+	0	0	0
Output		+	+	+
Prices		-	+	+
Policy rate			+	-
Bank risk				

Notes. Table shows zero and sign restrictions applied to each variable in response to the four identified shocks.

We identify firm risk shocks by assuming that these shocks are the only ones that contemporaneously affect firm risk. The technology shock moves output and prices in opposite directions. Demand shocks and monetary policy shocks instead move output and prices in the same direction. Monetary policy shocks move the policy rate and output in opposite directions, while demand shocks move the policy rate and output in the same direction. No restrictions are imposed on the response of bank risk to the four shocks. This identification strategy is consistent with the literature (Furlanetto et al., 2017; Basu and Bundick, 2017). Given that we estimate a five-variable VAR, but we only identify four shocks, we are left with a fifth shock that does not satisfy any of the restrictions (we verify this at every iteration). Accordingly, we interpret that fifth shock as capturing other (unspecified) shocks, or measurement error.

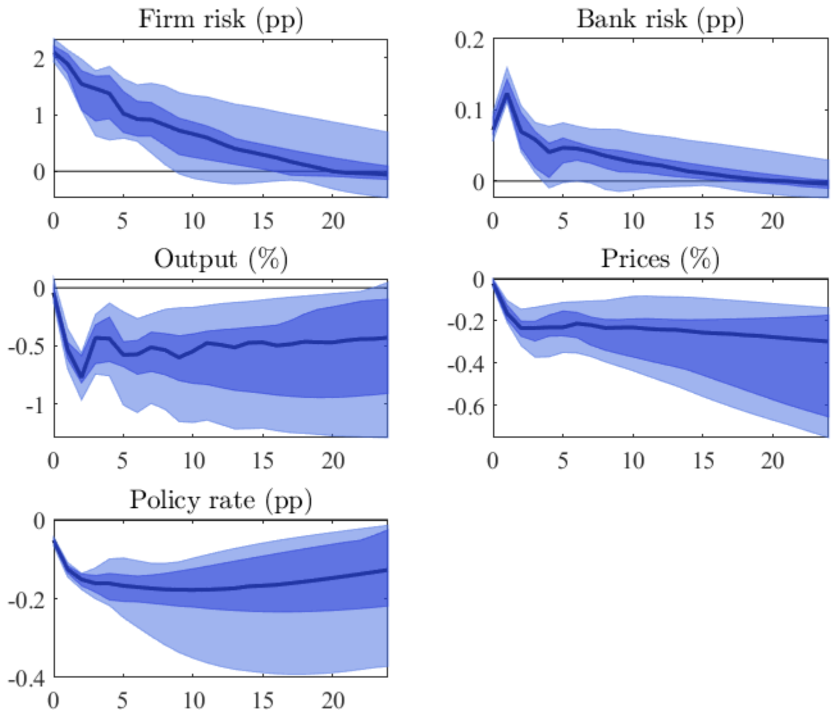
Figure 1 shows that an increase in firm risk leads to a significant fall in output and prices. This is consistent with the view that adverse firm risk shocks induce a demand-driven recession. Moreover, bank risk rises, which indicates that firm risk carries over to the banking sector in the form of a higher implicit bank default probability. Finally, the observed decrease in the policy rate following the shock indicates that the central bank responds by easing monetary policy to support the recovery.[7]

The estimated model is also used to assess the relative importance of different shocks in explaining the fluctuations in the main variables. Figure 2 reports the conditional variance decomposition of the five variables. At horizons beyond two months, firm risk shocks account for a third of fluctuations in output and prices. Moreover, firm risk shocks play a major role for the forecast error variance of the policy rate, bank risk, and, unsurprisingly, firm risk. Given the importance of firm risk shocks, our quantitative model focuses on analyzing their transmission mechanism, and on the effectiveness of macroprudential policies in stabilizing output in response to such shocks.

In a set of additional estimation exercises in the online appendix, we show that our main VAR results are robust to a number of alternative specifications. First, the US is not a

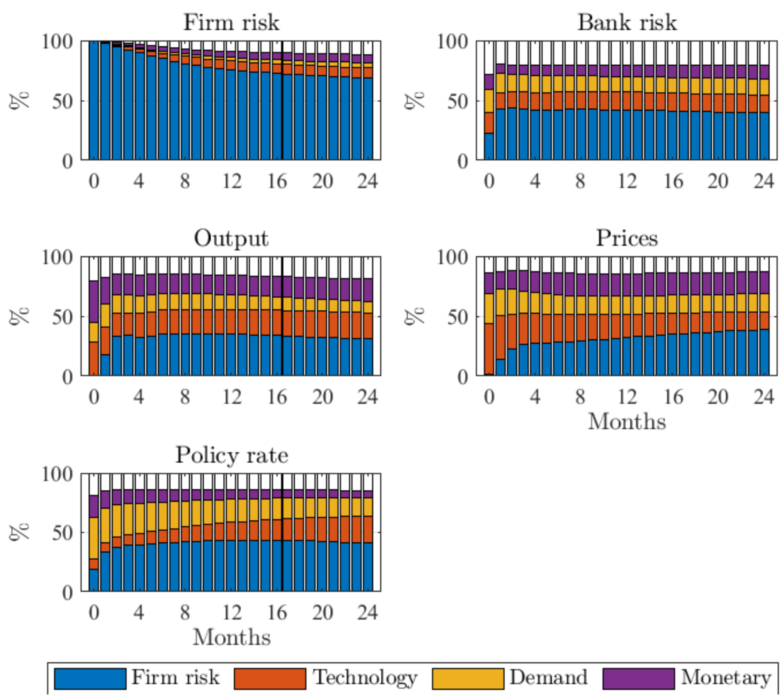
[7] Figures 3 to 5 in the online appendix report the impulse response functions to technology, demand, and monetary policy shocks.

Figure 1: Impulse responses to a firm risk shock in the United States



Notes. Sample period: January 2005 to June 2020. Shock size is one standard deviation. The light blue shaded area denotes the 95% bootstrap confidence interval, while the dark blue shaded area denotes the 68% interval.

Figure 2: Forecast error variance decomposition



special case, since we observe similar responses to firm risk shocks also in the Euro area. Second, the specific measures of firm and bank risk do not matter for the overall pattern.

1. *Firm risk* is alternatively measured as the excess bond premium for corporates computed by Gilchrist and Zakrajšek (2012a).[8] As a third proxy for firm risk, we use 'spread per unit of leverage' (SPL) calculated by the Bundesbank. This time series is obtained by combining end-of-the-month CDS-spread data in basis points from Markit and quarterly end-of-the-period debt and equity data from Bloomberg for all the firms in the EURO Stoxx 50 and Dow Jones 30. After computing the SPL for every firm as the ratio of CDS-spread to debt divided by equity, the aggregate SPL is given by the median across firms. The main message of Figure 1 is unchanged when using the excess bond premium. However, the response of output becomes statistically insignificant when using the SPL.

2. As an alternative measure of *bank risk*, we use the excess bond premium for financials (Gilchrist and Zakrajšek, 2012b). Measuring bank risk using the forward (rather than spot) credit spread provided by Jondeau et al. (2020) also makes little difference.

Third, replacing GDP with industrial production leaves our results intact. Fourth, our results are not affected if we identify *only* firm risk shocks through a Cholesky decomposition, similarly to Basu and Bundick (2017). The results are robust whether we order the variables as firm risk, bank risk, output, prices, and policy rate, or as real output, prices, the policy rate, firm risk and bank risk. Finally, when we include the credit-to-output ratio in the VAR, we order it last and impose a recursive identification, we find that it increases significantly after a firm risk shock. This result is consistent with the evidence provided by Borio et al. (2018). After a firm risk shock, output falls faster than credit, implying that the credit-to-output ratio increases.

A similar transmission pattern of firm-level risk shocks is found in the VAR study on German data in Bachmann and Bayer (2013), in Gilchrist et al. (2014), and in the DSGE model estimated on US data by Christiano et al. (2014). The aforementioned papers concentrate on the macroeconomic impact of firm risk shocks; the transmission via the banking sector has, to our knowledge, not been studied yet.

In the following section, we develop a business cycle model that can replicate the patterns uncovered here.

3 Model

We now sketch the more relevant parts of the model that feature a costly state verification problem both for entrepreneurs and for banks. Banks monitor failed entrepreneurs and a bank resolution authority monitors failed banks. Given the non-state-contingent nature

[8] The corresponding reference for the Euro area is Gilchrist and Mojon (2018).

of the loan contract, entrepreneurial defaults affect bank balance sheets. We first discuss the non-financial sector; second, we explain the workings of the financial sector. Third, we present the monetary and macroprudential policy rules. The rest of the model on the household sector, goods production and market clearing, as well as the full model derivation are explained in detail in the online appendix.

3.1 Non-financial sector

This section discusses the loan contract between entrepreneurs and banks. As in Bernanke et al. (1999), there is a costly state verification problem where the entrepreneur's return cannot be observed by the lender without incurring a monitoring cost. This leads to a debt contract between the borrower and the lender that specifies a fixed repayment rate. In the case of default, the lender engages in costly monitoring and seizes the entrepreneur's remaining capital. The risk to the entrepreneur has an aggregate as well as an idiosyncratic component. The latter depends on the aggregate return to capital, which is observable.

Entrepreneurs. There is a continuum of risk-neutral entrepreneurs indicated by the superscript E. Each entrepreneur is denoted by j. They combine net worth and bank loans to purchase capital from the capital production sector and rent it to intermediate goods producers. Entrepreneurs face a probability $1-\chi^E$ of staying in business in the next period, where $\chi^E \in (0,1)$. Let $\mathcal{W}_t^{Ej}$ be entrepreneurial wealth accumulated from operating firms. Entrepreneurs have zero labor income. Incumbent entrepreneurs' net worth is the wealth held by entrepreneurs at t who are still in business in $t+1$, that is $(1-\chi^E)\mathcal{W}_{t+1}^{Ej}$. Entrepreneurs who fail return to their household, bringing with them their residual wealth $\chi^E\mathcal{W}_{t+1}^{Ej}$. Of this, a fraction ι is provided to new entrepreneurs as startup financing. Thus, total entrepreneurial net worth is given by

$$n_{t+1}^{Ej} = (1-\chi^E+\iota\chi^E)\mathcal{W}_{t+1}^{Ej}, \tag{1}$$

and entrepreneurial profits retained by the households are $\Xi_{t+1}^E = (1-\iota)\chi^E\mathcal{W}_{t+1}^E$, where $\mathcal{W}_{t+1}^E = \int_j \mathcal{W}_{t+1}^{Ej}\mathrm{d}j$.

Entrepreneurial wealth in period $t+1$ depends on the value of the capital stock bought in the previous period, $q_tK_t^j$, and its ex-post nominal return R_{t+1}^E. Of these total earnings on capital, a fraction $1-\Gamma_{t+1}^{Ej}$ is left to the entrepreneur,

$$\mathcal{W}_{t+1}^{Ej} = (1-\Gamma_{t+1}^{Ej})\frac{R_{t+1}^E q_t K_t^j}{\Pi_{t+1}}. \tag{2}$$

To measure wealth in terms of final consumption goods, it needs to be discounted by the gross rate of inflation, $\Pi_{t+1} = P_{t+1}/P_t$.

Entrepreneur j purchases capital K_t^j at the real price q_t per unit. The amount $q_tK_t^j$, spent on capital goods, exceeds her net worth n_t^{Ej}. She borrows the remainder,

$$b_t^j = q_t K_t^j - n_t^{Ej}, \tag{3}$$

from the full range of banks, which in turn obtain funds from depositors and equity holders ('bankers'). Capital is chosen at t and used for production at $t+1$. It has an ex-post gross return $\omega_{t+1}^{Ej} R_{t+1}^E$, where R_t^E is the aggregate return on capital (as stated above) and ω_t^{Ej} is an idiosyncratic disturbance. The idiosyncratic productivity disturbance is *iid* log-normally distributed with mean $\mathbb{E}\{\omega_t^{Ej}\} = 1$ and a time-varying standard deviation $\sigma_t^E = \sigma^E \varsigma_t^E$, where ς_t^E is a firm risk shock. The probability of default for an individual entrepreneur is given by the respective cumulative distribution function evaluated at the threshold $\overline{\omega}_t^{Ej}$, to be specified below, $F_t^{Ej} = \int_0^{\overline{\omega}_t^{Ej}} f^E(\omega_t^{Ej}) \mathrm{d}\omega_t^{Ej}$, where $f^E(\cdot)$ is the respective probability density function.

The ex-post gross return to entrepreneurs, in terms of consumption, of holding a unit of capital from t to $t+1$ is given by the rental rate on capital, r_{t+1}^K, plus the gain from undepreciated capital, $(1-\delta)q_{t+1}$, divided by the real price of capital in period t. In nominal terms, this is:

$$R_{t+1}^E = \frac{r_{t+1}^K + (1-\delta)q_{t+1}}{q_t} \Pi_{t+1}. \tag{4}$$

The financial contract, which we turn to next, determines how the project return is divided between the entrepreneur and the bank.

Financial contract. After the financial contract is signed, the entrepreneurs' idiosyncratic productivity shock realizes. Those entrepreneurs whose productivity is below the threshold,

$$\overline{\omega}_{t+1}^{Ej} = \frac{Z_t b_t^j}{R_{t+1}^E q_t K_t^j} = \frac{x_t^{Ej}}{R_{t+1}^E}, \tag{5}$$

declare default. In (5), $x_t^{Ej} \equiv Z_t b_t^j / (q_t K_t^j)$ is the entrepreneur's loan-to-value ratio, the contractual debt repayment divided by the value of capital purchased and Z_t is the contractual repayment rate. Here, the cutoff $\overline{\omega}_{t+1}^{Ej}$ is contingent on the realization of the aggregate state R_{t+1}^E, such that aggregate shocks produce fluctuations in firm default rates, which in turn impinge on bank balance sheets.

The financial contract works as follows. In the default case, the entrepreneur has to turn the whole return $\omega_{t+1}^{Ej} R_{t+1}^E q_t K_t^j$ over to the bank. Of this, a fraction μ^E is lost as a monitoring cost that the bank needs to incur to verify the entrepreneur's project return. In the non-default case, the bank receives only the contractual payment $\overline{\omega}_{t+1}^{Ej} R_{t+1}^E q_t K_t^j$. The remainder, $(\omega_{t+1}^{Ej} - \overline{\omega}_{t+1}^{Ej}) R_{t+1}^E q_t K_t^j$, goes to the residual claimant, the entrepreneur. Consequently, if the entrepreneur does not default, the payment to the bank is independent of the realization of the idiosyncratic shock.

Following the notation in Bernanke et al. (1999), we define the share of the project return

$R^E_{t+1} q_t K^j_t$ accruing to the bank, gross of monitoring costs, as $\Gamma^{Ej}_t = G^{Ej}_t + (1 - F^{Ej}_t)\overline{\omega}^{Ej}_t$, where $G^{Ej}_t = \int_0^{\overline{\omega}^{Ej}_t} \omega^{Ej}_t f^E(\omega^{Ej}_t) \mathrm{d}\omega^{Ej}_t$ is the share of the project return subject to firm defaults. Being risk-neutral, the entrepreneur cares only about the expected return on his investment given by

$$\mathbb{E}_t \left\{ \left[1 - \Gamma^{Ej} \left(\frac{x^{Ej}_t}{R^E_{t+1}} \right) \right] R^E_{t+1} q_t K^j_t \right\}, \tag{6}$$

where the expectation is taken with respect to the random variable R^E_{t+1}.

In order for the bank to agree to the contract, the return that the bank earns from lending funds to the entrepreneur must be at least as high as the return R^F_{t+1} the bank would obtain from lending to a (fictitious) riskless firm,

$$\mathbb{E}_t \left\{ \left[(1 - F^{Ej}_{t+1})\overline{\omega}^{Ej}_{t+1} + (1 - \mu^E) \int_0^{\overline{\omega}^{Ej}_{t+1}} \omega^{Ej}_{t+1} f^E(\omega^{Ej}_{t+1}) \mathrm{d}\omega^{Ej}_{t+1} \right] R^E_{t+1} q_t K^j_t \right\} \geq \mathbb{E}_t\{R^F_{t+1} b^j_t\}. \tag{7}$$

Using the borrowing requirement (3), we can replace b^j_t with $(q_t K^j_t - n^{Ej}_t)$ in the bank's participation constraint (7) and derive the financial contract. The entrepreneur chooses x^{Ej}_t, K^j_t to maximize (6), subject to the bank's participation constraint (7). The optimality conditions of the contracting problem are provided in the online appendix.

As shown in the online appendix, each entrepreneur chooses the same leverage, so the problem can be aggregated. Aggregating capital holdings and net worth over entrepreneurs, we define $K_t = \int_j K^j_t \mathrm{d}j$ and $n^E_t = \int_j n^{Ej}_t \mathrm{d}j$.

The bank's ex-post gross return on loans, in nominal terms, is given by

$$R^F_{t+1} = \left(\Gamma^E_{t+1} - \mu^E G^E_{t+1} \right) \frac{R^E_{t+1} q_t K_t}{b_t}. \tag{8}$$

3.2 Financial sector

The financial sector consists of a range of banks with idiosyncratic productivity. Banks receive equity funding from bankers and deposit funding from households. Their assets are the loans which they provide to the entrepreneurs. Deposits are fully insured; depositors therefore have no incentive to monitor a bank's activities and receive the risk-free return that coincides with the policy rate.[9] Since bankers are the only agents in the economy allowed to hold bank equity, the size of total equity funding is restricted to the bankers' accumulated wealth.[10] This restriction keeps the equity return - per unit of equity held - high. Bankers

[9] van der Kwaak et al. (2023) propose a rationale for full deposit insurance in models without bank runs. Reducing the proportion of deposits that are fully reimbursed in the event of a bank default raises the cost of deposit funding and, consequently, increases the likelihood of bank default. This happens despite the fact that lowering the fraction of deposits that are reimbursed in case of bank default reduces bank moral hazard.

[10] Similar to Van den Heuvel (2008), Clerc et al. (2015), Lang and Menno (2025), Coimbra and Rey (2023) and many other studies, we abstract from endogenous equity issuance. Section 2.11 in the online appendix shows empirically that banks indeed issue equity rather infrequently.

have limited liability and can walk away if a bank defaults. As deposit funding is cheap and equity funding is expensive, banks therefore have an incentive to maximize leverage and will hold only the minimum amount of capital as required by the macroprudential authority. Those financial institutions that are unable to pay depositors using their returns on corporate loans fail; they are monitored by a tax-funded bank resolution authority.

Banks. Bank i has productivity ω_{t+1}^{Fi}, which we assume to be log-normally distributed with mean one and standard deviation σ^F. The operating profits of bank i in period $t+1$ are given by the revenues from its lending activity minus the costs paid for deposits, $\omega_{t+1}^{Fi} R_{t+1}^F b_t^i - R_t^D d_t^i$, where R_{t+1}^F is the interest rate obtained from the lending activity, R_t^D is the deposit rate and d_t^i is the amount of deposits issued by the bank. Banks are subject to limited liability, i.e. they declare bankruptcy if their operating profits fall below zero. The bank fails if it is not able to pay depositors using its returns on corporate loans. As in the entrepreneurial sector, there exists a threshold productivity level below which bank i fails, i.e. its operating profits turn negative,

$$\overline{\omega}_{t+1}^{Fi} = \frac{R_t^D d_t^i}{R_{t+1}^F b_t^i}. \tag{9}$$

The macroprudential regulator imposes a minimum capital requirement on banks. Banks that do not comply with this capital requirements incur a cost (see also Angeloni and Faia (2013) and Benes and Kumhof (2015)). At the beginning of period $t+1$, a surviving bank has to pay a cost γb_t^i if its operating profit is less than a fraction $\phi_t \in (0,1)$ of the return on loans, i.e. if

$$\omega_{t+1}^{Fi} R_{t+1}^F b_t^i - R_t^D d_t^i < \phi_t \omega_{t+1}^{Fi} R_{t+1}^F b_t^i. \tag{10}$$

There is no limited liability with respect to this cost. The penalty in (10) is not meant to be realistic; rather, it is a reduced-form tool, which ensures that banks maintain a capital buffer above the minimum capital requirement ϕ_t. It stands in for real-world measures such as dividend restrictions or changes to the bank's management. Importantly, specifying the penalty in this way allows us to model endogenous bank equity buffers without the necessity to handle occasionally binding constraints.[11] We define a cost threshold as the value of ω_{t+1}^{Fi} for which (10) holds with equality, i.e.

$$\overline{\omega}_{t+1}^{\phi i} = \frac{R_t^D d_t^i}{(1-\phi_t) R_{t+1}^F b_t^i} = \frac{\overline{\omega}_{t+1}^{Fi}}{1-\phi_t}. \tag{11}$$

Note that ϕ_t represents the capital requirement because the left-hand side of (10) is equal to pre-cost bank equity at the beginning of period $t+1$, and, on the right-hand side, $\omega_{t+1}^{Fi} R_{t+1}^F b_t^i$ is the value of assets at the beginning of period $t+1$. The definition of the capital requirement in (10) differs from Clerc et al. (2015) in that it is *future* rather than current net worth that

[11] In Karadi and Nakov (2021) and Akinci and Queralto (2022), banks maintain equity buffers above the market-induced minimum capital ratio; however, the authors need to resort to non-linear solution methods to solve their model under an occasionally binding constraint.

determines the adequacy of the capital buffer.

Modeling contemporaneous minimum capital requirements as in Clerc et al. (2015) would generate an indeterminacy problem due to a feedback mechanism where increased defaults and bank equity losses reduce bank credit, further increasing default rates. This is shown by Lewis and Roth (2018). In models with a similar mechanism, as Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), the assumption of an incentive constraint breaks this feedback loop and solves the indeterminacy problem. The way we model minimum capital requirements is similar to the incentive constraint of Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) as this constraint is a function of future bank equity and future return on assets. Also Corbae and D'Erasmo (2021) specify a capital requirement that depends on future net worth. Rubio and Yao (2020) specify a similar constraint in the form of a loan-to-value (LTV) ratios for households taking out mortgage loans. There, impatient households can borrow from patient households but have to satisfy an LTV ratio limiting the amount they can borrow to a certain fraction of the future expected value of their housing.

The cost of deviating from the minimum capital requirement implies a distribution of bank capital ratios, where the capital ratio is defined as

$$\varrho_{t+1}^{Fi} = 1 - \frac{R_t^D d_t^i}{\omega_{t+1}^{Fi} R_{t+1}^F b_t^i}. \tag{12}$$

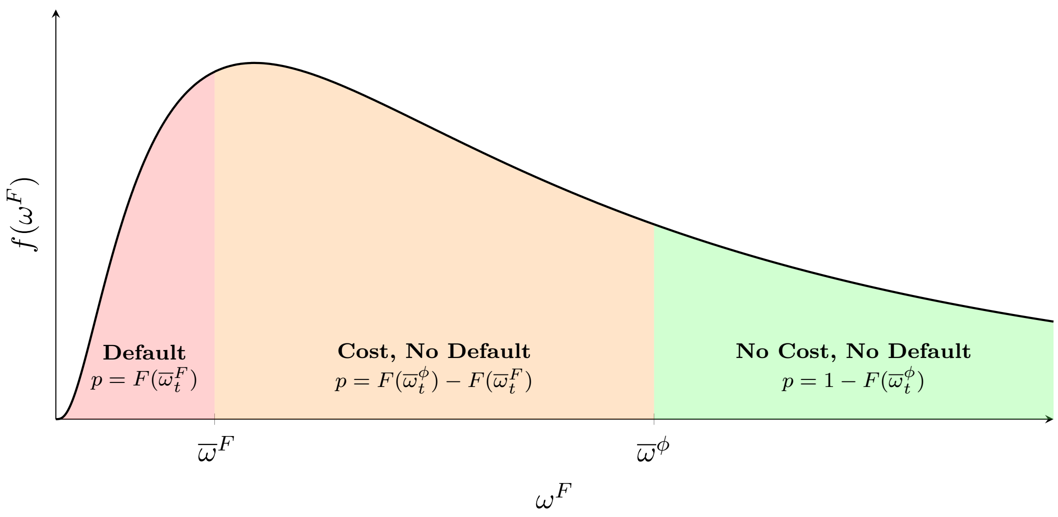
Heterogeneity in the capital ratio across banks is consistent with US data as shown in the online appendix. Our baseline calibration for γ implies that the cost has a relatively small impact on output and investment dynamics, but a larger impact on bank defaults, in response to firm risk shocks. For lower values of γ, steady state bank capital buffers decrease (see Section 3.2 of the online appendix), resulting in a greater rise in bank defaults following a firm risk shock.[12]

In the following, we introduce notation that is analogous to the entrepreneurial sector. Let $F_t^F = \int_0^{\overline{\omega}_t^F} f^F(\omega_t^F) \mathrm{d}\omega_t^F$ denote the probability of bank default. The share of the return on loans subject to bank defaults is defined as $G_t^F = \int_0^{\overline{\omega}_t^F} \omega_t^F f^F(\omega_t^F) \mathrm{d}\omega_t^F$. When the bank resolution authority monitors a failed bank, a fraction μ^F of this share is lost. Finally, we define $\Gamma_t^F = G_t^F + \overline{\omega}_t^F \int_{\overline{\omega}_t^F}^{\infty} f^F(\omega_t^F) \mathrm{d}\omega_t^F$. Since deposits are insured, depositors receive $R_t^d d_t$ in all states of the world.

Figure 3 shows the bank productivity distribution and the two thresholds for illustrative purposes. If productivity is above the cost threshold, $\omega^{Fi} \geq \overline{\omega}^{\phi i}$, bank i fulfills the capital requirement and does not fail. If productivity is below the cost threshold, $\omega^{Fi} < \overline{\omega}^{\phi i}$, the bank does not fulfill the capital requirement and it has to pay a cost equal to a proportion γ of the loans contracted in the previous period. If productivity is below the default threshold, $\omega^{Fi} < \overline{\omega}^{Fi}$, the bank fails and it is monitored by the bank resolution authority.

[12] For a more detailed analysis of the dynamic implications of incorporating a bank cost of deviating from the minimum capital requirement, please refer to the online appendix.

Figure 3: Bank productivity distribution



Notes. The figure shows the distribution of bank productivity ω^F, partitioned into three regions: (i) defaulting banks ($\omega^F < \overline{\omega}_t^F$), (ii) solvent but non-compliant banks ($\overline{\omega}_t^F < \omega^F < \overline{\omega}_t^\phi$), and (iii) compliant, non-defaulting banks ($\omega^F > \overline{\omega}_t^\phi$).

Bank profits can be aggregated across banks to yield

$$\int_{\overline{\omega}_{t+1}^{Fi}}^{\overline{\omega}_{t+1}^{\phi i}} (\omega_{t+1}^{Fi} R_{t+1}^F b_t^i - R_t^D d_t^i - \gamma b_t^i) dF^F(\omega_{t+1}^{Fi}) + \int_{\overline{\omega}_{t+1}^{\phi i}}^{\infty} (\omega_{t+1}^{Fi} R_{t+1}^F b_t^i - R_t^D d_t^i) dF^F(\omega_{t+1}^{Fi}). \quad (13)$$

In (13), the first term captures profits of banks with intermediate productivity that are required to pay the cost of deviating from the minimum capital requirement. The second term are the profits of high-productivity banks. Profits of defaulting banks are zero. Using the default threshold (9) to replace $R_t^D d_t^i$ with $\overline{\omega}_{t+1}^{Fi} R_{t+1}^F b_t^i$, and using the definition of $\Gamma^F(\overline{\omega}_{t+1}^{Fi})$, we can rewrite aggregate bank profits as

$$\Psi_{t+1}^{Fi} = (1 - \Gamma^F(\overline{\omega}_{t+1}^{Fi})) R_{t+1}^F b_t^i - \gamma b_t^i [F^F(\overline{\omega}_{t+1}^{\phi i}) - F^F(\overline{\omega}_{t+1}^{Fi})]. \quad (14)$$

The first term in (14) is the bank's expected revenue after the bank has made interest payments to the depositors, but before the (possible) payment of the cost of deviating from the minimum capital requirement. The second term represents the expected cost of deviating from the minimum capital requirement.

Banks choose the volume of loans b_t^i that maximizes profits (14), where we note the dependence of the threshold productivity levels, $\overline{\omega}_{t+1}^{Fi}$ and $\overline{\omega}_{t+1}^{\phi i}$, on loans b_t^i. As shown in the online appendix, each bank chooses the same leverage, so the problem can be aggregated. All banks behave the same in equilibrium, such that we drop the index i from here on. Using simplified notation in (14), the bank's first order condition becomes

$$\mathbb{E}_t\left\{R^F_{t+1}\left[(1-\Gamma^F_{t+1})-\ \Gamma^{F\prime}_{t+1}\frac{R^D_t n^B_t}{R^F_{t+1}b_t}\right]\right.$$
$$\left.-\gamma\left[F^\phi_{t+1}-F^F_{t+1}+\left(\frac{F^{\phi\prime}_{t+1}}{1-\phi_t}-F^{F\prime}_{t+1}\right)\frac{R^D_t n^B_t}{R^F_{t+1}b_t}\right]\right\}=0, \tag{15}$$

where $F^\phi_t = F^F(\overline{\omega}^\phi_t)$, $F^F_t = F^F(\overline{\omega}^F_t)$ and $\Gamma^F_t = \Gamma^F(\overline{\omega}^F_t)$. Therefore, differently from Benes and Kumhof (2015) and Clerc et al. (2015), the optimal choice of loans is a function of the two threshold productivity levels, $\overline{\omega}^{Fi}_{t+1}$ and $\overline{\omega}^{\phi i}_{t+1}$, the minimum capital requirement, ϕ_t, and the cost of deviating from the minimum capital requirement, γ. Macroprudential policy, by affecting the capital requirement, has thus a direct effect on the amount of loans supplied by banks.

Bankers. Following Gertler and Karadi (2011), households have a unit mass and consist of two types of people. A proportion $\mathcal{F}$ of household members are bankers and the remaining $1-\mathcal{F}$ are workers. Consumption is nevertheless equalized across members through perfect intra-household risk sharing. Every period, some individuals switch between the two occupations. In particular, a person who is currently a banker has a constant probability $1-\chi^B$ of remaining a banker in the next period, which is independent of the time already spent in the banking sector.[13] Every period, $\chi^B\mathcal{F}$ bankers thus quit banking and become workers. The same number of workers randomly become bankers, such that the proportions of bankers and workers within the household remain fixed. Bankers who quit transfer their wealth to their respective household. The household uses a fraction ι of this transfer to provide its new bankers with startup funds, as is described below.

A banker's only investment opportunity is to provide equity to banks. We suppose that a banker holds a diversified portfolio of bank equity, by investing his net worth in all banks. Let n^B_t denote the aggregate net worth of bankers. Bankers obtain an ex-post aggregate nominal return of R^B_{t+1} on their investment, which determines their wealth in the next period,

$$\mathcal{W}^B_{t+1}=\frac{R^B_{t+1}n^B_t}{\Pi_{t+1}}. \tag{16}$$

The return on equity is the ratio of bank profits to banker net worth,

$$R^B_{t+1}=\frac{\Psi^F_{t+1}}{n^B_t}. \tag{17}$$

Aggregate net worth of existing bankers is the wealth held by bankers at t who are still

[13] The average lifetime of a banker is thus $1/(1-\chi^B)$, where $\chi^B\in(0,1)$. Bankers have a finite horizon such that they do not accumulate enough wealth to fund all investments without the need for external borrowing.

around one period later, $(1-\chi^B)\mathcal{W}_{t+1}^B$. A banker who leaves the banking business turns his residual equity over to the household. Newly entering bankers receive startup funds from their respective households, which are a fraction ι of the value of exiting bankers' wealth, i.e. $\iota\chi^B\mathcal{W}_{t+1}^B$. Therefore, aggregate banker net worth is given by the sum of existing and new bankers' net worth,

$$n_{t+1}^B = (1-\chi^B+\iota\chi^B)\mathcal{W}_{t+1}^B, \tag{18}$$

and bank profits retained by the households are $\Xi_{t+1}^F = (1-\iota)\chi^B\mathcal{W}_{t+1}^B$.

3.3 Monetary policy and minimum capital requirements

We now specify two types of macroeconomic policies: monetary policy and a minimum capital requirement. The policy rate and the capital requirement are set according to feedback rules. We consider a monetary policy rule by which the central bank may adjust the policy rate in response to its own lag and inflation.[14] The respective feedback coefficients are τ_R and τ_Π such that:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\tau_R}\left[\left(\frac{\Pi_t}{\Pi}\right)^{\tau_\Pi}\right]^{1-\tau_R} e_t^m, \tag{19}$$

where e_t^m represents the monetary policy shock. Thanks to full deposit insurance financed through lump-sum taxation, the policy rate and the deposit rate are identical, $R_t = R_t^D$. Macroprudential policy is given by a rule for the capital requirement that depends on credit fluctuations, such that:

$$\frac{\phi_t}{\phi} = \left(\frac{b_t}{b}\right)^{\zeta_b}. \tag{20}$$

3.4 Rest of the model

The remainder of the model is a standard New Keynesian setup. Households choose their optimal consumption and labor supply within the period, and their optimal bank deposits across periods. Within the production sector, we distinguish between final goods producers, intermediate goods producers, and capital goods producers. Final goods producers are perfectly competitive. They create consumption bundles by combining intermediate goods using a constant-elasticity-of-substitution technology and sell them to the household sector and to capital producers. Intermediate goods producers use capital and labor to produce, with a Cobb-Douglas technology, the goods used as inputs by the final goods producers. They set prices subject to quadratic adjustment costs, which introduces a New Keynesian Phillips curve in our model. Finally, capital goods producers buy the final good and convert it to capital, which they sell to the entrepreneurs. All the details on the optimization problems of these agents are extensively discussed in the online appendix.

[14] We abstract from the existence of a zero lower bound on the nominal interest rate. Rubio and Yao (2020) analyze the macroeconomic implications of macroprudential policies in the presence of a zero lower bound.

Market clearing. Consumption goods produced must equal goods demanded by households, goods used for investment, resources lost when adjusting prices and investment, as well as resources lost in the recovery of funds associated with entrepreneur and bank defaults,

$$Y_t = c_t + (1 + g_t)I_t + \frac{\kappa_p}{2}(\Pi_t - 1)^2 Y_t + \mu^F G_t^F \frac{R_t^F b_{t-1}}{\Pi_t} + \mu^E G_t^E \frac{R_t^E q_{t-1} K_{t-1}}{\Pi_t}, \tag{21}$$

where $\kappa_p > 0$ scales the price adjustment costs. Firms' labor demand must equal labor supply, $(1 - \alpha)s_t Y_t / l_t = \varphi l_t^\eta / \Lambda_t$, where $\alpha \in (0, 1)$ is the capital share in production, s_t represents real marginal costs, $\varphi > 0$ is the relative weight on labor disutility and $\eta \geq 0$ is the inverse Frisch elasticity of labor supply.

Aggregate uncertainty. The model features four exogenous disturbances: firm risk, TFP, monetary policy and discount factor shocks. Firm risk shocks follow an autoregressive process in logs, $\ln \varsigma_t^E = \rho_E \ln \varsigma_{t-1}^E + \varepsilon_t^E$, with persistence $\rho_E \in (0, 1)$. Let the parameter σ_E denote the standard deviation of the *iid* normal disturbance ε_t^E. The remaining three shocks, e_t^k, with $k = \{a, m, b\}$, also follow AR(1) processes, with autoregressive parameters ρ_k and *iid* normal disturbances ε_t^k with zero mean and standard deviations σ_k.

We are now ready to provide a formal definition of equilibrium in our economy.

Definition 1. An equilibrium is a set of allocations $\{l_t, K_t, I_t, c_t, Y_t, n_t^E, b_t, n_t^B, d_t, x_t^E\}_{t=0}^\infty$, prices $\{w_t, r_t^K, q_t, \Pi_t, s_t\}_{t=0}^\infty$ and rates of return $\{R_t^F, R_t^E, R_t^B\}_{t=0}^\infty$ for which, given the monetary and macroprudential policies $\{R_t,\ \phi_t\}_{t=0}^\infty$ and shocks $\{\varsigma_t^E, e_t^a, e_t^m, e_t^b\}_{t=0}^\infty$, entrepreneurs maximize the expected return on their investment, firms and banks maximize profits, households maximize utility and all markets clear.

4 Taking the model to the data

To investigate whether our model is suitable for policy analysis, we subject it to an impulse response matching exercise with the aim of replicating the empirical results presented in Section 2. We divide the model parameters into two groups. The first set of parameters are calibrated to match certain targets or steady state ratios; the second set are dynamic parameters that we estimate by matching our VAR impulse responses to firm risk shocks and three other macroeconomic shocks: technology shocks, discount factor shocks and monetary policy shocks. Then, we assess the overall fit of the model. In Section 5, we will use the model for a number of policy experiments.

4.1 Calibration

In line with the empirical analysis, we interpret a time period as one month. The calibration of our model parameters is summarized in Table 2. We set $\Pi = 1$ to obtain a steady state with zero inflation. The subjective discount factor β is set to 0.9967, implying a monthly

Table 2: Calibrated parameters

Value	Description	Target/Reference
$\beta = 0.9967$	Household discount factor	Nominal interest rate $R^D = 4\%$ p.a.
$\eta = 1$	Inverse Frisch labor elasticity	Christiano et al. (2014)
$\alpha = 0.4$	Capital share in production	labour share 60% of income
$\delta = 0.008$	Capital depreciation rate	10% depreciation rate p.a.
$\varepsilon = 6$	Substitutability between goods	mark-up of 20%
$\varphi = 0.63$	Weight on labor disutility	Labor supply $= l = 1$
$\chi^E = 0.0064$	Entrepreneur exit rate	Entrepreneur leverage $= qK/n^E = 2$
$\sigma^E = 0.2376$	Entrepreneur risk	Entrepreneur default rate $= F^E = 3\%$ p.a.
$\mu^E = 0.08$	Entrepreneur monitoring cost	Entrepreneur return spread $= R^E/R^D - 1 = 238$ bp p.a.
$\phi = 0.06$	Tier 1 capital requirement	Basel Accords
$\mu^F = 0.3$	Bank monitoring cost	Clerc et al. (2015)
$\sigma^F = 0.032$	Bank risk volatility	Bank default rate $= F^F = 0.9\%$ p.a.
$\chi^B = 0.0081$	Banker exit rate	Bank equity return spread $= R^B/R^D - 1 = 600$ bp p.a.
$\gamma = 0.09\%$	Bank cost of deviating from cap. req.	Average Tier 1 capital ratio = 9.62%
$\iota = 0.002$	Transfer to new entr./bankers	Gertler and Kiyotaki (2010)
$\zeta_b = 0$	Coefficient on counter. capital buffer	Baseline calibration without counter. capital buffer

risk-free (gross) nominal interest rate of 4 per cent per annum. The inverse of the Frisch elasticity of labor supply is set to $\eta = 1$, as in Christiano et al. (2014). This value lies in between the micro estimates of the Frisch elasticity, which are typically below 1, and the calibrated values used in macro studies, which tend to be above 1. As in Christiano et al. (2014), the capital share in production is set to $\alpha = 0.4$, while the depreciation rate is $\delta = 0.008$, such that 10% of the capital stock has to be replaced each year. The substitution elasticity between goods varieties is $\varepsilon = 6$, implying a gross steady state markup of $\frac{\varepsilon}{\varepsilon-1} = 1.2$ (Christensen and Dib, 2008). We normalize labor at the steady state, $l = 1$, and set the weight on labor disutility, φ, to meet this target.

Following Bernanke et al. (1999), we set (i) the ratio of capital to net worth, qK/n^E, equal to 2; and (ii) a monthly entrepreneur default rate of $F^E = 0.0025$, which corresponds to an annual default rate of 3%. We choose the fraction of realized payoffs lost in bankruptcy, μ^E, to match the spread between the return on capital and the deposit rate, R^E/R^D in the data. The spread is obtained taking the average of the spread of Gilchrist and Zakrajšek (2012a) between January 2005 and June 2020 and is equal to 238 basis points per year. As far as the banking sector is concerned, we calibrate a steady state capital requirement for banks, i.e. the ratio of equity to loans, of 6%, that is $\phi = 0.06$ in line with the Tier 1 capital requirement of the Basel Accords. Bank monitoring costs are calibrated to $\mu^F = 0.3$ as in Clerc et al. (2015).[15] Bank risk is equal to $\sigma^F = 0.032$ to target the bank default rate in the data. The banker turnover rate χ^B is calibrated at 0.0081 to target an equity return premium of 600 basis points.[16] The value of χ^B is in the ballpark of the numbers

[15] Differently from the monitoring cost related to the entrepreneurial sector, bank monitoring costs μ^F do not affect the computation of the steady state financial variables. They appear only in the aggregate resource constraint.

[16] The series of the spread is computed as the difference between the return on average equity for all US

found in the literature, e.g. Gertler and Kiyotaki (2010) and Angeloni and Faia (2013). As in Gertler and Karadi (2011), the proportional transfer to the entering entrepreneurs and bankers is set to $\iota = 0.002$. The cost of deviating from the minimum capital requirement is calibrated to 0.09% to target a ratio of bank net worth to bank assets of 9.62%, which is the average Tier 1 capital ratio observed in the data. The value of the penalty is close to the value set by Benes and Kumhof (2015) in a model without bank default. Given the capital requirement, bank leverage and bank default, the fraction of banks that pay this cost is implicitly determined.

We now report and discuss the implied financial parameters and interest rates. In our model, bank resolution costs are substantially higher than firm monitoring costs ($\mu^F > \mu^E$). This may reflect the greater opaqueness of bank balance sheets, which makes monitoring more difficult (Morgan, 2002). Moreover, the role of banks in financial intermediation suggests that the costs and externalities associated with bank failures are particularly high. For example, Kupiec and Ramirez (2013) find that bank failures cause non-bank failures and have long-lasting negative effects on economic growth. Our target for the probability of bank default F^F of 0.9% p.a. is the ratio of bank failures to the number of commercial banks over the period 1984-2015 as reported by the Federal Deposit Insurance Corporation.[17] Alternative proxies for F^F exist. De Walque et al. (2010) use the Z-score method to compute the probability that banks' own funds are not sufficient to absorb losses, which yields 0.4% p.a. If we count bank *closings* rather than failures, we find a rate of 2.7% p.a. in US data.[18] Our value therefore lies in between these two estimates. The bank equity ratio is set to 9.62%, a value close to that in Gerali et al. (2010).

The risk-free rate corresponds to the deposit rate R^D and to the policy rate R and it is equal to 4% per year at the steady state. The realized return on bank loans R^F is equal to 4.69% per year at the steady state. This return contains a discount which is related to the monitoring cost that the bank must incur when an entrepreneur declares default. The next higher rate of return is the return on capital, R^E, which equals 6.47% per year. The return on capital is higher than the realized loan return R^F, because it needs to compensate the entrepreneur for running the risk of default while it is not reduced by the monitoring cost. Finally, the return on equity earned by bankers R^B is equal to 10.24% at the steady state. This value exceeds the realized loan return, because it contains a compensation to bankers (or equity holders) for the risk of bank default.

4.2 Minimum distance estimation and model fit

The model's dynamic parameters are estimated by minimizing the distance between the model-predicted impulse responses to shocks and their empirical VAR counterpart, where

banks and the 10-Year treasury constant maturity rate.

[17] The annual number of bank failures in the US, starting in 1936, can be downloaded from `www.fdic.gov`.

[18] Bank closings are downloaded from the Bureau of Labor Statistics Business Dynamics database, `https://www.bls.gov/bdm/`. The industry considered is 'Credit intermediation and related activities'.

the weights are the inverse of the variance of the responses (see e.g. Christiano et al., 2005).

Table 3: Estimated parameters

Symbol	Description	Estimate
Adjustment costs		
κ_p	Price adjustment cost	2882.9
κ_I	Investment adjustment cost	6.5122
Monetary policy rule		
τ_R	Coefficient on lag policy rate	0.8621
τ_Π	Coefficient on inflation	1.3188
Shock processes		
σ_E	Size firm risk shock	0.0894
ρ_E	Persistence firm risk shock	0.8893
σ_a	Size TFP shock	0.0032
ρ_a	Persistence TFP shock	0.9800
σ_m	Size monetary policy shock	0.0068
ρ_m	Persistence monetary policy shock	0.3496
σ_b	Size discount factor shock	0.0003
ρ_b	Persistence discount factor shock	0.8693

The estimate of the Rotemberg price adjustment cost parameter, κ_p, is equal to 2883, which corresponds to a price duration of around 2 years in the Calvo model of staggered price adjustment; this value is in line with previous estimates for the United States (see e.g. Del Negro et al., 2015; Villa, 2016).[19] The investment adjustment cost parameter, κ_I, is estimated at 6.5 and it falls in the credible interval found by Smets and Wouters (2007).

The coefficients of the monetary policy rule on the lagged policy rate and inflation are 0.86 and 1.32, respectively. The inflation coefficient is at the lower end of the range of the values suggested by Taylor (1999) and Gertler and Karadi (2011).

The size and persistence of risk shocks are estimated at 0.089 and 0.889. The TFP shocks are the most persistent, with an AR(1) coefficient of 0.98, while the monetary policy shocks exhibit lower inertia, with $\rho_m = 0.35$.

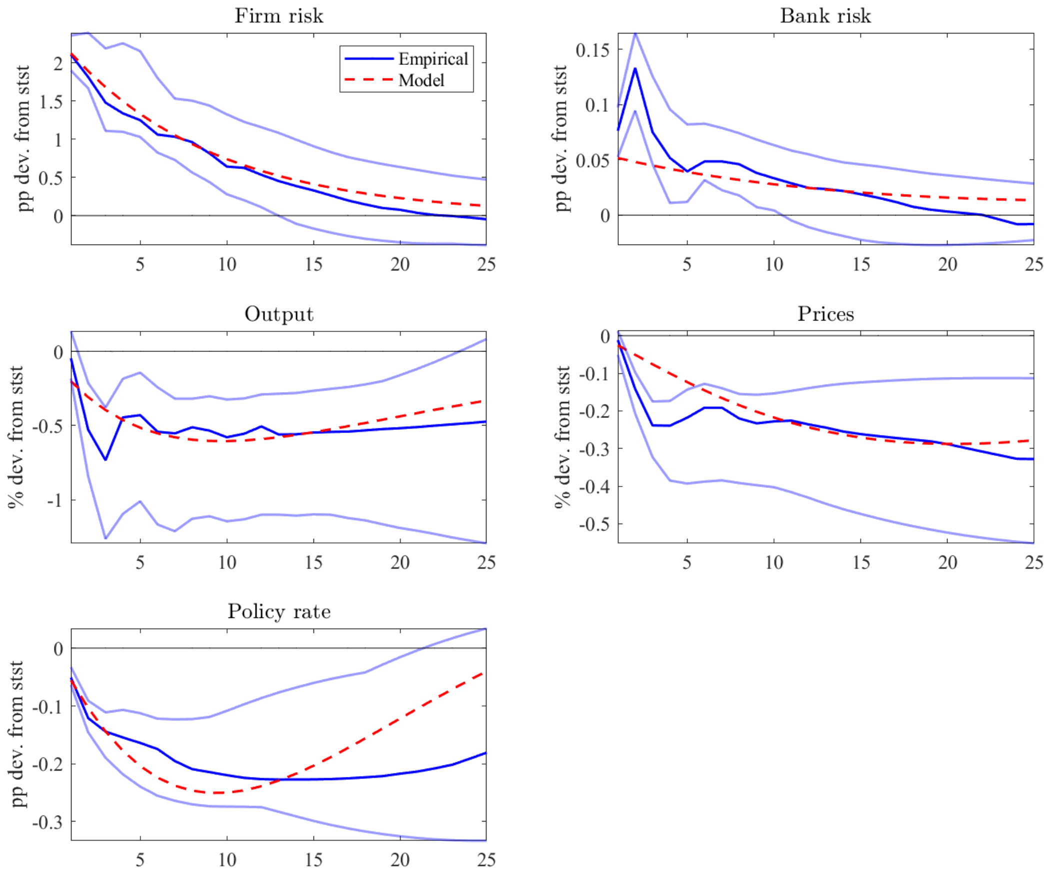
As shown in Figure 4, the baseline model can reasonably match the empirical impulse responses to the firm risk shock.[20] In particular, the persistence of firm risk in the model is very close to that in the data. In addition, the dynamics of output and the policy rate in the model fall in the confidence band of the VAR estimates. The impulse responses for prices generated by the DSGE model display a smoother and more gradual decline following the shock, whereas the VAR-based responses exhibit a more pronounced initial drop within

[19] For the algebraic relationship between the Rotemberg and the Calvo parameter, see Cantore et al. (2014).

[20] A comparison of the model-implied and VAR-based impulse responses to TFP, monetary policy, and discount factor shocks is reported in the online appendix, Section 3.3.

the first two months. Beyond this initial period, the responses from the model and the VAR closely align, with negligible differences observed over the subsequent two-year horizon.

Figure 4: Model and VAR impulse responses to firm risk shock



Notes. The light blue lines denotes the 95% bootstrap confidence interval.

5 Policy analysis

This section discusses the effects of bank fragility and capitalization on the transmission of firm risk shocks. First, we describe the steady state implications of capital requirements.[21] Second, we analyze the transmission of risk shocks in the baseline model, which is meant to capture the current regulatory framework. Third, we compare the predicted impulse responses to the ones generated by variants of the model with different macroprudential policies in action.

[21] Details on the steady state computation, as well as a graphical illustration, are provided in the online appendix.

5.1 Steady state implications of capital requirements

To comply with the higher capital requirement, banks reduce their loan supply and increase their capital ratio. As shown by equation (9), the fall in leverage decreases the bank default threshold $\overline{\omega}^{Fi}_{t+1}$, thereby decreasing the bank default rate. At the same time, the decrease in lending lowers firm leverage and thus the risk of firm failures.

The cost threshold $\overline{\omega}^{\phi i}_{t+1}$ in (11) is affected by two countervailing forces. On the one hand, there is a direct positive effect of the capital requirement on the cost threshold. On the other hand, since the bank default threshold declines with a higher capital requirement, this leads to a drop in the cost threshold. The second effect is larger, such that the probability of banks paying the cost of deviating from the minimum capital requirement decreases with a higher capital requirement.

A higher capital requirement has implications for real activity at the steady state. First, by reducing bank and firm defaults, the associated default costs are lower. We refer to this effect as the *default risk channel*. Second, it decreases loan supply and entrepreneurs' financial resources, thereby decreasing investment. Lower long-run investment leads to lower production, consumption, and output. We refer to the latter mechanism as the *bank equity channel*. As we raise the capital requirement, the amount of output that is lost due to defaults falls. However, consumption and investment fall, too. Only when the capital requirement is very low does a further decline in ϕ lead to a fall in consumption caused by the sharp increase in bank defaults.

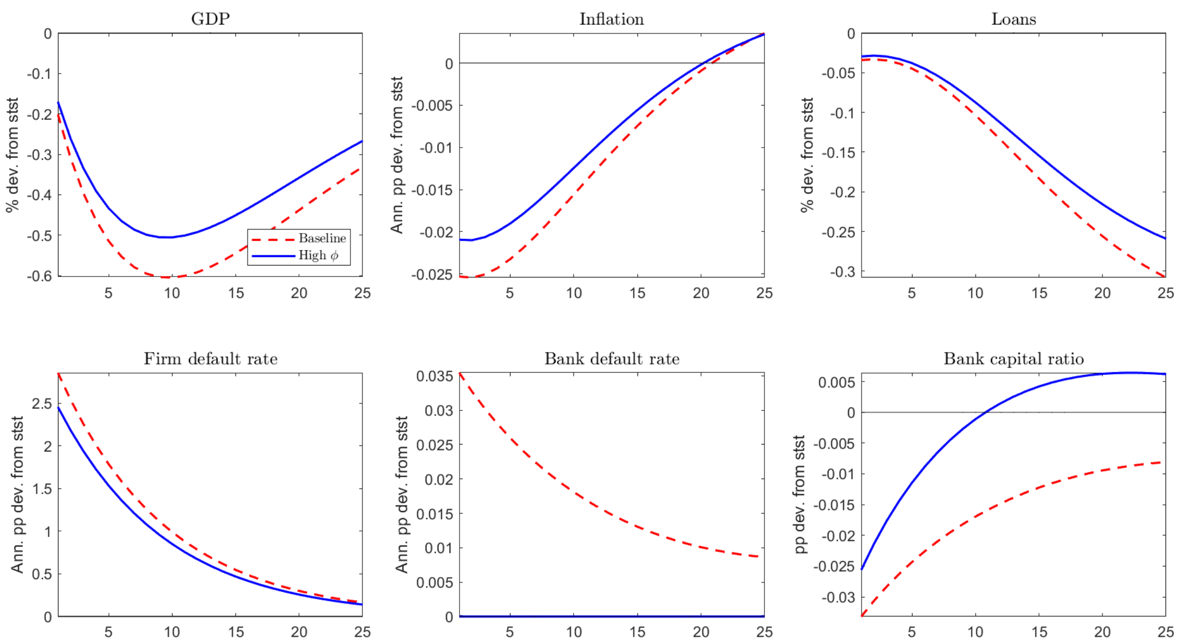
These results highlight a trade-off inherent in the capital requirement due to the simultaneous effects of the default risk channel and the bank equity channel. Increasing the policy instrument, on the one hand, increases the stability of the banking sector. The lower bank defaults imply that fewer resources are diverted away from consumption. On the other hand, banks provide less credit to entrepreneurs. This leads to a lower equilibrium level of capital, output and consumption.

5.2 Transmission of firm risk: baseline calibration

An exogenous one-standard-deviation increase in firm risk, plotted in Figure 5, implies that investment projects become riskier and firms are thus more likely to default. The annual default rate of firms rises by about 3 percentage points. Due to higher firm defaults, banks face higher losses, bank equity falls and the bank default rate rises. The fall in equity is larger than the fall in loans and the bank capital ratio decreases.[22] The external finance premium (or firm risk spread) rises and entrepreneurs reduce their investment demand. As investment falls, so do both output and inflation: we observe a demand-driven downturn. The central bank reacts by cutting the policy rate.

[22] The impulse responses of investment, the deposit rate and the external finance premium are available in the online appendix.

Figure 5: Impulse responses to a firm risk shock: baseline vs. high capital ratio ϕ



Notes. Impulse response functions to a one-standard-deviation increase in firm risk under two alternative regulatory frameworks: baseline model (dashed lines) and model with substantially higher capital requirement (solid lines). In the second framework, the capital requirement is set to $\phi = 14\%$.

5.3 Effectiveness of macroprudential policy instruments

We next consider the effects of macroprudential policy on the propagation of firm risk shocks. First, we study the implications of policies affecting bank leverage. One policy tool that affects bank leverage directly is a (substantially) higher minimum capital ratio as proposed by Admati and Hellwig (2013).

Second, we discuss the role of countercyclical capital buffer policies in combination with time-invariant capital requirements. This policy approach has been proposed within the Basel III regulations and has been adopted by several countries, see Alam et al. (2019). Notably, this type of policy has also been investigated by Clerc et al. (2015), Angeloni and Faia (2013) and Elenev et al. (2021). Clerc et al. (2015) find that countercyclical capital buffer policies can potentially destabilize the banking sector. In contrast, Angeloni and Faia (2013) and Elenev et al. (2021) find that such policies can reduce volatility in investment and output.

High(er) minimum capital requirements. The activation of bank capital requirements involves a trade-off between macroeconomic and financial stability. While, following a firm risk shock, they reduce bank risk-taking and government bailouts through the default risk channel, they also decrease credit provision through the bank equity channel. When firm default risk rises, the number of non-performing loans increases, leading to a reduction in bank equity. To comply with the capital regulations, banks are required to decrease their loan supply, potentially exacerbating the recessionary effects of the shock.

Figure 5 compares the impulse responses of our baseline economy (dashed lines) with an economy that essentially eliminates bank default by means of a sufficiently high minimum capital requirement (solid lines). More specifically, the capital requirement is set to 14%, the highest possible value in this model as higher values give rise to unstable equilibria. This parametrization implies that no banks default in equilibrium.

High minimum capital ratios effectively insulate the banking sector from a wave of corporate insolvencies, as the default rate of banks no longer responds to firm risk shocks. The bank capital ratio declines less than in the baseline scenario and even rises above steady state in the medium term before going back to its pre-shock level. Hence, high capital requirements are effective in preserving financial stability. By avoiding a contraction in loan supply that is due to bank defaults, high capital requirements mitigate the reduction in borrowing following a firm risk shock. Compared to the baseline model, investment falls by less, resulting in a smaller decline in GDP, inflation, and the policy rate.[23] However, as Figure 5 demonstrates, high capital requirements alone do not substantially stabilize the business cycle, in line with the findings by Conti et al. (2023).

In the following section, we analyze the effectiveness of a countercyclical capital buffer – activated jointly with high minimum capital requirements – in providing macroeconomic stabilization while safeguarding financial stability.

Countercyclical capital buffer (CCyB). The Basel III policy recommendation of a countercyclical capital buffer prescribes a rise in the capital requirement in response to a rise in the credit-to-GDP gap above a certain threshold, see Basel Committee on Banking Supervision (2010a,b).[24] We introduce such a policy by allowing the bank capital requirement to respond countercyclically to changes in borrowing, such that $\zeta_b > 0$ in the macroprudential rule (20). As there is no clear definition of credit-to-GDP gap in our model, we proxy this concept with credit fluctuations.

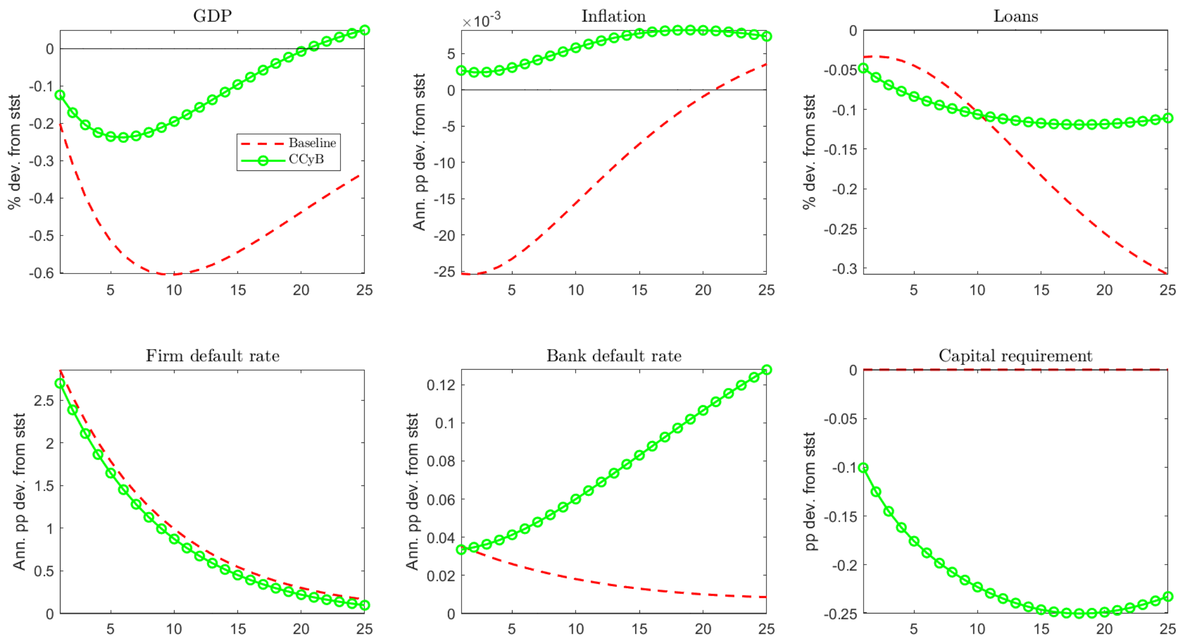
Figure 6 shows that a countercyclical capital buffer (solid lines with circles) is effective in dampening the negative effects of a firm risk shock on the macroeconomic variables, as in Angelini et al. (2014). In this exercise, the countercyclical capital buffer coefficient is set to $\zeta_b = 34.97$. This value implies that the capital requirement ϕ_t drops by 0.25 percentage points at its trough in response to a risk shock.[25] The drop in investment, output and inflation is reduced when the CCyB is activated. This is because the reduction in the capital requirement allows banks to lend more than if the CCyB coefficient were zero. As a result, the drop in loans and investment is reduced. Finally, the joint behavior of inflation and the policy rate implies that the real interest rate increases by less in response to the

[23] The impulse responses of investment and the deposit rate for the exercises in this section are available in the online appendix.

[24] Tente et al. (2015), p.14, discuss how the countercyclical capital buffer rate is computed for Germany.

[25] According to the iMaPP database of macroprudential policy actions, 0.25pp is a typical step size for the CCyB (Alam et al., 2019).

Figure 6: Impulse responses: baseline and CCyB



Notes. Impulse response functions to a one standard deviation increase in firm risk under two alternative regulatory frameworks: baseline model (dashed lines), model with CCyB (solid lines with circles).

shock, thereby reinforcing the stabilization effect induced by the countercyclical capital requirement. However, Figure 6 reveals a drawback of the CCyB: bank fragility increases in this case of low capital requirement. The rise in bank defaults due to a risk shock is stronger when a CCyB is in place because banks increase their leverage to a larger extent to provide loans to entrepreneurs in this case of low capital requirements.

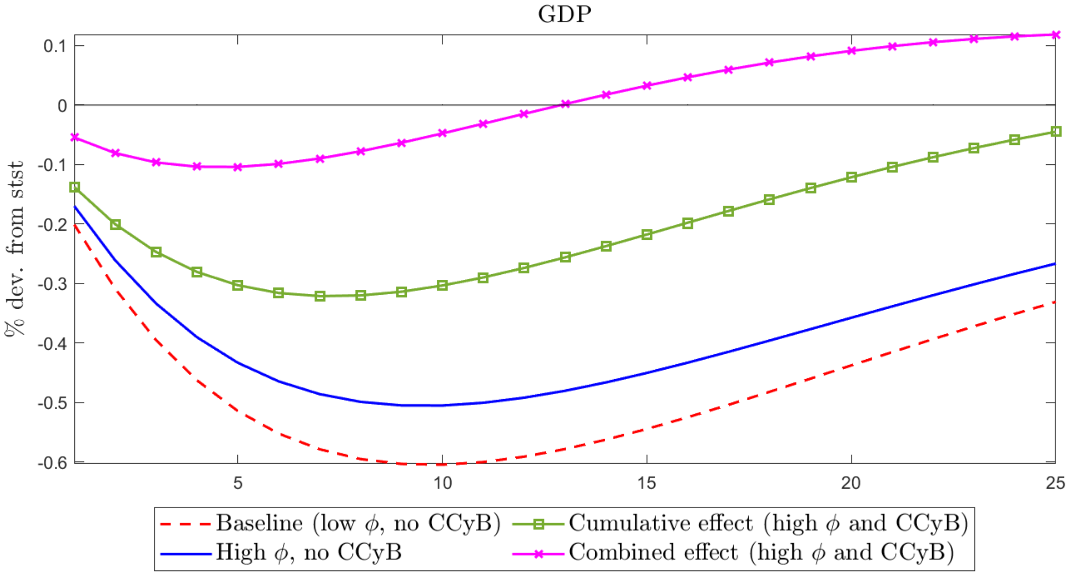
Figure 7 shows that high capital requirements and a countercyclical capital requirement are complementary. The solid line with squares depicts the hypothetical response of output under high capital requirements and a countercyclical capital buffer, without any interaction between the two policies. This curve is obtained by simply adding the gains of introducing a countercyclical capital buffer in the baseline model to the model with high capital requirements and no CCyB. The solid line with crosses depicts the model response of output when the two policies are both in place. The figure reveals that the drop in output is dampened when the two policies interact, implying that they are complementary. The joint effect is stronger than the combined effect of the two policies enacted separately.

High capital requirements increase bank stability but decrease firms' access to financial resources in downturns. A countercyclical capital requirement allows firms to have access to financial resources during downturns but increases bank default risk. The joint implementation of these two policies alleviates this trade-off.[26]

In summary, our findings suggest that while high capital requirements can help stabilize

[26] This result is shock-specific. In the online appendix, we show that it holds also in response to technology shocks but not in response to monetary policy or demand shocks.

Figure 7: Complementarity of high capital requirements and CCyB



Notes. Impulse response functions to a one-standard-deviation increase in firm risk under four alternative regulatory frameworks: baseline model (dashed line), model with substantially higher capital requirements and no CCyB (solid line), hypothetical scenario that adds the gains of introducing a countercyclical capital buffer in the baseline model to the model with high capital requirements and no CCyB (solid line with squares) and model with both CCyB and substantially higher capital requirements (solid line with crosses). In the third and fourth frameworks, the CCyB parameter is set to $\zeta_b = 12.35$. This value implies that the capital requirement ϕ_t drops by 0.25 percentage points at its trough in response to a risk shock in the model with CCyB and substantially higher capital requirements.

the financial sector, this policy may not be sufficient to mitigate the adverse consequences of firm risk shocks on the macroeconomy. Releasing a countercyclical capital buffer, in addition to a sufficiently high capital requirement, is effective in dampening the fluctuations in real variables, thereby alleviating the trade-off between macroeconomic and financial stability.[27]

Robustness. The results presented in the previous sections are robust to different specifications. First, we examine whether our results hold in a simpler model featuring flexible prices. There is often a debate on whether a simple real business cycle model could explain the transmission mechanisms better than a more complicated nominal model. Section 3.9 of the online appendix shows that the presence of price rigidity is important in explaining the magnitude of the response of output to a firm risk shock. Moreover, our main policy result holds also under flexible prices: neither high capital requirements nor the CCyB alone can mitigate the adverse effects of a firm risk shock. The two policies are complementary and, when implemented together, can effectively stabilize the economy.

[27] There is a recent strand of literature stressing that banks may indeed be reluctant to use their buffers for a variety of reasons: market stigma, uncertainty related to potential future losses, and uncertainty on supervisory expectations regarding the restoration of any buffer (Hernandez de Cos, 2021). An appropriate setting to study this issue could be a standard organic CET1 capital generation model and an equity valuation model as in Abad and Pascual (2022).

Secondly, we investigate whether our results depend on the specification of the debt contract between banks and entrepreneurs. Section 3.10 of the online appendix shows that all the results of our paper hold when we stipulate real debt contracts instead of nominal ones.

In our model, we assume that bank liabilities are subject to full deposit insurance. All our results go through if we remove this assumption and allow depositors to suffer losses on their return on deposits when banks fail. The results can be found in Section 3.11 of the online appendix.

We finally check whether our results are robust to a different specification of the CCyB rule. We allow the capital requirement to respond to credit growth instead of to deviations of credit from steady state, in the spirit of Christiano et al. (2010). Our results survive this change, as reported in Section 3.12 of the online appendix.

6 Conclusion

During recessions such as the Covid-19 crisis with the lockdown measures, many firms are faced with an increased risk of default. In this paper, we provide an empirical and theoretical analysis of the transmission of firm risk shocks in the presence of the banking sector.

In a vector autoregression estimated on US data, an exogenous increase in firm risk increases bank risk spreads and decreases output and inflation. To capture these observed dynamics, we develop a sticky-price business cycle model with leveraged firms and banks, building on Clerc et al. (2015). We operationalize the model by setting some of the parameters to target macro-financial data moments and estimate others via impulse response matching. The model performs well at replicating the empirical impulse responses, not only to firm risk shocks but also to demand, technology and monetary policy shocks.

With our carefully parameterized model at hand, we demonstrate that high minimum capital requirements are effective in reducing bank failures. This *default risk channel* supports credit and investment. A drawback of high capital requirements, however, is that they decrease banks' capacity to provide credit to firms. This *bank equity channel* has a negative effect on credit and investment. The release of a countercyclical capital buffer (CCyB) can help reduce the contraction in lending through the bank equity channel. The main takeaway from our analysis is that the joint activation of a high capital requirement and a CCyB is effective for macroeconomic stabilization. The two policies are complementary as the CCyB allows firms to have access to financial resources during downturns and the high capital requirement prevents a rise in bank defaults.

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