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Long-term loans and capital requirements in universal banking: Sectoral spillovers and crowding out effects

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Long-Term Loans and
Capital Requirements in Universal Banking:
Sectoral Spillovers and Crowding Out Effects

by Thomas Lejeune and Jolan Mohimont



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Abstract

We extend the reference DSGE model used for policy analysis at the NBB with a financial sector, by incorporating multi-period fixed-rate corporate and mortgage loans, an imperfect pass-through from policy rates to the deposit rate, and bank capital requirements. Adding multi-period fixed-rate loans amplifies the propagation of default risks and strengthens the effectiveness of macroprudential policy. This amplification operates through a bank capital channel and a market timing effect that delays borrowing and investment when rates are expected to fall. The bank capital channel also propagates shocks across sectors, and amplifies the effects of monetary policy when the duration of banks' assets is larger than that of their liabilities. With universal banks, that grant both corporate and mortgage loans, sectoral prudential policy instruments can have unintended consequences on credit supply in the untreated sector. These crowding out effects increase with the loan duration in the treated sector and decrease with the risk weight differential between the treated and untreated sectors. Finally, we apply our model to the mortgage risk weight add-on introduced by the NBB in 2013.

Keywords: Macroprudential policy, credit risks, loan maturity, financial accelerator, sectoral spillovers, unintended consequences, DSGE.

JEL Codes: E3, E44, E5, G21.

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Non-technical summary

Since the Global Financial Crisis (GFC), it has become evident that financial frictions significantly influence the propagation of macroeconomic shocks and that the financial sector itself can be a source of disturbances for the real economy. In response to the GFC, global policies like Basel III were implemented to enhance the resilience of the financial system. In this context, tools such as the New-Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model have been developed to analyze macro-financial developments and macroprudential policies.

This paper extends the NK-DSGE model of the NBB, BEMGIE, to financial frictions and macroprudential policies. Inspired by an extensive body of literature, this extension features entrepreneurs and homeowners who can default on their loans, exposing banks to credit default risks. Moreover, interest rates are fixed in nominal terms for the entire life of the contract, exposing banks to interest rate risks, which may be attenuated by rigid deposit rates. To manage these risks, regulators set minimum capital requirements and impose penalties on banks that fail to meet these rules. Banks hold precautionary buffers to mitigate the risk of breaching these requirements, with the resulting costs passed on to borrowers, creating a bank capital channel. In times of distress, this channel can be alleviated by macroprudential policy, such as the relaxation of countercyclical capital buffers.

The paper departs from existing literature by explicitly modeling long maturities and fixed interest rates typically associated with corporate and mortgage loans in practice. It shows that multi-period fixed-rate loans amplify the effects of borrower risk shocks and macroprudential policies through the bank capital channel and a market timing effect (where borrowers delay borrowing and investment when lending rates are expected to fall). Compared to traditional models with one-period loans, raising capital requirements imposes higher transition costs on banks because they can only adjust interest rates on new loans, not on existing ones. However, easing capital requirements during financial stress helps mitigate financial acceleration more effectively in the multi-period setting.

Additionally, the model highlights the implications of an imperfect pass-through from policy rates to deposit rates for the transmission of monetary policy in the presence of the bank capital channel and the interest rate risk faced by banks. A limited sensitivity of deposit rates to the policy rate provides a natural hedge against interest rate risk. In contrast, a significant duration mismatch between banks' assets and liabilities amplifies the effects of monetary policy shocks.

Finally, the model is populated with universal banks that provide both corporate and mortgage loans, leading to significant sectoral spillovers through the bank capital channel. For example, an increase in mortgage defaults can lead to higher lending rates for entrepreneurs and reduced corporate lending and investment. Similarly, sectoral prudential policy instruments can have unintended consequences for non-targeted sectors, with crowding out effects that increase with loan duration and the difference in risk weights between sectors. That said, it is important to note that these measures also fulfill their primary purpose within our universal banking framework. As a practical example, the model is applied to the mortgage risk weight add-on introduced in Belgium in 2013, demonstrating its potential impact on bank behavior and credit supply across sectors. It is found that the measure encouraged banks to increase their capital buffers with only a minor impact on new mortgage rates and volumes.

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1 Introduction

Since the Global Financial Crisis (GFC), it has become clear that financial frictions have a genuine effect in the propagation of macroeconomic shocks and that the financial sector itself can be a source of disturbance for the real economy. In response to the GFC, policies were implemented around the world to improve the resilience of the financial system (Basel III). In Belgium, new tasks were assigned to the National Bank of Belgium (NBB) in terms of macroprudential supervision. In this context, tools have been developed to analyze macro-financial developments and macroprudential policies. The New-Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model is an important part of this new policy toolkit used for macro-financial policy analysis. While the first generation of NK-DSGE models initially focused on macroeconomic developments, substantial efforts have been made since the GFC to model the financial system. NK-DSGE models are now used to study the effects of financial shocks and the interactions between the financial cycle, macroprudential policies, monetary policies, and the macroeconomy. In this context, the multi-country NK-DSGE model of the NBB, BEMGIE (Belgian Economy in a Macro General and International Equilibrium model, [de Walque et al., 2023](#)), is a natural starting point to incorporate a detailed financial sector for macro-financial analysis.

In this paper, we extend the Belgian block in BEMGIE with a banking sector that faces interest rate and credit default risks and must comply with capital requirements. Inspired by the 3D model of [Clerc et al. \(2015\)](#), we assume that entrepreneurs and homeowners can default on their NFC and mortgage loans, opening a borrower leverage channel as originally proposed by [Bernanke et al. \(1999\)](#) for entrepreneurs and applied to the mortgage segment by [Aoki et al. \(2004\)](#).¹ In addition, interest rates are fixed in nominal terms for the entire life of the contract (e.g., [Christiano et al., 2004](#) and [Christensen and Dib, 2008](#)). This implies that banks are exposed to interest rate and default risks, which is empirically relevant and gives a non-trivial role to the banking sector. To ensure that banks can manage these risks, regulators set minimum capital requirements (as in Basel III) and impose penalties on banks that fail to meet these rules. Following [Beneš and Kumhof \(2015\)](#), banks hold precautionary buffers to mitigate the risk of breaching minimum capital requirements, and the resulting capital costs are passed on to their borrowers, opening a bank capital channel. In times of distress, however, this bank capital channel can be alleviated by macroprudential policy

¹ BGG build on the agency problem originally proposed by [Townsend \(1979\)](#). They assume the existence of asymmetric information and costly monitoring in the relationship between banks and their borrowers such that an external finance premium endogenously emerges.

(e.g. a relaxation of counter-cyclical capital buffers), helping banks navigate the challenging financial environment.

We depart from this literature along several dimensions to better reflect actual practice in the banking sector. Although the model is calibrated to Belgian data, we believe that these additional features are also relevant for other economies. First, while the above literature focuses exclusively on short-term loans, we explicitly model the long maturities and fixed interest rates typically associated with NFC and mortgage loans. Inspired by [Beneš and Lees \(2010\)](#), we assume that bank loans are repaid in an infinite number of geometrically decaying payments, which allows us to easily calibrate the durations observed in bank balance sheets.

We show that the empirically relevant addition of multi-period loan with fixed interest rates amplifies the effects of borrower risk shocks and of macroprudential policies through the bank capital channel and a market timing effect. In a one-period loan model, an unexpected increase in the default rate affects bank profitability for only one period – even if the shock is persistent – as banks quickly adjust their interest rates to higher default risks. In the case of multi-period fixed-rate loans, banks can only adjust their spreads on new loans, not on the outstanding amount of previously issued loans. Banks thus incur losses over more than one period, which weighs on their capital position and amplifies the effect of borrower risk shocks.

This stronger bank capital channel with multi-period fixed-rate loans also reinforces the effects of macroprudential policy. On the one hand, it increases the transition costs of raising capital requirements, because it is more difficult for banks to adjust to higher capital requirements if they can only adjust the interest rate they charge on their new loans, rather than on the full outstanding amounts as in models with one-period debt or flexible interest rates. On the other hand, easing capital requirements in times of financial stress mitigates the financial acceleration that operates through the bank capital channel more than in a model with one-period loans.

In addition, our multi-period fixed-rate loan model generates a market timing effect that significantly affects the dynamics of borrowing and investment. When the bank lending rate is expected to fall - for example, when it returns to steady state after a temporary rise - there is an incentive to postpone borrowing and investment to avoid locking in the high current interest rates. This market timing effect amplifies the impact of risk shocks and macroprudential policies. Moreover, it pushes down credit volumes after a monetary tightening,

in line with the credit channel of monetary policy (Bernanke and Gertler, 1995; Altavilla et al., 2019) and with the empirical evidence presented in Peersman (2011) for the euro area. This is different from the positive short-term response of credit generated by a one-period counterfactual, which replicates well the findings of Beneš and Kumhof (2015).

The literature surveyed in detail in de Bandt et al. (2024) has so far mostly focused on one-period loans, where lending rates are sometimes assumed to be sticky (e.g., Gerali et al., 2010; Darracq Pariès et al., 2019). While both the sticky-rate and the multi-period loan frameworks can generate similar dynamics for the average lending rate, our multi-period loan framework has the advantage of properly distinguishing the lending rate on new loans from that on the outstanding amounts. This distinction implies that we can capture the dynamics of the average lending rate on the outstanding amount – which is crucial for the bank capital channel – and of the lending rate charged on new loans – which affects current investment decisions and interacts with the market timing effect. A few other papers consider multi-period fixed-rate loans (e.g., Andreasen et al., 2013; de Bandt and Chahad, 2016; Bluwstein et al., 2020). However, they do not model the interactions between the bank capital channel, macroprudential regulations, and multi-period NFC and mortgage loans as we do in this paper.

A second distinctive feature of our model is the imperfect pass-through from policy rates to the deposit rate. This imperfect pass-through has important implications for the transmission of monetary policy through the bank capital channel (Drechsler et al., 2017) and for the interest rate risk faced by banks (Drechsler et al., 2021). Indeed, the limited sensitivity of deposit rates to market rates provides a natural hedge against the interest rate risk associated with long-maturity loans. It is well known that deposits resemble long-term debt. In fact, banks evaluate the duration of their non-maturity deposits with statistical models in their asset and liability management strategies, and these statistics are closely monitored by regulators. In our framework, we can easily use these statistics to match the duration of bank deposits and discuss the impact of a potential duration mismatch on bank balance sheets.

During the recent episode of monetary tightening, Belgian deposit rates adjusted unexpectedly slowly compared to lending rates, which benefited Belgian banks (NBB, 2024). When the adjustment of rates on the side of banks' liabilities is not faster than the ones on banks assets, the model predicts no amplification through the bank capital channel.

However, the specific nature of this episode – which followed a prolonged period of negative policy rates accompanied by a large inflow of sticky savings deposits – implies that different outcomes cannot be ruled out in the future. There is also considerable uncertainty in estimating the duration of non-maturity deposits, and external factors (e.g. the rise of fintech, the government’s issuance of a competitive bond) could change the sensitivity of deposit rates to market rates. Although banks actively manage maturities and use hedging instruments to reduce their exposure, they cannot completely eliminate all the interest-rate risk to which they are inherently exposed (e.g., [Paul, 2023](#)). Moreover, as illustrated by [Coulier et al. \(2024\)](#), the recent increase in interest rates has triggered a shift from overnight deposits – which behaviorally have a relatively long duration – to more rate-sensitive term deposits. This shift is shown to largely be unexpected by banks, to widen the duration gap (net of hedging) between banks’ assets and liabilities, and to impact their lending behavior towards non-financial corporations. In this context, it is crucial to understand the potential consequences of a duration mismatch.

We show that a duration mismatch between banks’ assets and liabilities amplifies the effects of monetary policy shocks through the bank capital channel. In the aftermath of a contractionary event, additional pressure arises when banks’ lending rates adjust more slowly than the cost of their liabilities. As a result, bank capital declines to a greater extent than in a one-period loan setup. Such a larger decline in bank capital translates into a larger increase in the bank rate charged on new loans, which affects the investment decisions of entrepreneurs and homeowners. This exercise highlights the importance of monitoring banks’ exposure to interest rate risk.

A third feature of our model is that it is populated with universal banks that take deposits and provide both NFC and mortgage loans. This assumption is consistent with the actual practice of Belgian banks, but differs from the 3D model, which assumes that banks specialize in a particular credit segment. In the presence of universal banks, sectoral spillovers are sizeable. For example, an increase in mortgage defaults leads to an increase in the lending rate charged to NFCs and to a reduction in NFC lending and investment. We also show that these spillovers operate through the bank capital channel and increase with the loan duration.

Finally, we show that in the presence of universal banks, sectoral prudential policy instruments can have unintended consequences for the non-targeted sector of the economy.

Universal banks have the opportunity to comply with stricter sectoral regulation by reducing lending to the sector of their choice. In our framework, universal banks find it optimal to spread the burden of a sector-specific shock – such as an increase in mortgage risk weights – across the two credit segments. These unintended crowding out effects increase with the loan duration and with the difference in risk weights between the non-targeted (e.g., NFCs) and targeted (e.g., mortgages) sectors. That said, one should not overlook that these measures also achieve their primary objective in our universal banking setup. For example, our model suggests that the mortgage risk weight add-on introduced by the NBB in 2013 encouraged banks to increase their capital buffers at the cost of a small response in new mortgage rates and loan volumes, in line with the empirical study by [Ferrari et al. \(2017\)](#).

The structure of the paper is as follows. In Section 2 we describe our model. Section 3 presents the calibration. We illustrate the financial channels of the model with a reporting of macro and financial dynamics after a monetary policy shock and a borrowers' risk shock in Section 4. Finally, two macroprudential experiments on the CCyB and sectoral risk-weights are documented in Sections 5 and 6.

2 Model

Our model extends BEMGIE with a fully-fledged financial sector in the Belgian economy. The standard BEMGIE model, described in details in [de Walque et al. \(2023\)](#), is a multi-country New Keynesian DSGE setup featuring three fully-fledged blocs: Belgium, the euro area and the United States. The rest of the world appears under the form of exogenous shocks. The domestic core of the modelled blocs in BEMGIE follows closely [Smets and Wouters \(2007\)](#) and presents thus many of the characteristics found relevant in the empirical DSGE literature to fit the data: among others, habits in consumption, adjustment costs in investment, price and wage rigidities and indexation. The open economy dimension is designed with a special attention to the inclusion of imported inputs and energy in production, the import content of exports and mechanisms that limit the pass-through of volatile external variables –such as exchange rate and oil prices – to domestic variables. Belgium is modelled as a small open economy inside a monetary union, and thus shares the nominal interest and exchange rate with the (rest of) the euro area. The Belgian economy is assumed to be too small to generate significant spillovers on the other regions of the model. The dynamics of the euro area, the US, and the rest of the world are detailed in [de Walque et al. \(2017, 2023\)](#).

To enrich the model with financial frictions, we introduce four new categories of agents: (1) entrepreneurs, (2) homeowners, (3) banks, and (4) a prudential authority. We refer to [de Walque et al. \(2023\)](#) for the behaviors of domestic households, firms, and the government and detail here the ones of the new agents. Compared to the standard BEMGIE, there are two differences regarding the behavior of households. First, they do not invest in physical capital and housing stocks, as these tasks are now performed by entrepreneurs and homeowners. Second, they hold an exogenously given stock of bank deposits.

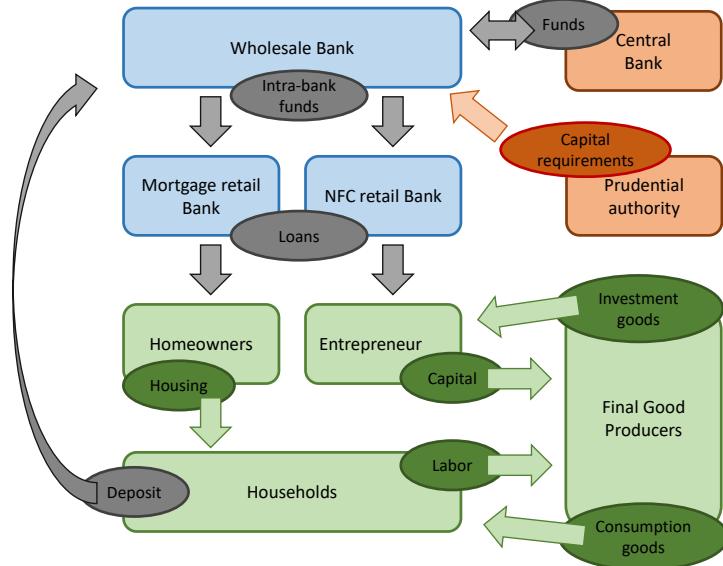


Figure 1: Overview of the structure of the model

Figure 1 shows how the new agents interact with domestic households, firms, and public authorities. The bank consists in a wholesale unit and two sector-specific retail units. The wholesale bank manages the bank capital and faces capital requirements set by a prudential authority. It combines the bank net worth with households' deposits and central bank funding to finance the retail units. Retail banks grant multi-period loans to entrepreneurs and homeowners. Those borrowers finance their investments in productive capital and housing with a combination of bank loans and their own funds. They rent the stock of productive capital and housing services to firms and households, respectively. In what follows, we detail our assumptions regarding these four new categories of domestic agents.

2.1 Entrepreneurs

Entrepreneurs finance their investments in productive capital with a combination of bank loans and their own funds. Bank loans are multi-period contracts with fixed interest rates. Entrepreneurs face aggregate and idiosyncratic risks to the returns on their investment, which affect their ability to repay their loans obligations. Figure 2 summarizes the sequence of entrepreneurs' decisions within each period. We describe the different stages, highlight the differences between our setup and the original BGG framework and solve the entrepreneurs' optimization problem in what follows.

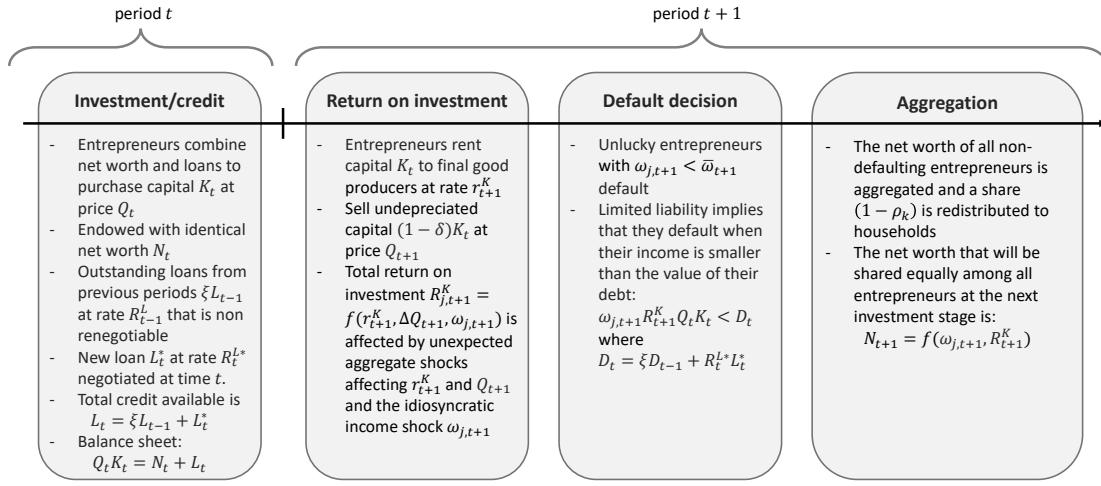


Figure 2: Sequence of entrepreneurs' decisions within each period

Investment and credit stage. We begin by presenting the last stage of period t that corresponds to the start of an investment project. At the end of every period t , entrepreneurs purchase the stock of productive capital K_t at price Q_t . Their liabilities consist in a combination of bank loans L_t^k and their own net worth $N_{j,t}^k$. The balance sheet of an entrepreneur j is thus given by:

$$Q_t K_{j,t} = L_{j,t}^k + N_{j,t}^k \quad (1)$$

Entrepreneurs have access to multi-period loans repaid in an infinite number of geometrically decaying payments as in Beneš and Lees (2010). A loan $L_{j,t}^{k,*}$ taken at time t is paid back in repayments proportional to the amount borrowed and decays at a fixed rate $\xi \in (0, 1)$. The principal repayment consists of a fraction $(1 - \xi)$ of the residual outstanding amount.

Thus, the outstanding amount of a loan $L_{j,t}^{k,*}$ granted at time t is $\xi L_{j,t}^{k,*}$ at time $t+1$, $\xi^2 L_{j,t}^{k,*}$ at time $t+2$, and $\xi^s L_{j,t}^{k,*}$ at time $t+s$. The interest payment is a fixed rate $R_t^{L,k} - 1$ on that outstanding amount (R is a gross rate of interest). Table 1 summarizes the structure of a loan contract.

Table 1: Loan contract signed at period t by Entrepreneur j .

Period	Outstanding debt	Interest payment	Principal repayment
t	$L_{j,t}^{k,*}$		
$t+1$	$\xi L_{j,t}^{k,*}$	$(R_t^{L,k} - 1)L_{j,t}^{k,*}$	$(1 - \xi)L_{j,t}^{k,*}$
$t+2$	$\xi^2 L_{j,t}^{k,*}$	$(R_t^{L,k} - 1)\xi L_{j,t}^{k,*}$	$(1 - \xi)\xi L_{j,t}^{k,*}$
$t+3$	$\xi^3 L_{j,t}^{k,*}$	$(R_t^{L,k} - 1)\xi^2 L_{j,t}^{k,*}$	$(1 - \xi)\xi^2 L_{j,t}^{k,*}$

The total outstanding amount of loans available to an entrepreneur is given by the sum of newly granted loans $L_{j,t}^{k,*}$ and previous loans granted s periods ago, that decayed at the rate ξ^s :

$$L_{j,t}^k = \sum_{s=0}^{\infty} \xi^s L_{j,t-s}^{k,*} \quad (2)$$

The interest rate is fixed at time t and cannot be re-negotiated. The total loan repayment obligations $O_{j,t}^k$ are given by the sum of the promised interest and principal repayments:

$$O_{j,t}^k = \sum_{s=0}^{\infty} (R_{t-s}^{L,k} - \xi) \xi^s L_{j,t-s}^{k,*} \quad (3)$$

Compared to more common debt contract with finite maturities and constant repayments, this specification introduces fixed-rate and multi-period loan with three desirable modelling features. First, it is easy to calibrate ξ to match desired empirical measures such as an average interest rate fixation period or a Macaulay's duration in loan contracts (see Section 3). Second, we can rewrite Equations (2) and (3) recursively:

$$L_{j,t}^k = \xi L_{j,t-1}^k + L_{j,t}^{k,*} \quad (4)$$

$$O_{j,t}^k = \xi O_{j,t-1}^k + (R_t^{L,k} - \xi) L_{j,t}^{k,*} \quad (5)$$

This simplifies the optimization problem because we can set any loan duration by adjusting ξ without altering the equations of the model and at the cost of only two new state variables. This is in contrast to a setup with a loan with fixed and finite maturity and constant repayments that would imply a very large number of new state variables to model long

maturities.² Third, we can integrate this multi-period loan contracts with geometrically decaying payments into the original BGG framework with only a few minor tweaks that will be discussed below.

Return on investment. Entrepreneurs rent capital services to firms. They choose the intensity of capital utilization $u_{j,t+1}$ such that total capital services in period $t+1$ amounts to $u_{j,t+1}K_{j,t}$. Capital depreciates at rate δ^k and the undepreciated capital stock $(1 - \delta^k)K_{j,t}$ is sold at price Q_{t+1} at the end of the period. The ex-post (nominal) return to capital is thus given by:

$$R_{j,t+1}^K = \omega_{j,t+1}^k \left(\frac{u_{j,t+1}^k r_{t+1}^k - a(u_{j,t+1}^k) + (1 - \delta)Q_{t+1}}{Q_t} \right) \quad (6)$$

where r_{t+1}^k is the rental rate of capital and $a(u)$ is the cost of varying the rate of utilization of capital. Equation (6) shows that unexpected aggregate shocks in $t+1$ affect entrepreneurs' income through their impact on the (nominal) price and rental rate of capital. Moreover, following BGG, an entrepreneur j faces an idiosyncratic shock to the return on its investment denoted ω_j^k which is log-normally distributed with mean one and variance $\sigma_{k,t}^2$. This variance follows an AR(1) process with an entrepreneur risk shock.

Default decision. Limited liability implies that entrepreneurs default when their net worth falls below zero, that is when $\omega_{t+1}^k R_{t+1}^K Q_t K_{j,t} < D_{j,t}^k$. We denote $\bar{\omega}^k$ the cut-off value for the realization of the idiosyncratic shock below which the entrepreneur defaults:

$$\bar{\omega}_{t+1}^k = \frac{D_{j,t}^k}{R_{t+1}^K Q_t K_{j,t}} \quad (7)$$

² Note that, as mentioned by Beneš and Lees (2010), the setup with geometrically declining repayments does not contradict the effort to model fixed-rate loans. What matters is that the repayment scheme is fixed at the beginning of the contract and cannot be re-negotiated, as it is the case here. Moreover, it replicates well the declining repayment scheme observed at the aggregate level (e.g. household or NFC sector). For instance, think of many individual borrowers with a traditional fixed-rate mortgage. For each individual, the stream of cash flow is constant: she/he pays the same amount periodically until the maturity date of the loan. However, at the aggregate level, there is a range of mortgage loans with different maturities at each point in time. Each of such cohort of loans decays over time, as more and more loans of the cohort reach maturity, resulting in a decrease in the repayment amount for that cohort.

where $D_{j,t}^k$ is the sum of the repayments $O_{j,t}^k$ due at time t and the book value of the outstanding debt carried over to the next period:

$$D_{j,t}^k = O_{j,t}^k + \xi L_{j,t}^k \quad (8)$$

$$= \xi D_{j,t-1}^k + R_t^{L,k} L_{j,t}^{k,*} \quad (9)$$

In Equation (7), note that $\bar{\omega}_{t+1}^k$ – and thus the probability of default – are increasing functions of leverage, as in the original BGG-framework.

Aggregation. The net worth of all non-defaulting entrepreneurs is aggregated and a share $(1 - \rho_k)$ of this net worth is redistributed to households. The aggregate entrepreneurs' net worth at the end of period $t + 1$ is given by N_{t+1}^k :

$$N_{t+1}^k = \rho_k \left[\int_{\bar{\omega}_{t+1}^k}^{\infty} \omega_j^k R_{t+1}^k Q_t K_t f(\omega_j^k) dj - \int_{\bar{\omega}_{t+1}^k}^{\infty} D_{j,t}^k f(\omega_j^k) dj \right] \quad (10)$$

We assume that in the next investment stage this net worth is shared equally among all entrepreneurs. This assumption implies that all entrepreneurs remain homogeneous. They always start with the same net worth and thus always make the same investment and credit decisions before the realization of the idiosyncratic risk.

Differences with the original BGG-setup. Our setup differs from the original BGG-framework in a few dimensions. Most importantly, we introduce multi-period contracts (e.g. Beneš and Lees, 2010) with interest that are fixed in nominal terms (e.g. Christiano et al., 2004 and Christensen and Dib, 2008) for the full duration of the contract. This implies that banks carry the interest rate and default risks, which is empirically relevant and gives a non-trivial role to the banking sector. For tractability and simplicity, we also made two different assumptions. First, we assume that net worth of entrepreneurs is redistributed equally in every period to ensure that they remain homogeneous. Second, we assume that banks set the lending rate based on aggregate financing conditions (more details in Section 2.3.3). When choosing their loan level, entrepreneurs thus do not internalize the impact of their borrowing decisions on their risk premium. Instead, they face a stigma when defaulting on their loans. This allows entrepreneurs to internalize the consequences of default and brings the dynamics of the model close to the BGG-model (see Appendix B) but simplifies the optimization problem, that would otherwise be much more complex due to the presence of nested infinite-sums with multi-period contracts.

Optimization problem. Entrepreneurs maximize the sum of their discounted expected dividends paid to households net of the cost associated to stigma:

$$E_t \sum_{t=0}^{\infty} (1 - \rho_k) \Xi_t \left\{ \int_{\bar{\omega}_{t+1}^k}^{\infty} \omega_j^k R_{t+1}^K Q_t K_t f(\omega_j^k) dj - \int_{\bar{\omega}_{t+1}^k}^{\infty} D_{j,t}^k f(\omega_j^k) dj - \zeta \int_0^{\bar{\omega}_{t+1}^k} D_{j,t}^k f(\omega_j^k) dj \right\} \quad (11)$$

where Ξ_t is their discount factor and ζ captures the stigma-intensity. Note that in contrast to BGG, $R_t^{L,k}$ is not indexed by j in Equation (9). Moreover, their objective function (11) has an infinite sum over time. Multi-period loans imply that their optimization problem is dynamic and not static as in BGG. Using a similar notation as in BGG and the entrepreneurs' balance sheet (1), we rewrite their objective function (11) as

$$E_t \sum_{t=0}^{\infty} \Xi_t \left\{ (1 - G(\bar{\omega}_{t+1}^k)) R_{t+1}^K (L_{j,t}^k + N_{j,t}^k) - (1 - (1 - \zeta) F(\bar{\omega}_{t+1}^k)) D_{j,t}^k \right\} \quad (12)$$

where $G(\bar{\omega}_{t+1}^k) = \int_0^{\bar{\omega}_{t+1}^k} \omega_j^k f(\omega_j^k) dj$ captures the fact that defaulting entrepreneurs get a zero return on their investment and $F(\bar{\omega}_{t+1}^k) = \int_0^{\bar{\omega}_{t+1}^k} f(\omega_j^k) dj$ represents the default rate. Entrepreneurs maximize (12) w.r.t $L_{j,t}^k$, $D_{j,t}^k$, and $L_{j,t}^{k,*}$ under Constraints (4), (7) and (9). The FOCs can be expressed with these two equations:

$$\begin{aligned} \underbrace{(1 - G(\bar{\omega}_{t+1}^k)) R_{t+1}^K}_{\text{Expected return on cap.}} &= \underbrace{(1 - F(\bar{\omega}_{t+1}^k)) R_t^{L,k}}_{\text{Expected loan cost}} + \underbrace{\zeta \left(F(\bar{\omega}_{t+1}^k) R_t^{L,k} + F'(\bar{\omega}_{t+1}^k) (R_t^{L,k} - R_{t+1}^K \bar{\omega}_{t+1}^k) \bar{\omega}_{t+1}^k \right)}_{\text{Stigma cost internalization}} \\ &+ \underbrace{\xi \Xi_{t+1} \lambda_{t+1} (R_t^{L,k} - R_{t+1}^{L,k})}_{\text{Market timing}} \end{aligned} \quad (13)$$

$$\lambda_t = (1 - F(\bar{\omega}_{t+1}^k)) + \zeta F(\bar{\omega}_{t+1}^k) + \zeta \bar{\omega}_{t+1}^k F'(\bar{\omega}_{t+1}^k) + \xi \Xi_{t+1} \lambda_{t+1} \quad (14)$$

where λ_t is the shadow value associated with Constraint (9) capturing the cost of one monetary unit of repayment commitment made at time t , and

$$F(\bar{\omega}_{t+1}^k) = \text{Ncdf} \left(\frac{\log(\bar{\omega}_{t+1}^k) + \sigma_{k,t}^2/2}{\sigma_{k,t}} \right) \quad (15)$$

$$G(\bar{\omega}_{t+1}^k) = \text{Ncdf} \left(\frac{\log(\bar{\omega}_{t+1}^k) - \sigma_{k,t}^2/2}{\sigma_{k,t}} \right) \quad (16)$$

$$F'(\bar{\omega}_{t+1}^k) = \frac{1}{\bar{\omega}_{t+1}^k \sigma_k} \text{Npdf} \left(\frac{\log(\bar{\omega}_{t+1}^k) + \sigma_{k,t}^2/2}{\sigma_{k,t}} \right) \quad (17)$$

Equations (13) and (14) link the expected return on capital to the bank lending rate and to the expected stigma costs. As such, an increase in bank spread (and/or in borrower risk) should be accompanied with an increase in the expected return on capital, which can only be achieved through a decline in aggregate investment. It also creates a market timing motive for entrepreneurs to borrow. If the bank lending rate is expected to rise, borrowers have an incentive to increase their current borrowing in order to lock in the current interest rate. In this case, entrepreneurs tolerate either lower returns on their investments or higher lending rates, which satisfies Equation (13).

2.2 Homeowners

We model mortgage credit in a similar vein than NFC credit, and follow [Aoki et al. \(2004\)](#). Housing entrepreneurs take multi-period loans and manage the housing stock that they rent to households. FOCs are similar to the Entrepreneurs section, mutatis mutandis:

$$\underbrace{(1 - G(\bar{\omega}_{t+1}^h)) R_{t+1}^H}_{\text{Expected return on housing}} = \underbrace{(1 - F(\bar{\omega}_{t+1}^h)) R_t^{L,h}}_{\text{Expected loan cost}} + \underbrace{\zeta \left(F(\bar{\omega}_{t+1}^h) R_t^{L,h} + F'(\bar{\omega}_{t+1}^h) (R_t^{L,h} - R_{t+1}^H \bar{\omega}_{t+1}^h) \bar{\omega}_{t+1}^h \right)}_{\text{Stigma cost internalization}} + \underbrace{\xi^h \Xi_{t,t+1} \lambda_{t+1} (R_t^{L,h} - R_{t+1}^{L,h})}_{\text{Market timing}} \quad (18)$$

$$\lambda_t^h = (1 - F(\bar{\omega}_{t+1}^h)) + \zeta F(\bar{\omega}_{t+1}^h) + \zeta \bar{\omega}_{t+1}^h F'(\bar{\omega}_{t+1}^h) + \xi^h \Xi_{t,t+1} \lambda_{t+1} \quad (19)$$

and

$$F(\bar{\omega}_{t+1}^h) = \text{Ncdf} \left(\frac{\log(\bar{\omega}_{t+1}^h) + \sigma_{h,t}^2/2}{\sigma_{h,t}} \right) \quad (20)$$

$$G(\bar{\omega}_{t+1}^h) = \text{Ncdf} \left(\frac{\log(\bar{\omega}_{t+1}^h) - \sigma_{h,t}^2/2}{\sigma_{h,t}} \right) \quad (21)$$

$$F'(\bar{\omega}_{t+1}^h) = \frac{1}{\bar{\omega}_{t+1}^h \sigma_h} \text{Npdf} \left(\frac{\log(\bar{\omega}_{t+1}^h) + \sigma_{h,t}^2/2}{\sigma_{h,t}} \right) \quad (22)$$

where the subscript h stands for "housing" and replaces the subscript k used for capital in the previous section, and where R^H is the price of housing services. We allow for a different interest rate duration period for mortgage loans, ξ^h , compared to the NFC loans presented in the previous section.

2.3 Banks

A bank consists in a wholesale unit and two sector-specific retail branches. Wholesale banks manage their capital and allocate funds to retail banks. Any wholesale bank faces capital requirements and pays a penalty when its Capital Adequacy Ratio (hereafter CAR) – defined as the ratio of capital to risk-weighted assets – falls below a regulatory constraint as in [Beneš and Kumhof \(2015\)](#). A compensation for the risk of breaching capital requirements introduces a first wedge between the risk-free rate and the bank lending rate, which is a function of the bank’s CAR. Finally, retail banks grant multi-period loans to entrepreneurs and homeowners. Credit risks add a second wedge between the risk-free rate and the bank lending rate, which is a function of current - and future - borrowers’ leverage.³

2.3.1 Bank liabilities and the deposit rate

The bank liabilities consist in its own net worth, households deposits, and funds obtained from the central bank. We assume that the bank has a probability $(1-\xi_d)$ of being allowed to adjust its deposit rate. It sets the optimal deposit rate $R_t^{d,*}$ by imposing a mark-down on the policy rate R_t over its expected duration:

$$E_t \sum_{s=0}^{\infty} (\xi_d)^s \Xi_{t,t+s} \left\{ \epsilon_d R_{t+s} - R_t^{d,*} \right\} = 0 \quad (23)$$

where $\epsilon_d < 1$ is the mark-down parameter. In Equation (23), the deposit rate is a weighted average of present and expected future short-term interest rates. Up to a first order approximation, this framework is equivalent to a staggered rate setting framework à la [Calvo \(1983\)](#). The average deposit rate is simply given by: $R_t^d = \xi_d R_{t-1}^d + (1 - \xi_d) R_t^{d,*}$.

Our motivation for introducing this friction is to obtain an imperfect pass-through of the short-term interest rate set by the central bank to banks funding costs as documented in the literature (see for instance [De Bondt, 2005](#); [De Graeve et al., 2007](#); [Gerali et al., 2010](#)).⁴

³ In practice, banks strategically chose between fixed and variable rate loans, and can also decide to modify the maturity/duration of their asset portfolio. We do not model these strategic decisions and the model can thus not generate dynamics where the duration of the loan portfolio varies due to changes in these strategic decisions after shocks. The model however considers these decisions as given ex-post, once these decisions are made, in its calibration which is based on the average maturity at the level of the loan portfolio.

⁴ In reality bank funding liabilities consists in very responsive debt instrument (e.g. wholesale short-term debt) and more stable funding sources (e.g. deposits and long-term debt securities). [Jacob and Munro \(2018\)](#) model unstable and stable sources of funding separately, which allows them to study the implications of the stable funding requirement (SFR) included in Basel III liquidity regulations. We leave this more sophisticated modeling of the bank liability side for future research.

Moreover, this rigidity prevents the model to generate counterfactual abrupt adjustments in bank capital after a monetary policy shock.

For simplicity, we assume that household demand for bank deposits is exogenously determined. This assumption is consistent with the low elasticity of deposit demand to changes in the interest rate reported in [Chiu and Hill \(2018\)](#) (for the UK) and captures the relative stability of households deposits compared to other funding sources.⁵ Our calibration also implies that the cost of deposits is lower than that of other sources of funds, but that deposits are not sufficient to cover the bank's full funding needs. Thus, the marginal cost of bank liabilities is given by the risk-free rate, as in [Beneš and Kumhof \(2015\)](#).

2.3.2 Wholesale banks and capital adequacy costs

Wholesale banks use their own capital N_t^w , bank deposits B_t^d , and central bank funds B_t^{cb} to allocate funds to NFC-retail banks L_t^k and mortgage-retail banks L_t^h . Their balance sheet is thus given by:

$$N_t^w + B_t^d + B_t^{cb} = L_t^k + L_t^h \quad (24)$$

The wholesale bank sets sector-specific wholesale bank rates charged to NFC and mortgage retail banks. At the end of every period, retail banks transfer the operating profit or losses to wholesale banks. Therefore, total incomes earned by the wholesale bank are given by:

$$(R_{t-1}^{w,k} L_{t-1}^k + R_{t-1}^{w,h} L_{t-1}^h) + \Pi_t^{rb} + \omega_{j,t}^w (L_{t-1}^k + L_{t-1}^h)$$

where the first term represents income from (inter-bank) loans to NFC and mortgage-retail branches, the second term are the profits (or losses) of the retail units redistributed to the wholesale bank, and the final term is an idiosyncratic shock to the return on loans books.

Banks thus face two different types of risks affecting their incomes. (1) Aggregate risks originate from operating profits or losses made by the retail branches facing interest rate and default risks when extending credit to entrepreneurs and homeowners (see next subsection). (2) Idiosyncratic risks introduce a purely random component to the bank's loan returns. The

⁵ Note that it would be easy to introduce a shock that can capture, for example, an unexpected decline in deposit demand.

latter captures the idea that some unlucky banks might unexpectedly be more exposed to default than the rest of the sector. The term $\omega_{j,t}^w$ is normally distributed with mean zero and variance σ_w^2 and introduces dispersion in banks' income. Following [Beneš and Kumhof \(2015\)](#), wholesale banks face capital requirements and pay a penalty whenever their CAR fall below regulatory requirements given by:

$$\frac{N_t^w}{\tau_t^k R_{t-1}^{w,k} L_{t-1}^k + \tau_t^h R_{t-1}^{w,h} L_{t-1}^h} \geq \bar{car}_t \quad (25)$$

where \bar{car}_t is the regulatory threshold for the bank CAR, and τ_k and τ_h are the risk weights. The idiosyncratic risk $\omega_{j,t}^w$ implies that in equilibrium, a time-varying fraction of banks will breach capital requirements and will be forced to pay a penalty. The ex-post cut-off value for the idiosyncratic shock (denoted $\bar{\omega}^w$) below which the bank pays the penalty is given by

$$\frac{(R_t^{w,k} L_t^k + R_t^{w,h} L_t^h) + \Pi_{t+1}^{rb} + \bar{\omega}_{t+1}^w (L_t^k + L_t^h) - R_t B_t^{cb} - R_t^d B_t^d - \chi_{fc}}{\tau_t^k R_t^{w,k} L_t^k + \tau_t^h R_t^{w,h} L_t^h} = \bar{car}_t$$

where χ_{fc} is a fixed operating cost. This expression can also be expressed as

$$\bar{\omega}_{t+1}^w = \frac{R_t B_t^{cb} + R_t^d B_t^d - (1 - \tau_t^k \bar{car}_t) R_t^{w,k} L_t^k - (1 - \tau_t^h \bar{car}_t) R_t^{w,h} L_t^h - \Pi_{t+1}^{rb} + \chi_{fc}}{L_t^k + L_t^h}$$

It shows that the bank cut-off value directly depends on the realized profits of retail banks. As such, losses made by the retail banks will increase the likelihood of wholesale banks breaching the regulatory capital requirement. The wholesale bank maximizes its expected net worth (bank capital) w.r.t L_t^h and L_t^k :

$$E_t N_{t+1}^w = E_t \left\{ R_t^{w,k} L_t^k + R_t^{w,h} L_t^h - R_t B_t^{cb} - R_t^d B_t^d + \Pi_{t+1}^{rb} - \chi_w (L_t^h + L_t^k) J(\bar{\omega}_{t+1}^w) \right\} \quad (26)$$

where $R_t^{w,k}$ and $R_t^{w,h}$ are the wholesale bank rate to the NFC and mortgage retail banks, $\chi_w (L_t^h + L_t^k)$ is a penalty paid if the bank breaches its capital requirement, and $J(\bar{\omega}_{t+1}^w)$ is the breach probability. The FOC wrt L_t^k and L_t^h are

$$R_t^{w,k} - R_t = \chi_w E_t \left(J(\bar{\omega}_{t+1}^w) + J'(\bar{\omega}_{t+1}^w) \frac{\delta \bar{\omega}_{t+1}^w}{\delta L_t^k} (L_t^h + L_t^k) \right) \quad (27)$$

$$R_t^{w,h} - R_t = \chi_w E_t \left(J(\bar{\omega}_{t+1}^w) + J'(\bar{\omega}_{t+1}^w) \frac{\delta \bar{\omega}_{t+1}^w}{\delta L_t^h} (L_t^h + L_t^k) \right) \quad (28)$$

where,

$$J(\bar{\omega}_{t+1}^w) = \text{Ncdf} \left(\frac{\log(\bar{\omega}_{t+1}^w) + (\sigma_w)^2/2}{\sigma_w} \right) \quad (29)$$

$$J'(\bar{\omega}_{t+1}^w) = \frac{1}{\bar{\omega}_{t+1}^w \sigma_w} \text{Npdf} \left(\frac{\log(\bar{\omega}_{t+1}^w) + (\sigma_w)^2/2}{\sigma_w} \right) \quad (30)$$

$$\frac{\delta \bar{\omega}_{t+1}^w}{\delta L_t^k} = \frac{R_t - (1 - \tau_t^k \bar{c}ar_t) R_t^{w,k} - \bar{\omega}_t^w}{L_t^k + L_t^h} \quad (31)$$

$$\frac{\delta \bar{\omega}_{t+1}^w}{\delta L_t^h} = \frac{R_t - (1 - \tau_t^h \bar{c}ar_t) R_t^{w,h} - \bar{\omega}_t^w}{L_t^k + L_t^h} \quad (32)$$

In terms of interpretation, the wholesale bank rates are the rates at which a risk-free entrepreneur or homeowner could borrow at the bank for a maturity of one period. The gap between the wholesale bank rate and the risk-free rate represents the compensation for banks' capital adequacy costs. The latter relates to banks capital position and thus opens a bank capital transmission channel for macro-financial shocks and macroprudential regulations.

2.3.3 Retail banks and multi-period loans

Retail banks extend wholesale bank loans to entrepreneurs and homeowners. Here, we present the optimization problem of NFC-retail banks (it is similar for the mortgage sector). At every period t , the retail bank offers multi-period loans repaid in an infinite number of geometrically decaying payments. The retail bank objective is thus to maximize its expected discounted flow of profits associated with a new loan $L_t^{k,*}$ issued at time t :

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Xi_{t,t+s} \left\{ (1 - F(\bar{\omega}_{t+s+1}^k) LGD_{t+s+1}^k) R_t^{L,k} - \varepsilon^{rb} R_{t+s}^{w,k} \right\} \xi^s L_t^{k,*} \quad (33)$$

where $R_t^{w,k}$ the wholesale bank rate corresponding to the retail bank's cost, $F(\bar{\omega}_t^k)$ the probability of entrepreneurs' default, ε^{rb} governs the bank mark-up, and LGD^k is the loss-given-default (LGD) computed as

$$LGD_t^k = 1 - \frac{(1 - \mu_k) R_t^K G(\bar{\omega}_t^k) Q_{t-1} K_{t-1}}{F(\bar{\omega}_t^k) \bar{R}_{t-1}^{L,k} L_{t-1}^k}. \quad (34)$$

In equation (33), $\xi^s R_t^{L,k} L_t^{k,*}$ captures a geometrically decaying outstanding amount due on loan $L_t^{k,*}$ issued at time t . The FOC gives the bank participation constraint:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi^s \Xi_{t,t+s} \left\{ (1 - F(\bar{\omega}_{t+s+1}^k) LGD_{t+s+1}^k) R_t^{L,k} - \varepsilon^{rb} R_{t+s}^{w,k} \right\} \quad (35)$$

Equation (35) shows that retail banks set their lending rate based on a weighted average of present and expected future wholesale banks rates and default risks (function of expected default rates and LGDs), capturing the borrower's leverage channel. Also note that when rates are fully flexible ($\xi = 0$), there is no mark-up ($\varepsilon^{rb} = 1$), and no bank regulatory requirements ($R_t^w = R_t$), equation (35) simplifies to $(1 - F(\bar{\omega}_{t+1}^k) LGD_{t+1}^k) R_t^{L,k} = R_t^{w,k} = R_t$, which is equivalent to the bank's participation constraint in the BGG-framework with nominal debt contracts. Finally, equation (35) can be expressed recursively as:

$$R_t^{L,k} = \varepsilon^{rb} \frac{X_t^1}{X_t^2} \quad (36)$$

$$X_t^1 = R_t^{w,k} + \Xi_{t,t+1} \xi \mathbb{E}_t X_{t+1}^1 \quad (37)$$

$$X_t^2 = (1 - F(\bar{\omega}_{t+1}^k) LGD_{t+1}^k) + \Xi_{t,t+1} \xi \mathbb{E}_t X_{t+1}^2 \quad (38)$$

2.3.4 Bank profits and capital dynamics

In this model, the dynamics of bank capital play a crucial role and depends on retained banks' profits. Profits of the banking sector reads:

$$\begin{aligned} \Pi_t^b &= \left((1 - F(\bar{\omega}_t^k) LGD_t^k) \bar{R}_{t-1}^{L,k} - R_{t-1} \right) L_{t-1}^k + \left((1 - F(\bar{\omega}_t^h) LGD_t^h) \bar{R}_{t-1}^{L,h} - R_{t-1} \right) L_{t-1}^h \\ &+ (R_{t-1} - 1) N_{t-1}^w + (R_{t-1} - R_{t-1}^d) B_{t-1}^d - \chi_w L_{t-1}^w J(\bar{\omega}_t^w) \end{aligned}$$

where $\bar{R}_t^{L,k}$ and $\bar{R}_t^{L,h}$ are the average bank loan rates on the total outstanding amount of NFC and mortgage credit. They are given by:

$$\bar{R}_t^{L,k} = \frac{D_t^k}{L_t^k} \quad (39)$$

$$\bar{R}_t^{L,h} = \frac{D_t^h}{L_t^h} \quad (40)$$

Bank capital is then given by:

$$N_t^w = (1 - \rho_w) N_{t-1}^w + \Pi_t^b \quad (41)$$

where ρ_w determines banks' redistributed dividends to households.

2.4 Prudential authority

The prudential authority sets capital requirements, collects penalties from banks breaching capital requirements, and manages entrepreneurs' default (it recovers a fraction μ_k and μ_h of the entrepreneur and homeowner's assets). It has three tools: the minimum CAR ($mcar_t$), the countercyclical capital buffer (ccb_t), and the sectoral risk-weights (τ_t^k and τ_t^h). The bank CAR below which the bank pays a penalty is thus given by

$$\bar{car}_t = mcar_t + ccb_t \quad (42)$$

Note that the threshold below which the bank must pay a penalty is higher than the MCAR when the CCyB rate is higher than zero. When the CCyB is activated, the CCyB rate follows

$$ccb_t = \gamma_{ccb} \frac{L_t^w - L^w}{L^w} \quad (43)$$

where $L_t^w = L_t^k + L_t^h$ is the total outstanding amount of bank loans composed of mortgage and NFC loans. Note that the CCyB is only activated in Section 5. In the other sections, the CCyB rate always remains at zero.

3 Calibration

The baseline calibration is reported in Table 2 and discussed in the following two subsections, dedicated to the calibration of standard parameters and the ones of the financial friction extension, respectively.

3.1 Standard parameters

Parameters for the real and nominal sides of Belgian, euro area and US economies are calibrated at the calibrated or estimated values obtained in [de Walque et al. \(2023\)](#). This paper uses Bayesian full-information maximum likelihood methods to estimate the BEMGIE model without financial frictions. We describe here the most relevant non-financial parameters of the Belgian bloc and refer to [de Walque et al. \(2023\)](#) for deeper details.

Table 2: Calibrated parameters.

Parameter	Symbol	Value	Target
<i>Capital investment / Entrepreneurs</i>			
Investm.-to-GDP	γ_i	0.18	national account average 1995-2019
Depreciation rate	δ_i	0.025	Smets and Wouters (2007)
Adjustment costs	ψ_i	6.3	de Walque et al. (2023)
Utilization rate	ν_k	0.72	de Walque et al. (2023)
Idiosyncr. shock volatility	σ_k	0.37	annual default rate of corp. loans (4.2%)
Loss given default	μ_k	0.17	LGD rate of corp. loans (26%)
Share of retained earnings	ρ_k	0.025	debt-to-equity ratio of 68%
Default stigma	ζ_k	0.26	dynamics of BGG model
Loan repayment decay	ξ_k	0.92	average int. rate fixation period of 2.5 years (ECB SDW)
<i>Housing investment / Homeowners</i>			
Investm.-to-GDP	γ_h	0.06	national account average 1995-2019
Depreciation rate	δ_h	0.0075	3D model (Clerc et al., 2015)
Adjustment costs	ψ_h	13.4	de Walque et al. (2023)
Utilization rate	ν_h	0.46	de Walque et al. (2023)
Idiosyncr. shock volatility	σ_h	0.34	annual default rate of mortg. loans (1.4%)
Loss given default	μ_h	0.04	LGD rate of mortg. loans (13%)
Share of retained earnings	ρ_h	0.025	mortgage credit-to-GDP of 52%
Default stigma	ζ_h	0.13	dynamics of BGG model
Loan repayment decay	ξ_h	0.98	average int. rate fixation period of 11.8 years (Badarinza et al., 2018)
<i>Banks and capital requirements</i>			
Min. capital-to-risk-weighted assets ratio	$m\bar{c}ar$	0.08	Basel III
Risk weight on NFC assets	τ_k	0.52	NBB data
Risk weight on mortgage assets	τ_h	0.11	NBB data
Idiosyncr. shock volatility	σ_w	0.014	voluntary buffers (3.5%)
Penalty cap. requ. violation	χ_w	0.0035	wholesale bank spread of 0.55% per annum (Beneš and Kumhof, 2015)
Share of retained earnings	ρ_w	0.016	capital requ. breach prob. of 2% per quarter (Beneš and Kumhof, 2015)
Retail bank market power	ε_k^{rb}	1177	average bank lending margin of 1.53% (ECB SDW)
Fixed cost	χ_{fc}	0.003	average bank ROE of 10% per annum
Bank funding repayment decay	ξ_f	0.93	duration of non-maturity deposits

The steady-state great ratios of Belgian consumption, business investment, housing investment, public expenditures and imports to GDP are calibrated respectively to 0.61, 0.18, 0.06, 0.15 and 0.75 (with a trade balance assumed to be in equilibrium at steady state). The depreciation rate on capital assets is set to 2.5% on a quarterly basis. Following [Clerc et al. \(2015\)](#), the housing depreciation parameter is set to 0.75%, which is equivalent to a depreciation rate of 3 % per year. Given this depreciation parameter and the great ratios, the share of housing services in total consumption is obtained to be around 0.12. This value is somewhat smaller than - but not too far from - the average share of actual, imputed rents and other housing services in total private consumption in national accounts: 0.16 for the period 1995-2019. The elasticity of substitution between housing and other consumption expenditures is set to 0.76, the value obtained in the estimation of the standard model.

Capital and housing investment adjustment costs and utilization rate parameters are calibrated to the large values obtained in the estimation by [de Walque et al. \(2023\)](#). That is 6.3 and 13.4 for adjustment costs in respectively capital and housing investments. This indicates a smooth but very forward-looking reaction of investment to changes in asset prices. The parameter driving the utilization intensity of capital and housing assets is set to 0.72 and 0.46, respectively. It produces a volatile utilization rate and hence a smooth evolution in the rental rate of capital assets and in the price of real estate services in response to changes in output.

3.2 Financial sector

Entrepreneurs and homeowners We set σ_k and μ_k to target (annual) default and LGD rates of 4.2 and 26 % for corporate loans. For mortgage loans, we target values of 1.4 and 13 %. The values are obtained from the FINREP, COREP, and PHL databases.⁶ We calibrate ρ_h to ensure that homeowners' net worth adjusts to a level consistent with a mortgage credit to GDP ratio of 52 %, its empirical value before the start of the 2020 pandemic (which implies a leverage ratio of 1.61). We set ρ_k such that entrepreneurs' debt to equity ratio amounts to 0.68 at steady state (equivalent to a leverage ratio of 1.68), as observed in Belgian financial accounts. This value implies a NFC credit to GDP ratio of 64 %, which is higher than in the data (32%). The difference is explained by the fact that we target NFC debt to equity ratio (instead of a credit to GDP ratio) to better capture total NFC leverage, which plays a

⁶ PHL stands for Prêts hypothécaires - Hypothecaire Leningen and has data about residential real estate exposures of credit institutions. FINREP and COREP are available on the ECB Data Portal and stand for FINancial REPorting Standards and COmmon REPorting Standards.

crucial role for the financial channel as in the original BGG model. Moreover, banks may be directly or indirectly exposed to corporate bonds, and one may interpret our banking sector as a more broadly defined financial sector (including non-banks financial intermediation).

We calibrate the stigma-intensity parameter ζ to reproduce similar dynamics in the one-period loan version of our model compared to the BGG variant with predetermined nominal interest rates. To illustrate this point, we describe the effect of shocks that have an impact on borrowers' risk and on leverage in Appendix B. This simulation shows that one can approach BGG dynamics by simply calibrating the stigma parameter to the average LGD at steady state (thus forcing borrowers to internalize the cost of their potential defaults).

Banks and capital requirements The minimum CAR is 8 % as imposed by Basel III. The risk-weights on entrepreneurs (NFC) and homeowners (mortgage) loans are set to 52% and 11% respectively, corresponding to the average risk-weights set by Belgian banks.⁷ We calibrate σ_w , χ_w , and ρ_w to match three steady-state targets: (1) banks' voluntary buffers at 3.5 % of their risk-weighted assets, (2) a wholesale bank spread of 55 basis points (per annum) for wholesale loans to NFC retail branches, and (3) a capital requirement breach probability of 2% per quarter. The first target is based on the observed average banks' voluntary buffers in 2019 while the second and third follows the original calibration of [Beneš and Kumhof \(2015\)](#).

We set the retail bank market power parameter ε^{rb} to reach a pure credit spread of 38 basis points of both NFC and mortgage loans. Overall, this calibration implies that the average lending margin of Belgian banks is 153 basis points (equivalent to its observed average in the 2010-2019 period based on ECB SDW data). The average mortgage and NFC loans bank spreads (92 and 202 bp, respectively) are explained by three factors: a compensation for credit default risk (18 and 109 bp); a wholesale bank spread capturing the costs of capital management (36 and 55 bp) and a pure retail spread (38 bp for both). We then set the fixed-cost parameter χ_{fc} to match an average bank ROE of 10% on an annual basis (the ROE of Belgian banks fluctuated between 8 and 10 % between 2015 and 2019).

Loan and deposit durations Following [Beneš and Lees \(2010\)](#), we set the loan decay parameters (ξ_h and ξ_k) to match the Macaulay's durations of mortgage and NFC loans observed in the data. The observed Macaulay's duration matches the duration of the geometric

⁷ Note that most loans are granted by banks using an internal ratings-based (IRB) approach.

loans used in our model when

$$d = \frac{\sum_{j=1}^{\infty} j \frac{\xi_i^{j-1}}{(R^{L,i})^j}}{\sum_{j=1}^{\infty} \frac{\xi_i^{j-1}}{(R^{L,i})^j}} = \frac{R^{L,i}}{R^{L,i} - \xi_i} \quad (44)$$

for $i = h, k$ for mortgage and NFC loans respectively. Note that this duration is computed at the steady state using the lending interest rate to discount cash flows.

The observed Macaulay's duration d is computed using the average maturity at origination extracted from the data.⁸ For mortgage loans, the average maturity at origination is approximately 16 years, as calculated from the NBB mortgage lending (PHL) survey for the banking sector (see Figure 7 in [NBB, 2024](#)) over the period 2007-2023.⁹ The average maturity of 16 years of a fixed-payment loan gives a Macaulay duration of 7 years. Using the formula above with the steady-state mortgage lending rate and this duration, we obtain a loan decay parameter $\xi_h = 0.98$ for mortgage loans.

Regarding NFC loans, BECRIS data extracted in June 2024 indicates an average maturity at origination of 4 years. About 37% of these loans involve fixed payments of principal and interest, similar to a mortgage loan, and are associated with a Macaulay duration of 2 years. Bullet loans, where the full principal amount is repaid in the final cash flow, constitute approximately 34% of the total loans, with a computed duration of 3.5 years. We have less information about the remaining category, referred to as "other" in the data. Although we do not know the exact proportions, this category includes balloon-type loans, where a significant portion of the principal amount (though not necessarily 100%) is also repaid in the last cash flow. Depending on whether we classify the "other" category as fixed-payment or bullet, we obtain a duration range between 2.5 and 3 years. Using the midpoint of this range and the steady-state lending rate to NFC firms, our calibration of ξ_k is 0.92. For comparison, [Badarinza et al. \(2018\)](#) calculated an average initial interest rate fixation periods of 2.5 years for NFC loans.

⁸ For a textbook formula applied to fixed-rate loans, see for instance [Fabozzi \(2005\)](#), Page 493-497.

⁹ This dataset provides a breakdown of the total loans granted in a given year by their maturity at origination. We can therefore weight each maturity by its proportion of the total. When only a range of maturities is available (e.g., [10-15] years), we use the midpoint in the weighted average. On average, 74% of the loans are fixed-rate instruments. However, for each year, we also have data on the variability of interest rates for new loans, which helps to compute an average maturity that accounts for the time to the next repricing.

Our calibration implies that corporate loan rates adjust more rapidly than mortgage rates. This outcome is in line with estimated DSGE models that feature a lending rate rigidity mechanism. Using a euro area dataset from 1998Q1 to 2009Q1 which includes interest rates and volumes on loans to firms and households, [Gerali et al. \(2010\)](#) estimate larger rate adjustment costs for interest rate on households compared to NFC rates. In a model with staggered lending rates à la [Calvo \(1983\)](#), [Darracq Pariès et al. \(2016b\)](#) find a larger nominal rigidity when mortgage rates are added to NFC rates in their dataset, in an estimation based on bank interest rates published on the ECB SDW website. Empirical evidence from the interest rates on different Belgian loan products also points towards the direction of more pronounced stickiness for mortgage rates compared to corporate rates ([Baugnet and Hradisky, 2004](#); [De Graeve et al., 2007](#)).

On the liability side, we rely on NBB estimates of the Macaulay duration of bank sight and savings deposits (retail and wholesale non-financial) over the period 2019-2023. These durations range from 2.7 to 4.4 years, and can be matched with the average age of deposit contracts in the [Calvo \(1983\)](#) setup, $1/(1 - \xi_f)$. This results in a ξ_f between 0.91 and 0.94. We calibrate the decay parameter to the average of this interval, 0.93. The average deposit share in bank liabilities (excluding capital and reserves) is 0.85, corresponding to its value before the pandemic (NBB stat). It is used to calibrate the proportion of deposits in the bank liabilities in the model: $\bar{B}^d/(\bar{B}^d + \bar{B}^{cb})$.

4 The financial channels

In this section, we describe how changes in the risk-free interest rate and default risks propagate in the model via financial channels: the bank capital channel and the entrepreneurs and homeowners leverage channels. We evaluate the contribution of these channels to the dynamics of key macro and financial variables after a monetary policy shock and after an NFC risk shock. We also document the effect of multi-period loans contracts, and validate our model and its calibration by comparing our results with other important benchmarks in the literature.

To highlight the relative importance of the two channels, we include two specific plots in the figures that show the impulse responses of variables to shocks. A first plot illustrates the significance of the borrowers' leverage channel by displaying the spread between the retail lending rate and the wholesale interest rate ("risk channel" in the title of the plots).

A second plot shows the spread between the wholesale rate and the risk-free rate (“bank capital channel”). This spread widens when bank capital decreases, to reflect a higher likelihood of breaching capital requirements. To ensure comparability across different model configurations (one-period versus multi-period loan setups), and when necessary by applying the expectation hypothesis of the term structure, the interest rates in these spreads are calculated for loans of comparable Macaulay durations (2.75 years for NFC and 7 years for mortgages).

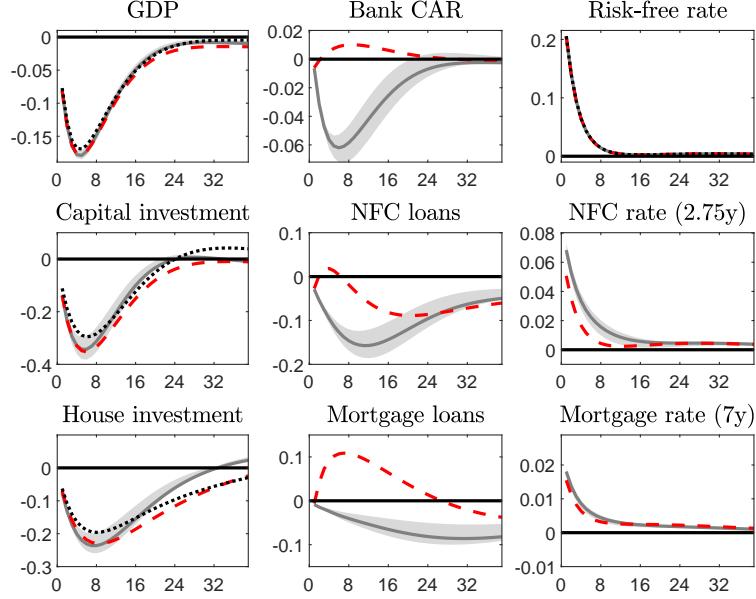
4.1 A monetary policy shock

We start our illustration of the dynamics generated by the model with an impulse response analysis of a conventional monetary policy surprise. The analysis of such a standard shock - yet key to monetary policy - helps us to assess how the model propagation mechanism compares with the literature. Moreover, it is also used to portray the contribution of financial frictions to the dynamics after a standard shock, relative to a counterfactual configuration of the model where these frictions are turned off. Figure 3 reports the impulse responses of key Belgian macroeconomic and financial variables to a restrictive monetary policy surprise. The shock is calibrated such as to produce an increase in the nominal short-term interest rate of 0.2% in annual terms. Each of the three lines refers to a different configuration of BEMGIE: the baseline model with its financial extension including multi-period loans (solid grey lines), a version of the model with one-period – and hence fully-flexible-rate – loan contracts (dashed red lines) and a standard version of the model without financial frictions (dotted black lines).

The monetary policy shock generates a contraction in investment variables. In the model with financial frictions, the initial drop in capital asset valuations and the subsequent deterioration of borrowers’ net worth leads to a jump in their leverage. Combined with an increase in bank lending rates, this results in a significant rise in required returns, which in turn accelerates the drop in capital asset prices compared to the model without any financial extension. The responses of other key macroeconomic variables are standard: inflation, output and its demand components fall.

Both the one-period and the multi-period loan setups amplify the investment decline compared to the counterfactual where financial frictions have been turned off, though the effect is quantitatively small. The impulse responses of the model with one-period loan

(a) Macroeconomic & credit variables



(b) Spreads decomposition into channels

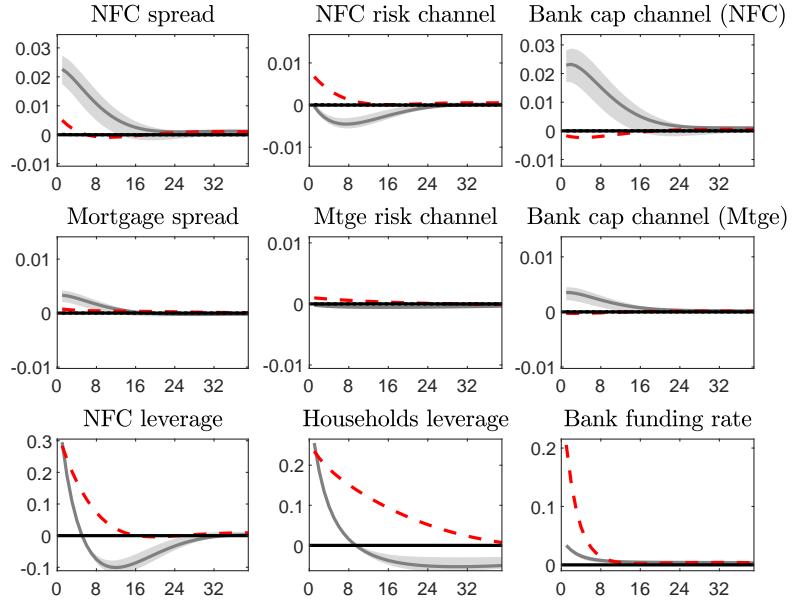


Figure 3: A monetary policy shock

Note: Variables in percentage deviation from steady state. Interest rates, default rates, and spreads annualized. Horizon in quarters. Leverage is defined as the ratio of borrowers' assets over net worth. NFC and mortgage rates and spreads apply to new multi-period loans. In the one-period setup, they represent the rates at which new multi-period loans would be granted. Bank funding rate is the rate that applies to total (new and outstanding) liabilities. Spreads are expressed in terms of a risk-free loan of identical duration. Grey = Baseline. Dashed-red = one period debts. Dotted-black = no financial frictions.

contracts are in line with Beneš and Kumhof (2015).¹⁰ The risk channel is reflected by a persistent increase in borrowers' leverage, which in turn leads bank to increase retail lending spreads. The bank capital channel is negligible in this configuration of the model, as there is no duration mismatch between banks' assets and liabilities. Regarding loan volumes, a hump-shaped increase in the short-term response of credit volumes can be observed.¹¹ This comes from a recovery in capital asset values that is faster than the recovery in borrowers' net worth, as pointed out in Beneš and Kumhof (2015). Consequently, households and entrepreneurs need to borrow more to finance desired levels of assets. An increase in bank loan volumes after a monetary policy tightening is however inconsistent with the predictions of the credit channel of monetary policy (Bernanke and Gertler, 1995; Altavilla et al., 2019) and at odd with the empirical evidence presented in Peersman (2011) for the euro area.

In the baseline multi-period loan setup, the response of real investment is also amplified compared to the no financial friction configuration, albeit through the bank capital channel and a market timing effect rather than through the borrowers' leverage channel as in the one-period debt model. In our baseline calibration, the pass-through to the interest rate on total amounts (new and outstanding) is more sluggish on the asset side than on banks liability side. This contributes to a contraction in banks' profit and a persistent decline in banks' capital, in contrast with the dynamics of the model with one-period loan setting.¹² The resulting increase in the probability of violating capital requirements leads to higher wholesale bank spreads. This in turn generates a stronger and more persistent response of retail lending rates. Additionally, the anticipated easing of temporarily tighter conditions on new loans incentivize borrowers to postpone borrowing and investment to avoid locking in the higher interest rates for an extended period. This market timing effect significantly contributes to a short-run decline in credit and amplifies the effect of the monetary shock.

It is however interesting to note that leverage does not increase as persistently in the multi-period loan setup compared to the one-period configuration. Indeed, long-term loans with fixed rates offer some protection to borrowers against the increase in interest rates and mitigates the real effects of monetary policy, similarly to what is found in the sticky-rate

¹⁰ See Figure 5 in Beneš and Kumhof (2015) and black dotted lines for a comparison to the conventional monetary policy shock.

¹¹ This effect is also present in the impulse responses of loan volumes to a monetary policy shock in Beneš and Kumhof (2015) and Darracq Pariès et al. (2016a).

¹² Note that the revenues from hedging instruments against interest-rate risks are not taken into account in the model. The simulation presented here therefore misses the balancing effects on bank profits of the cash flows coming from these hedging instruments.

model of [Gerali et al. \(2010\)](#) for the euro area. In addition, the market-timing effect encourages borrowers to deleverage when interest rates are temporarily elevated, resulting in a muted borrower leverage channel. However, the capital channel dominates the borrower leverage channel, so that overall, we obtain an amplification of monetary policy shocks in the multi-period loan setup.

The magnitude of the bank capital channel obtained in the multi-period loan configuration depends on the bank duration gap between its assets and liabilities. Depending on the calibration, it is possible to generate a more or less significant bank capital channel, as indicated by the shaded areas around the baseline impulse-response in Figure 3. In the recent years 2022-2023, the rise of policy rates has been associated with a surprisingly slow pass-through to the sight and savings deposits offered by Belgian banks.¹³ This suggests a smaller duration mismatch, and a more neutral role for the bank capital channel in the transmission of the monetary surprise. This situation could correspond to the lower bound of the shaded area generated by our model, which is associated with a larger calibrated deposit rate stickiness compared to the baseline calibration.

More recently, from end-2023 to 2024, we observe a large shift from sticky sight and savings deposits towards more rate-sensitive term deposits in the liabilities of Belgian banks (see Figure 5 Page 23 in [NBB, 2024](#)). This phenomenon is also observed in euro area data as reported in [Coulier et al. \(2024\)](#). As pointed out by these authors, this shift results in an increase in the duration gap (net of hedging) of banks, leading to more exposure to the interest rate risk. There is also uncertainty around the estimation of the duration of overnight deposits, and external factors (e.g. the rise of fintech, the government's issuance of a competitive bond) could change the sensitivity of deposit rates to market rates. In the model, a counterfactual can be constructed based on a small rate stickiness parameter on bank's liability side, thereby widening the duration mismatch. Such an experiment corresponds to the upper bound of the shaded area in Figure 3. In this counterfactual, bank capital responses are more sensitive to the policy rate compared to the baseline case. With respect to the one-period setup, there is now an amplification of the shock that emanates

¹³ See for instance [NBB \(2024\)](#), Page 27. The slow pass-through of policy rates to sight and savings deposit fell short of what could have been expected based on the pass-through observed in the past. The report points out the attempt by banks to restore commercial margins on their stock of deposits, which were compressed during the period of low policy rates, as a reason behind this change in the pass-through.

from the bank capital channel.¹⁴

In the baseline model, measuring the pass-through of the policy rate to the bank funding rate by the relative impulse responses,¹⁵ we obtain a response on impact around 20% for the rate on new deposits, while it is around 16% for the total cost of bank liabilities. In comparison, in a one-period debt setup where banks face costs in adjusting deposit rates, [Gerali et al. \(2010\)](#) report a pass-through to their measure of EA bank funding costs around 25% on impact after a monetary policy shock.¹⁶ On the loan side, the baseline model-implied pass-through is more limited for new mortgage credit (a bit less than 10% on impact and around 15% after one year) than for new corporate loans (a bit less than 35% on impact, slightly above 50% after one year), consistently with empirical evidence ([Baugnet and Hradisky, 2004](#); [De Graeve et al., 2007](#)). This is somewhat smaller than what is obtained in [Gerali et al. \(2010\)](#) where, for a monetary policy shock, the pass-through to interest rates applied to both households and firms credit is around 37.5% on impact, while the calibrated model of [Darracq Pariès et al. \(2016a\)](#) generates on impact a 60% pass-through to EA commercial lending rates.

¹⁴ In experiments not reported here, we also implemented a simulation with a negative net duration (duration of assets smaller than the one on liabilities). A significantly smaller decay parameter on the asset side compared to the calvo parameter on the liability side can turn the bank channel to be favorable: that is, it contributes negatively to the lending spread and generates a positive response of bank capital. In this case, it is interesting to note that, as credit contracts less, leverage does not undershoot in the medium run, and the risk channel starts to play a significant – and adverse – force. This force is however not sufficient to compensate the favorable ones from a lower interest-rate pass-through and the bank capital channel, and responses of real investment and output are attenuated compared to the one-period counterfactual.

¹⁵ More specifically, we divide the impulse response of the specific interest rate by the one of the monetary policy rate at each horizon. Our measure of the interest-rate pass-through is shock-dependent, as in [Binning et al. \(2019\)](#). It is thus not easily comparable to the unconditional interest-rate pass-through measured in empirical studies (see, for instance, [Baugnet and Hradisky, 2004](#); [De Graeve et al., 2007](#)), which is influenced by all sources of shocks affecting the monetary policy rate. As our model is not fully estimated, such an unconditional measure - dependent on the relative importance of the different shocks in the model - is not easy to produce. Moreover, empirical estimates are often measured relative to a reference market rate (e.g. corresponding maturity or highest correlation) while we report the pass-through of the short-term interest rate in the model.

¹⁶ See Figure 4 in [Gerali et al. \(2010\)](#). Their model is estimated based on euro area interest rates (on deposit and lending) that apply to new business coverage.

4.2 Risk shocks

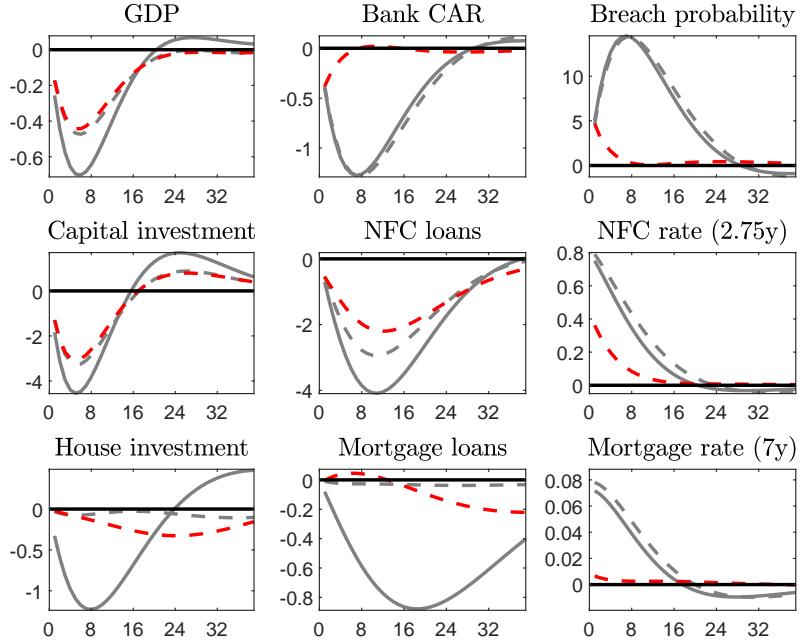
Fluctuations in borrowers' risk have often been identified as a key driver of business cycle fluctuations (e.g., [Christiano et al., 2014](#) in a study applied to the US). We thus simulate the impact of an increase in the variance of the idiosyncratic risk faced by Belgian entrepreneurs to evaluate its impact on the Belgian economy. We simulate this shock in two different configurations of our model: in the baseline with multi-period loans (in grey) and in an economy with one-period bank loans and debt (in black). Comparing the results in these two scenarios allows us to identify the contribution of the multi-period loan extension. We also discuss the role of the bank capital channels and borrower leverage by decomposing the credit spread into a wholesale spread (capturing the former) and a retail spread (capturing the latter) in Panel (b) of Figure 4.

For the baseline, a version of the model where the market timing channel is turned off is also reported (in dashed grey). This counterfactual helps us to give an idea on the importance of the market timing relative to the baseline, but caution is recommended when comparing the outcomes: 1/ a comparison of this counterfactual with the one-period setup is misleading as the loan maturities are different, 2/ we turn off the market timing based on the ad-hoc assumption that borrowers behave myopically with respect to the market timing term in Equation 13, ignoring the benefits they can have by optimizing their decisions on the evolution of future lending rates.

In the baseline model, an increase in entrepreneurs' risk is calibrated to cause a 4-percentage point increase in the annualized default rate of entrepreneurs, on impact. Retail banks respond to the increase in risk by raising the spread they charge on entrepreneurs' loans. Higher rates encourage entrepreneurs to deleverage and thus to reduce their investment, which also causes a fall in the price of physical capital that reinforces the impact of the shocks. At their troughs, investment in physical capital and GDP contracts by 4.5% and 0.7%, respectively.

The impact on consumption is, in contrast, more limited. Households respond to the fall in hours worked by cutting on consumption. However, there is no direct effect from lower physical capital or housing prices to consumption, as households do not use their capital as a collateral to take consumer loans. This practice is limited in Belgium (e.g., [Reusens and Warisse, 2018](#)).

(a) Macroeconomic & credit variables



(b) Spreads decomposition into channels

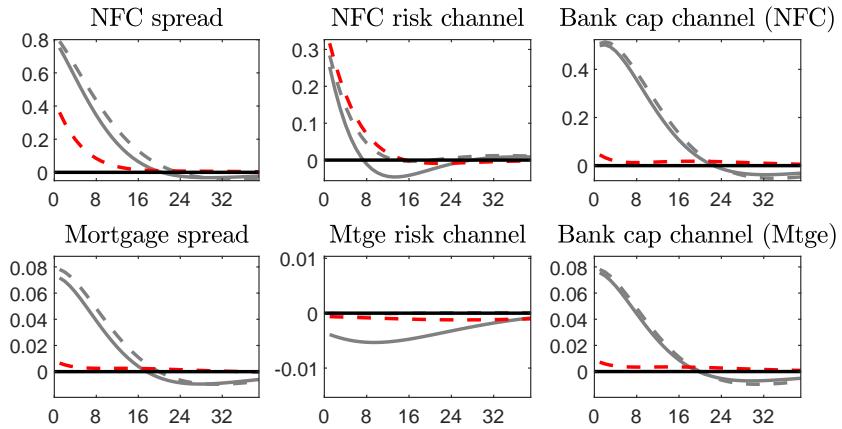


Figure 4: An entrepreneur risk shock (NFC)

Note: Variables in percentage deviation from steady state. Interest rates, default rates, and spreads annualized. Horizon in quarters. NFC and mortgage rates and spreads apply to new multi-period loans. In the one-period setup, they represent the rates at which new multi-period loans would be granted. Spreads are expressed in terms of a risk-free loan of identical duration. Grey = Baseline. Dashed-red = one period debts. Dashed-grey = Baseline with no market timing.

The multi-period loan setup amplifies the effects of borrower risk shocks through the bank capital channel compared to the one-period debt counterfactual. In a one-period loan model, the unexpected increase in the default rate affects bank profitability for only one period as banks quickly adjust their interest rates to higher default risks, and the bank CAR thus quickly returns to its steady state. In the case of multi-period fixed-rate loans, banks can only adjust their spreads on new loans, not on the outstanding amount of previously issued loans. In that case, banks continue to make losses in the subsequent periods, and the CAR reaches a deeper trough after 2 years. This weaker capital position translates into higher total spreads for entrepreneurs and homeowners and lower investment in physical capital and housing.

The market timing effect also contributes to the amplification of risk shocks in the multi-period loan setup. The transitory aspect of this rise in lending rates makes borrowers to postpone part of their investment to avoid being burdened with more expensive financing for long. This market timing effect adds a significant downward pressure on credit. Note that, as for the monetary policy shock, borrowers' deleveraging in the medium run attenuates somewhat the borrowers' leverage channel compared to the one-period loan setup.

Spillovers from an increase in NFC risks to the housing market are substantial in the multi-period loan model. The higher rate on mortgage loans encourages homeowners to deleverage, which results in a fall in house prices and mortgage loans volumes much more pronounced than in a model that does not combine a multi-period feature (and its market timing effect) and a bank capital channel. The predictions of our baseline model contrast with [Mendicino et al. \(2018\)](#) that uses a model similar to the 3D model of [Clerc et al. \(2015\)](#) calibrated to the euro area to simulate a NFC risk shock. They find a negative co-movement between mortgage and NFC loans volumes and spreads after an adverse shock to NFCs risks. In the 3D, banks specialize in either NFC or mortgage loans, limiting the ability of such a model to produce a positive co-movement in NFC and mortgage credit after a sector specific shock. In contrast, we obtain important spillovers from one sector to the next when banks offer a mix of NFC and mortgage loans and when multi-period debt contracts magnify the response of banks' capital ratios.

5 A cost-benefit analysis of the CCyB

We now turn to a cost-benefit analysis of the CCyB using an IRF analysis. First, we simulate the cost of raising the CCyB rate from zero to one percentage point, building some room for a potential release should an unexpected shock warrant it. When simulating these costs, the increase is assumed to be quasi-permanent in the sense that the CCyB rate remains at this level unless the economy is hit by an adverse shock. The benefits are measured by comparing the differential response of the economy to a financial stress with and without a release of the CCyB. It is assumed that the CCyB is released to support credit to households and NFCs when the shock hits and that the latter is gradually rebuilt as the economy recovers.

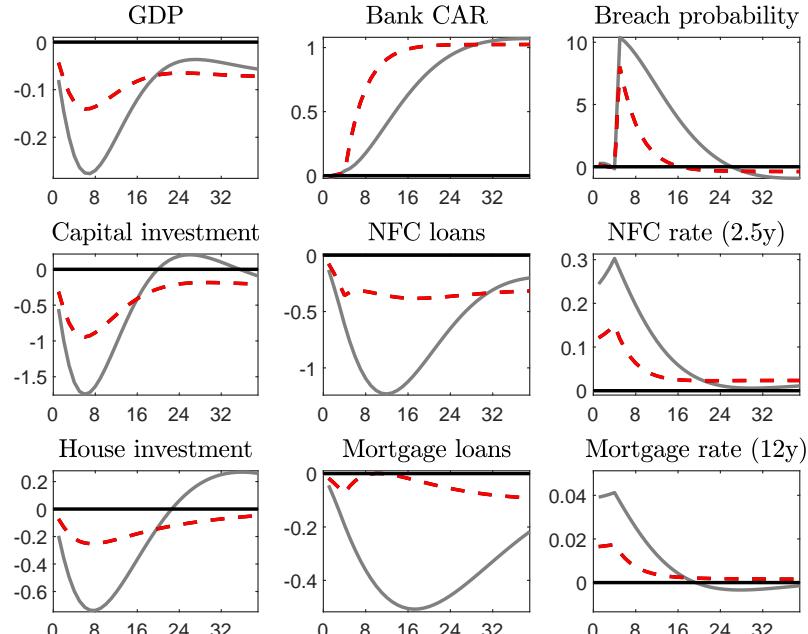
This experiment is closely related to the idea of introducing a positive neutral CCyB rate of 1%. The implication is that the cost of raising the neutral rate from zero to one must be paid once – and only once – while the benefits can be reaped many times over, since the room for maneuver created can be used indefinitely to smooth shocks as long as buffers are rebuilt between shocks. Where possible, we compare our results with other structural models and with empirical works applied to the Belgian economy.

5.1 Activation costs

We simulate the effect of a 1 percentage point increase in the CCyB rate applied to Belgian banks in the model (thus raising total capital requirement from 8% to 9%). In this simulation, the capital requirement is raised with a one-year notice. The persistence of the increase in capital requirements is set to 0.9999 and is thus quasi-permanent.

Figure 5 shows the response of selected macro and financial variables to the announcement of a future increase in regulatory capital requirements. Although Belgian banks initially hold sufficient capital buffers and thus continue to comply with the new capital requirements, the probability of breaching the requirements in the future increases. As a result, banks are demanding more compensation for the potential capital costs by increasing the wedge between wholesale rates and their funding rate. The increase in the wholesale rate applied to NFC loans is larger than that applied to mortgages because of the difference in risk weights. The positive response of wholesale spreads in turn induces retail banks to set higher lending rates for new loan contracts. This tightening of credit conditions originating from the bank capital channel has a contractionary effect on borrowing, asset prices and real investment, and hence output.

(a) Macroeconomic & credit variables



(b) Spreads decomposition into channels

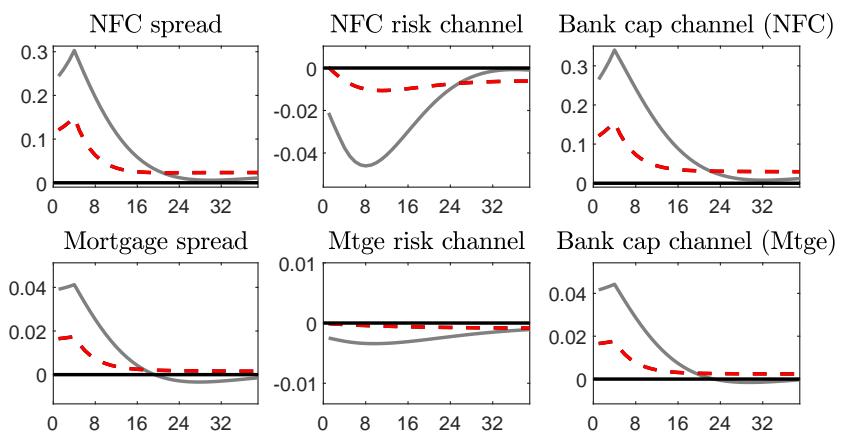


Figure 5: An expected increase in capital requirements (1 year notice)

Note: Variables in percentage deviation from steady state. Interest rates, default rates, and spreads annualized. Horizon in quarters. NFC and mortgage rates and spreads apply to new multi-period loans. In the one-period setup, they represent the rates at which new multi-period loans would be granted. Spreads are expressed in terms of a risk-free loan of identical duration. Grey = Baseline. Dashed-red = one period debts.

The contraction, in turn, pushes up default probabilities in the short run. However, default rates decline in the medium term as households and NFCs deleverage. Thus, the borrower leverage channel somewhat mitigates the increase in lending rates.

The adjustment towards a higher level of bank capital-to-risk-weighted asset ratio is gradual for two main reasons. First, in setting wholesale interest rates, banks weigh the cost of breaching capital requirements against the adverse indirect effect on profits of a too strong tightening in loan supply. Second, in our setup with multi-period loans, banks can only adjust their spreads on new loans, not on the outstanding amount of previously issued loans. It thus takes longer for income from lending to contribute significantly to profits and hence to bank capital.¹⁷ This is different from the configuration with one-period loan contracts, where the interest rate adjusts immediately on all loans. The convergence of bank capital to the desired long-term level is thus slower with the baseline calibration. This in turn produces an amplified response of the breach probability, of wholesale spreads and thus accelerates the dynamics of credit and investment compared to the one-period counterfactual.

This contraction in credit lending after an increase in capital requirement is in line with the empirical literature. [De Jonghe et al. \(2020\)](#) also find a significant decline in credit growth due to stronger bank-specific capital requirements with a one-quarter notice in Belgium. In the short run they obtain a decline of existing NFC credit growth at the intensive margin (that is, for existing bank-firm relationships) between -0.27pp and -0.13pp after a 1pp increase in individual bank capital requirements, depending on whether banks restore or not their capital buffers.¹⁸ After 1 year, the range of this effect is between -0.53 and -0.38 percentage points. In BEMGIE, NFC borrowings deteriorate by about -0.13pp and -0.77pp after respectively 1 and 5 quarters. The medium-run response is somewhat larger than what is reported on the intensive margin [De Jonghe et al. \(2020\)](#) but should be considered as a total effect, capturing both the intensive and extensive margins. On the extensive margin (new bank-firm relationships), [De Jonghe et al. \(2020\)](#) estimate a significantly larger effect around -0.80pp after 1 quarter, and -1.7pp after 1 year.

The quantitative response of output, around -0.28% in the baseline simulation, is con-

¹⁷ Hence, the model does not need any ad hoc mechanism, such as adjustment cost in bank capital (as for instance in [Bokan et al., 2018](#)), to generate this gradual response of bank capital.

¹⁸ Credit growth is measured as the quarterly change in the natural logarithm of authorized credit at the bank-firm level in their paper.

sistent with other DSGE models featuring bank capital requirements.¹⁹ Using a range of macroeconomic models used at the European Central Bank, [Cozzi et al. \(2020\)](#) obtain a range of response around [-0.35;-0.15] percentage points for the decline in GDP after a 1pp increase in bank capital requirements. The meta-analysis of [Fidrmuc and Lind \(2020\)](#) summarizes the results of 48 papers that evaluated the effects of one percentage point increase in capital requirements. On average, a one percentage point increase in capital requirements is found to cause a 0.20 % decline in GDP (with a range between -0.85 and -0.01 %).

Two elements of our model contribute to increasing the estimated cost of higher capital requirements. First, the simulations in the literature are usually conducted at the global level or for large economies, while we present the result for a regulatory capital increase in Belgium only. Consequently, the accommodative monetary stance that follows endogenously from the policy shock in models for larger economies is absent from our simulation. Hence, if other euro area countries apply similar capital requirements than Belgium, a monetary policy reaction can reduce our estimate. Second, our setup includes a multi-period debt structure, which has been shown to accelerate real dynamics. For comparison, GDP falls by about -0.16% in the one-period debt version of the model.

The effect of higher capital requirements on bank lending rates is mainly limited to the short run. In the long run, as banks' voluntary buffers are replenished and the probability of breach returns towards its equilibrium level, the increase in lending rates is limited to two basis points for NFCs and less than one basis point for mortgages. The small increase in these lending rates is explained by the fact that the return on capital is higher than the cost of other liabilities. The long-run output loss is 0.07%.

5.2 Benefits of releasing the CCyB during financial stress

We now turn our attention to a CCyB release in a situation of financial stress. The benefits are measured in terms of the CCyB's ability to smooth the adverse effects of a medium-size shock on credit supply and economic activity. It is important to note that some other important benefits of a positive CCyB – such as a reduction in the risk of bank failures – are

¹⁹ We remind the reader that this estimate is a percentage expressed in deviation from the steady-state trend of real GDP, which grows by 0.3% per quarter in the model. This figure therefore does not correspond to a recession situation. At steady state, GDP grows by about 2.4% in two years, compared to 2.1% with the CCyB activation.

not captured by this model, which is not designed to capture the effects of larger shocks – such as tail risk events that could otherwise destabilize the proper functioning of credit institutions.

The financial stress is modeled as an increase in NFC default risk of about one percentage point in the first quarter, making NFC loans twice as risky as in the steady state. We assume that the CCyB rate is 1% before the shock. In a first scenario, the CCyB remains unchanged. In a second, the CCyB is released. The release is gradual and calibrated to ensure that it is fully released at the worst of the crisis.²⁰ The difference between these two scenarios allows us to identify the impact of a potential release of the CCyB.²¹

The release of the CCyB mitigates the contraction in credit supply by preventing an amplification of the shock that would otherwise operate through the bank capital channel. When the CCyB is released, banks can absorb losses on their NFC loan portfolio without increased fear of breaching capital requirements. In this case, wholesale spreads are more stable. In contrast, when the CCyB is not released, wholesale spreads widen as banks pass on the expected cost of breaching capital requirements to their customers. In both cases, the borrower risk channel continues to contribute to the increase in NFC funding costs, but the contribution of the bank capital channel is much smaller with a release.

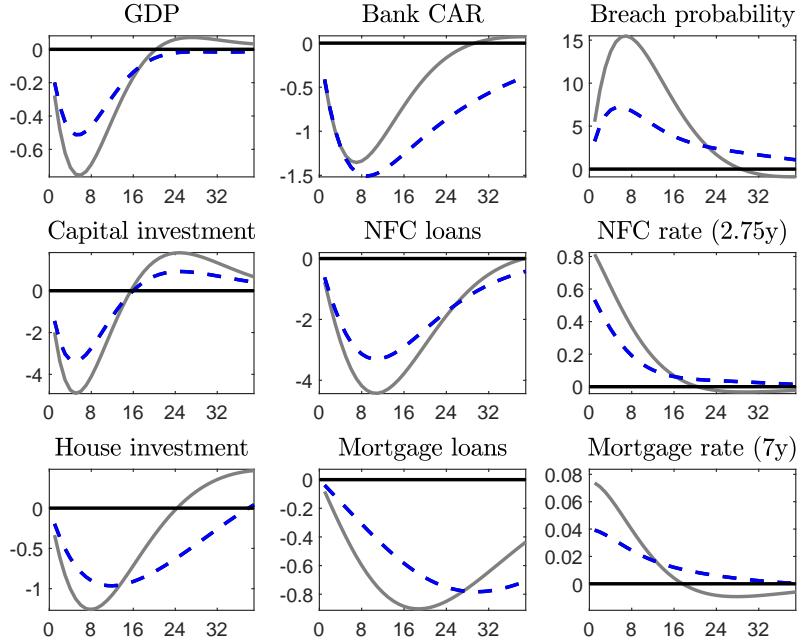
The overall short-run benefit of the CCyB release on investment and GDP is substantial. The release prevents a procyclical response of bank credit supply through the bank capital channel. It has a strong positive effect on credit, allowing firms to maintain a relatively higher level of investment. We find that business investment falls by 3.4% when the CCyB is released, compared to 4.9% when it is not. The peak difference between the GDP responses with and without CCyB release is around 0.24 pp. This means that the activation costs estimated in the previous subsection are almost entirely repaid with only CCyB release.

Moreover, the CCyB release initially mitigates spillovers to mortgage credit supply. Without a release, banks try to quickly rebuild their buffers with higher interest rates on both new NFC and mortgage loans. As a result, household credit, residential investment and house prices could fall.

²⁰ That is, the reaction parameter $\gamma_{ccb} = 0.5$ (see Equation 43), which ensures a release of 1%.

²¹ To ensure that the deep parameters of the model are identical in both scenarios, they share the same steady-state bank CAR of 9%.

(a) Macroeconomic & credit variables



(b) Spreads decomposition into channels

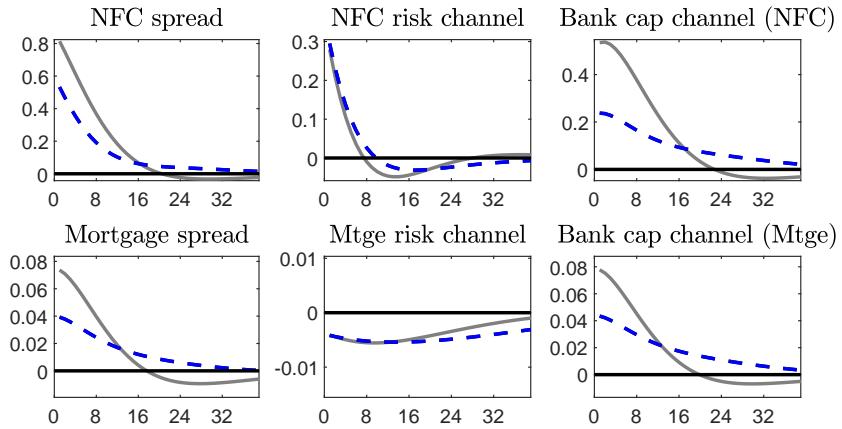


Figure 6: An increase in NFC risks with and without CCyB release

Note: Variables in percentage deviation from steady state. Interest rates, default rates, and spreads annualized. Horizon in quarters. NFC and mortgage rates and spreads apply to new multi-period loans. In the one-period setup, they represent the rates at which new multi-period loans would be granted. Spreads are expressed in terms of a risk-free loan of identical duration. Grey = Baseline without CCyB release. Dashed-blue = with CCyB release (calibrated to 1% of the risk-weighted assets at the worst of the shock).

The CCyB release is associated with a persistent decline in banks capital-to-asset ratios. Banks are allowed to absorb their losses without a sharp adjustment in credit volumes and/or interest rates, which initially supports economic activity, but results in a prolonged period of lower capital ratios in the banking sector. This result is also observed in [Beneš and Kumhof \(2015\)](#) and is partly mechanical: higher loan volumes imply lower capital ratios. Moreover, lower lending rates also imply that banks do not rebuild their capital as quickly as they would without the release. When considering whether to activate or release the CCyB, it is important to be able to measure these trade-offs. Note, however, that capital ratios remain higher than in a situation where the CCyB rate is initially at zero (before the shock) because banks start from a more favorable position.

We can also show that easing capital requirements in times of financial stress mitigates the financial acceleration that operates through the bank capital channel more than in a model with one-period loans (see Figure 11 in Appendix C). In the baseline multi-period loan model, the decline in bank capital following a risk shock is large and persistent, leading to a strong amplification of the shock. In contrast, in the one-period loan setting, the decline in capital is more muted and capital quickly returns to its steady state. Thus, for a given CCyB rule (with the same parameter γ_{ccb}), the effect of adjusting capital requirements is much weaker. In fact, the acceleration operating through the bank capital channel is limited in the one-period loan setup, limiting the benefits of relaxing the CCyB.

6 Crowding out effects of sectoral prudential measures

Changes in sector-specific capital requirements can be a relevant macroprudential tool to address the risks arising from specific sector exposures. Exposures to the mortgage sector have come under particular scrutiny by regulators, given the financial stability risks posed by excessive developments in the real estate market. For example, in 2013, the National Bank of Belgium decided to add 5 percentage points to the risk weight of residential real estate assets for several Belgian banks in order to strengthen their buffers against potential adverse developments in the real estate market.²² The outcomes of such a sector-specific measure on macro and financial variables are assessed in Figure 7.²³

²² That is, banks that calculate regulatory capital requirements using an IRB approach, which held the largest share of residential real estate loans among Belgian financial institutions.

²³ Note that we are focusing here on the activation costs of this measure. Releasing the buffers in the event of a shock to the mortgage segment would yield gains similar to those described in the previous section.

The 5 percentage point increase in mortgage risk weights is simulated as a very persistent policy shock (i.e. with an autoregressive coefficient of 0.9999). It leads to an immediate decline in the ratio of bank capital to risk-weighted assets. The resulting increase in the probability of breaching capital requirements induces the wholesale unit to set higher wholesale spreads on NFC and mortgage loans. As a result, lending rates on new NFC and mortgage loans increase and the profits are used to build up more bank capital. The objective of the measure is thus achieved as banks gradually increase their capital to asset ratio.

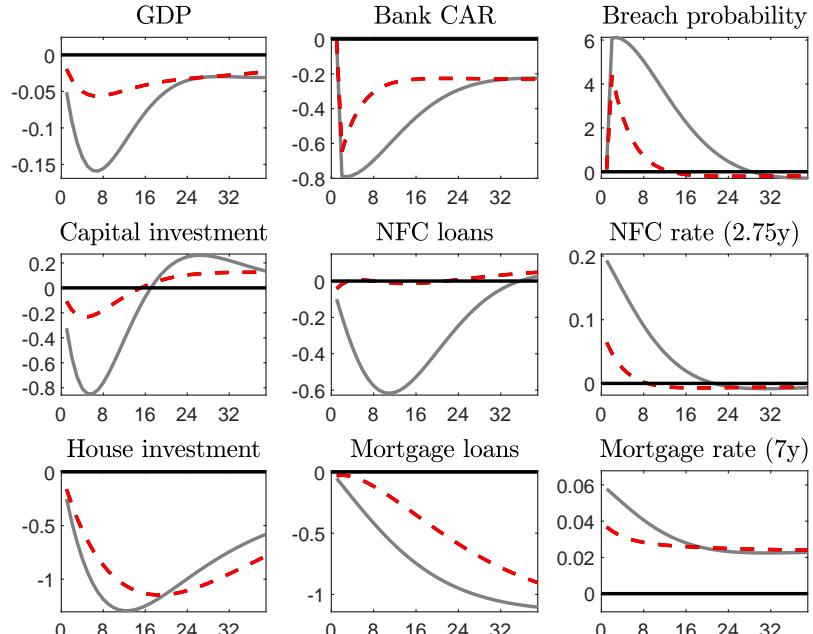
The costs of higher capital requirements are passed on to mortgage loans. The model prediction of a 6 basis points response of the interest rate applied to new mortgage loans on impact echoes the findings of [Ferrari et al. \(2017\)](#). These authors analyze the 2013 NBB risk weight add-on using panel regressions and finds that this measure had a limited effect on mortgage loan rates. Our model also predicts that lending rates are persistently raised by 2 basis points to compensate for the fact that capital is more costly than the other bank liabilities.

The increase in mortgage rates deters credit and housing investment. In line with [Ferrari et al. \(2017\)](#), our model suggests a small reaction of mortgage loan growth in the short term. The long-term response in BEMGIE is however more important as mortgage retail rates are persistently raised, and mortgage credit volumes contract up to around 1% after 10 years. This persistent impact emerges from the quasi-permanent feature of the simulated shock that makes the probability to breach capital adequacy persistently more sensitive to the mortgage loan exposures (see Equations 28 and 32) and thus pushes the wholesale mortgage spread above steady state as long as the measure is in place. After a short-lived spike, homeowners' leverage and default probabilities decline after the measure is implemented. The subsequent reduction in retail spreads gives rise to second-round effects that mitigate the contractionary nature of the policy.

Interestingly, the model generates significant spillovers to the NFC segment in the short run, in the form of unintended crowding-out effects²⁴. In our setup, banks feature a universal structure as the wholesale unit – subject to the capital requirement – is affected by both NFC and mortgage segment activities. With this structure the bank finds it optimal to share the consequence of the change in mortgage regulation in the two loan segments.

²⁴ This terminology is for example used in [ESRB \(2014\)](#).

(a) Macroeconomic & credit variables



(b) Spreads decomposition into channels

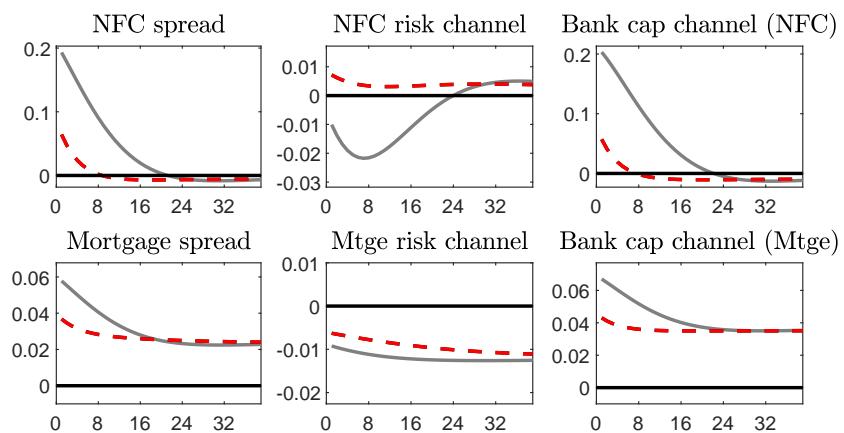


Figure 7: An increase in mortgage risk weights

Note: Variables in percentage deviation from steady state. Inflation, interest rates, default rates, and spreads annualized. Horizon in quarters. NFC and mortgage rates and spreads apply to new multi-period loans. In the one-period setup, they represent the rates at which new multi-period loans would be granted. Grey = Baseline. Dashed-red = one period debts.

The NFC wholesale rate is thus affected by the stricter mortgage risk-weight policy. This would not be the case in a more segmented banking structure, where banks specialize in one type of market (NFC or mortgage), as it is the case in the 3D model (Mendicino et al., 2018).

The unintended fall in business investment is the main channel through which the shock affects output, given the relatively low weight of residential investment compared to capital investment in Belgian GDP (0.06 vs. 0.18 respectively). In addition, the long maturity of bank loans – especially for mortgages – also amplifies the impact of this shock. Indeed, bank capital accumulation is slower when banks cannot adjust the interest rate on the outstanding amount of previously issued fixed-rate loans, and the market timing effect encourages borrowers to delay investment, as the increase in bank lending rates is stronger in the initial phase but gradually fades away.

These crowding out effects are limited to the short run. Once banks have built up their capital buffers and the probability of default has returned to its equilibrium level, the interest rate charged to NFCs also returns to its steady state. The overall impact on Belgian output is thus limited due to the low weight of residential investment in GDP, the limited and short-lived response of capital investment and the muted response of private consumption. Overall, the output costs of higher mortgage risk weights are limited in the short run and particularly low in the long run because business investment quickly recovers.

It is also interesting to note that while banks accumulate more capital, there is a long-run decline in capital ratios in terms of new risk-weighted assets. In fact, the decline in borrower riskiness and credit volume and the increase in bank capital bring the probability of violating the official capital requirements towards its steady state – in line with banks' risk appetite – without the need to restore the initial ratio of capital buffer to risk-weighted assets.

Finally, we describe the sensitivity of these unintended crowding out effects to changes in a few parameters, allowing us to identify situations in which these effects are particularly severe. We measure these unintended crowding out effects with the ratio of its indirect effect on the untreated sector (e.g., on business investment) to its direct effect on the treated sector (on housing investment). Specifically, we define the crowding out effects of an increase in

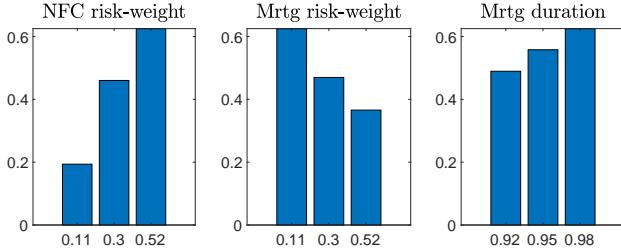


Figure 8: Crowding-out effects: sensitivity analysis

mortgage specific risk-weights (CEM) as

$$CEM = \frac{\sum_{t=0}^8 \hat{I}_t^k}{\sum_{t=0}^8 \hat{I}_t^h} \quad (45)$$

where \hat{I}_t^k and \hat{I}_t^h are the IRFs of business and housing investment to an increase in mortgage risk-weights, respectively. Note that our results are similar when using other key variables, such as the lending rate or the volume of credit.

The crowding out effects increase with the risk weight in the untreated sector. We have already explained that universal banks have the ability to comply with more stringent sector-specific capital requirements by reducing exposures in the sector of their choice. Reducing exposures in a segment with a high initial risk weight buys relatively more space and is more effective in reducing the risk of breaching capital requirements. This effect can be seen from Equations (27) and (31) that show how the cost of capital is passed through to lending rates for NFCs. Combining these equations gives

$$R_t^{w,k} - R_t = \chi_w E_t \left(J(\bar{\omega}_{t+1}^w) + J'(\bar{\omega}_{t+1}^w) \times \frac{R_t - (1 - \tau_t^k \bar{car}_t) R_t^{w,k} - \bar{\omega}_t^w}{L_t^k + L_t^h} \times (L_t^h + L_t^k) \right)$$

which shows that there is an interaction between $J'(\bar{\omega}_{t+1}^w)$ and the NFC risk-weight. The increase in J' – resulting from the higher sensitivity of the odds of breaching requirements when voluntary buffers are reduced by higher mortgage risk-weights – is magnified by the NFC risk-weight.

For a similar reason, the crowding out effects decrease in the initial risk weight of the treated sector. What matters is thus the risk weight gap, and we are more likely to observe unintended crowding out effects when the risk weight of the untreated sector is larger than

that of the treated sector – as it is the case for the mortgage add-on discussed above.

The crowding out effects also increase with the loan duration of the treated sector. Thus, increasing the risk weight in a segment that has long maturities – such as residential mortgages – has larger unintended consequence on the other sector. The reason is quite simple: with longer maturities and fixed rates, there is a large outstanding amount of mortgage loans for which the bank must hold higher buffers without being able to raise the interest rate to match the increase in capital adequacy costs. At the same time, there is a limited number of new mortgage loans for which the lending rate can be increased. In such a context, the bank has a stronger incentive to raise the lending rate charged on the untreated sector as well. The long maturity of mortgage loans temporarily protects homeowners from the increase in lending rates induced by higher capital requirements, but slows down the necessary adjustment of bank capital – if this capital is built up only with retained earnings – and thus encourages banks to raise all lending rates on new loans in the short run.

7 Conclusion

In this paper, we extend the DSGE model used at the NBB to include universal banks that provide both corporate and mortgage loans. We add multi-period fixed-rate loans, an imperfect pass-through from the policy rate to the deposit rate, and bank capital requirements to the model. These extensions generate a borrower leverage channel à la BGG, a bank capital channel in which capital adequacy costs are passed on to borrowers, a market timing effect that encourages households and NFCs to delay investment when lending rates are expected to fall, and a duration mismatch on bank balance sheets.

We show that the empirically relevant addition of multi-period fixed-rate loans amplifies the effects of borrower risk shocks and macroprudential policies compared to a one-period loan setup. This amplification operates through a bank capital channel and a market timing effect. The inability of banks to reset the interest rate on the outstanding amount of previously originated loans implies that they have more difficulty adjusting to an unexpected increase in the default rate of their borrowers or to stricter capital requirements. Thus, when offering new loans in these situations, banks increase their lending rate more in a multi-period loan framework, while NFCs and households are encouraged to delay investment to avoid locking in higher interest rates. At the same time, the easing of capital requirements in times of financial stress mitigates the financial acceleration operating through the bank cap-

ital channel more than in a model with one-period loans.

This bank capital channel also propagates shocks from one sector to the next in the presence of universal banks. For example, if the capital position of banks suffers after an unexpected increase in the default rates of NFCs, universal banks pass on their higher capital costs to all their borrowers and thus also raise the interest rate they charge on new residential mortgage loans, unless countercyclical capital buffers are released. In addition, the bank capital channel may amplify the effects of monetary policy when the duration of banks' assets is greater than that of their liabilities, highlighting the importance of monitoring banks' exposure to interest rate risk.

We also show that sectoral prudential policy instruments can have unintended crowding out effects in a universal banking structure. Indeed, universal banks find it optimal to share the burden of changes in sector-specific capital requirements to both NFC and mortgage segments. These crowding out effects increase with the loan duration in the treated sector and decrease with the risk weight differential between the treated and untreated sectors. Sectoral measures implemented in the mortgage segments (such as an increase in mortgage risk weights), where loans have typically a long maturity combined with low risk-weights, are thus more likely to suffer from these unintended crowding out effects. Nevertheless, these measures also achieve their objective at a relatively low cost in terms of output loss.

We see several interesting avenues for future research in the BEMGIE model with financial frictions. Our extension concerns the Belgian bloc of the model, but could also be applied and calibrated to the euro area economy, which is also fully-fledged in BEMGIE. This would make it possible to assess the heterogeneity in the responses of Belgian variables to shocks and policies compared to euro area dynamics. Moreover, the literature has demonstrated the advantages of estimating NK-DSGE with financial data in terms of parameter identification and forecasting performance (see for instance [Cai et al., 2019](#); [Cardani et al., 2019](#)). Finally, our design of bank liabilities has been kept relatively simple in order to introduce a limited pass-through of the policy rate to bank funding costs without affecting the decision rules of households. The model may benefit from a more sophisticated description of deposit demand and supply to better capture the deposit channel of monetary policy ([Drechsler et al., 2017](#)). In addition, a distinction between stable (deposits, long-term bonds) and less stable funds, similar to the approach of [Jacob and Munro \(2018\)](#), may also be interesting to consider in the model to capture liquidity risk and simulate prudential stable funding requirements.

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Appendix

A Model

A.1 Entrepreneurs

We show here how we derive equations (13) and (14) from the entrepreneurs' optimization problem. Entrepreneurs maximize the sum of their discounted expected returns net of the cost associated to stigma expressed in their objective function (12) w.r.t $L_{j,t}^k$, $D_{j,t}^k$, and $L_{j,t}^{k,*}$ under the constraints (4), (9), and knowing their default threshold $\bar{\omega}_{t+1}^k$ given by equation (7). Let us define ψ_t as the Lagrange multiplier associated with constraint (4) and λ_t as the Lagrange multiplier associated with constraint (9).

The FOCs are given by:

$$w.r.t. L_{j,t}^k : (1 - G(\bar{\omega}_{t+1}^k)) R_{t+1}^K - R_{t+1}^K (N_t^k + L_t^k) G'(\bar{\omega}_{t+1}^k) \frac{\delta \bar{\omega}_{t+1}^k}{\delta L_t^k} \quad (46)$$

$$+ (1 - \zeta) D_t^k F'(\bar{\omega}_{t+1}^k) \frac{\delta \bar{\omega}_{t+1}^k}{\delta L_t^k} + \psi_t - \xi \Xi_{t,t+1} \psi_{t+1} = 0$$

$$w.r.t. D_{j,t}^k : -(1 - (1 - \zeta) F(\bar{\omega}_{t+1}^k)) - R_{t+1}^K (N_t^k + L_t^k) G'(\bar{\omega}_{t+1}^k) \frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} \quad (47)$$

$$+ (1 - \zeta) D_t^k F'(\bar{\omega}_{t+1}^k) \frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} + \lambda_t - \xi \Xi_{t,t+1} \lambda_{t+1} = 0$$

$$w.r.t. L_{j,t}^{k,*} : R_t^{L,k} \lambda_t + \psi_t = 0 \quad (48)$$

Since LHS (46) + $R_t^{L,k} \times$ LHS (47) = 0, we get:

$$\begin{aligned} (1 - G(\bar{\omega}_{t+1}^k)) R_{t+1}^K &= (1 - (1 - \zeta) F(\bar{\omega}_{t+1}^k)) R_t^{L,k} \quad (49) \\ &+ R_{t+1}^K (N_t^k + L_t^k) G'(\bar{\omega}_{t+1}^k) \left[\frac{\delta \bar{\omega}_{t+1}^k}{\delta L_t^k} + R_t^{L,k} \frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} \right] \\ &- (1 - \zeta) D_t^k F'(\bar{\omega}_{t+1}^k) \left[\frac{\delta \bar{\omega}_{t+1}^k}{\delta L_t^k} + R_t^{L,k} \frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} \right] \\ &- \underbrace{(R_t^{L,k} \lambda_t + \psi_t)}_{=0 \text{ eqn. (48)}} + \xi \Xi_{t,t+1} (R_t^{L,k} \lambda_{t+1} + \underbrace{\psi_{t+1}}_{=-R_{t+1}^{L,k} \lambda_{t+1} \text{ eqn. (48)}}) \end{aligned}$$

Since $G'(\bar{\omega}_{t+1}^k) = \bar{\omega}_{t+1}^k F'(\bar{\omega}_{t+1}^k) = \frac{D_{j,t}^k}{R_{t+1}^K Q_t K_{j,t}} F'(\bar{\omega}_{t+1}^k)$ the second and third lines simplify:

$$\begin{aligned} (1 - G(\bar{\omega}_{t+1}^k)) R_{t+1}^K &= (1 - (1 - \zeta)F(\bar{\omega}_{t+1}^k)) R_t^{L,k} \\ &+ \zeta D_t^k F'(\bar{\omega}_{t+1}^k) \left[\frac{\delta \bar{\omega}_{t+1}^k}{\delta L_t^k} + R_t^{L,k} \frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} \right] \\ &+ \xi \Xi_{t,t+1} \lambda_{t+1} (R_t^{L,k} - R_{t+1}^{L,k}) \end{aligned} \quad (50)$$

Since $\frac{\delta \bar{\omega}_{t+1}^k}{\delta L_t^k} + R_t^{L,k} \frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} = \frac{R_t^{L,k}}{D_t^k} \bar{\omega}_{t+1}^k - \frac{R_{t+1}^K}{D_t^k} (\bar{\omega}_{t+1}^k)^2$, we get eqn. (13):

$$\begin{aligned} (1 - G(\bar{\omega}_{t+1}^k)) R_{t+1}^K &= (1 - (1 - \zeta)F(\bar{\omega}_{t+1}^k)) R_t^{L,k} \\ &+ \zeta F'(\bar{\omega}_{t+1}^k) \bar{\omega}_{t+1}^k (R_t^{L,k} - R_{t+1}^K \bar{\omega}_{t+1}^k) \\ &+ \xi \Xi_{t,t+1} \lambda_{t+1} (R_t^{L,k} - R_{t+1}^{L,k}) \end{aligned} \quad (51)$$

Finally, eqn. (47) can be written as

$$\begin{aligned} \lambda_t &= (1 - (1 - \zeta)F(\bar{\omega}_{t+1}^k)) \\ &+ R_{t+1}^K (N_t^k + L_t^k) G'(\bar{\omega}_{t+1}^k) \frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} \\ &- (1 - \zeta) D_t^k F'(\bar{\omega}_{t+1}^k) \frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} + \xi \Xi_{t,t+1} \lambda_{t+1} \end{aligned} \quad (52)$$

Again, since $G'(\bar{\omega}_{t+1}^k) = \frac{D_{j,t}^k}{R_{t+1}^K Q_t K_{j,t}} F'(\bar{\omega}_{t+1}^k)$ and $\frac{\delta \bar{\omega}_{t+1}^k}{\delta D_t^k} = \frac{\bar{\omega}_{t+1}^k}{D_t^k}$, we get eqn. (14):

$$\lambda_t = (1 - (1 - \zeta)F(\bar{\omega}_{t+1}^k)) + \zeta F'(\bar{\omega}_{t+1}^k) \bar{\omega}_{t+1}^k + \xi \Xi_{t,t+1} \lambda_{t+1} \quad (53)$$

B Comparaison to BGG-framework

Compared to a modified BGG-framework where the (nominal) loan rate is predetermined (so it is not contingent on the realization of shocks in period t), our maximization problem is slightly different. Indeed, in this BGG-framework entrepreneurs would maximize:

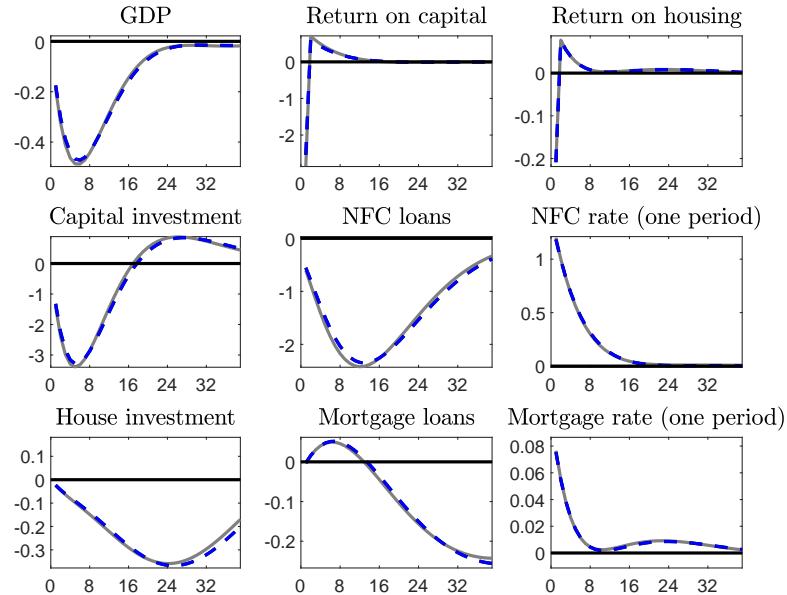
$$E_t \left\{ \int_{\bar{\omega}_{j,t+1}^k}^{\infty} \omega_j^k R_{t+1}^K Q_t K_t f(\omega_j^k) dj - \int_{\bar{\omega}_{j,t+1}^k}^{\infty} R_{j,t}^{L,k} L_t^j f(\omega_j^k) dj \right\} \quad (54)$$

under the constraint:

$$E_t R_{t+1}^{w,k} = E_t \left\{ (1 - F(\bar{\omega}_{j,t+1}^k)) R_{j,t}^{L,k} + (1 - \mu) R_{t+1}^K G(\bar{\omega}_{j,t+1}^k) Q_t K_t \right\} \quad (55)$$

We show that we can calibrate ζ to bring our model's dynamics close to the BGG variant with predetermined nominal interest rates in the one-period version of our setup (when interest rates are fully flexible). Figure 9 shows the IRFs to an NFC risk shock and to a NFC net worth shock in our model compared to the BGG variant with predetermined nominal rates. Figure 10 does the same for housing shocks. In both cases, the elasticities of the external finance premium – captured by the returns on capital and housing – are similar. We interpret these results as follow. In the BGG variant, entrepreneurs internalize the impact of their leverage decision through the response of the lending rate in Equation (55). In our model, while the lending rate only responds to aggregate leverage, a similar internalization occurs through the stigma. Entrepreneurs do not internalize the impact of their leverage decision on the bank loan rate, but they do internalize the impact of their leverage decision on their expected default rate, and thus, on their probability to face a stigma. With a proper calibration of the stigma parameters, both mechanisms deliver quantitatively similar results.

(a) Risk shock



(b) Net worth shock

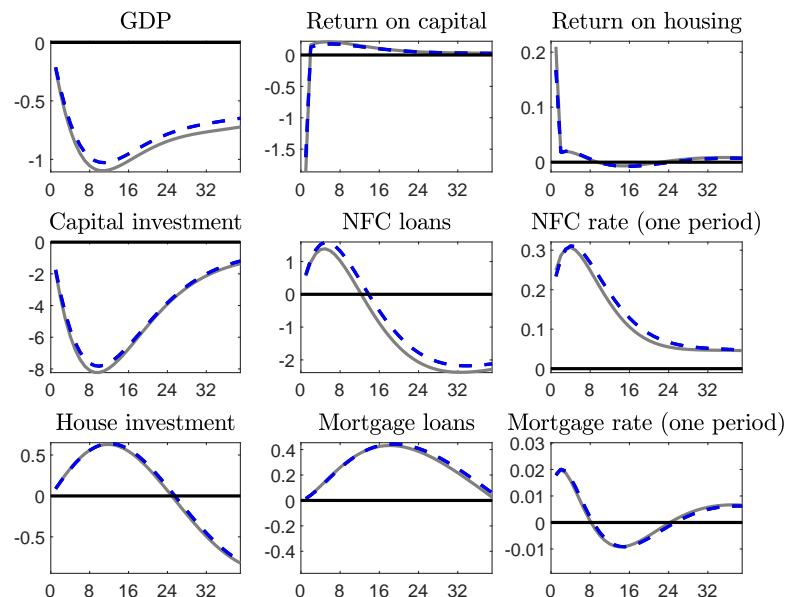
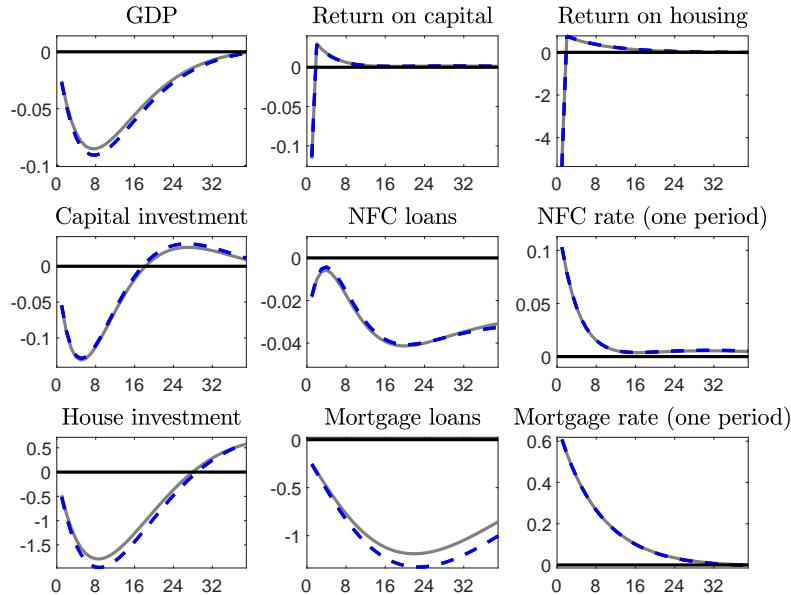


Figure 9: NFC shocks

Note: Variables in percentage deviation from steady state. Inflation, interest rates, default rates, and spreads annualized. Horizon in quarters. Grey = Baseline with one-period debt. Dashed-blue = BGG variant.

(a) Risk shock



(b) Net worth shock

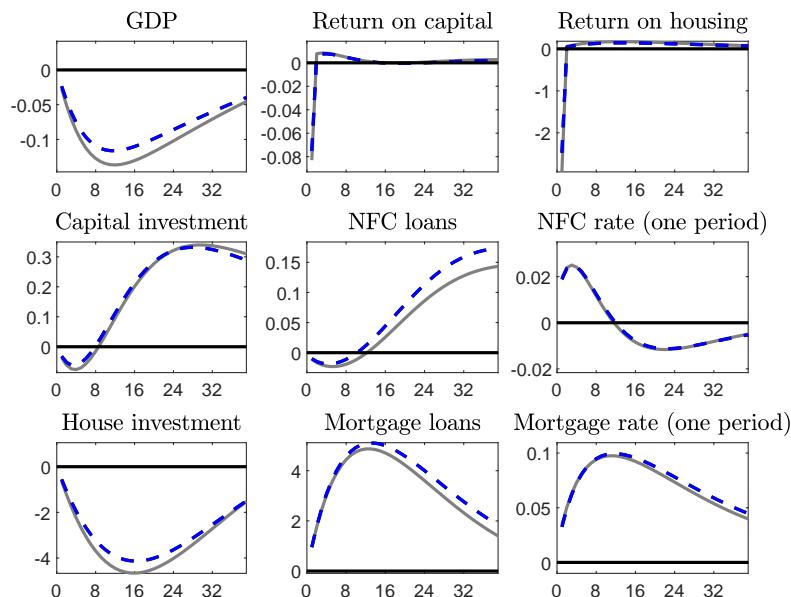


Figure 10: Housing shocks

Note: Variables in percentage deviation from steady state. Inflation, interest rates, default rates, and spreads annualized. Horizon in quarters. Grey = Baseline with one-period debt. Dashed-blue = BGG variant.

C CCyB release in one-period loan model

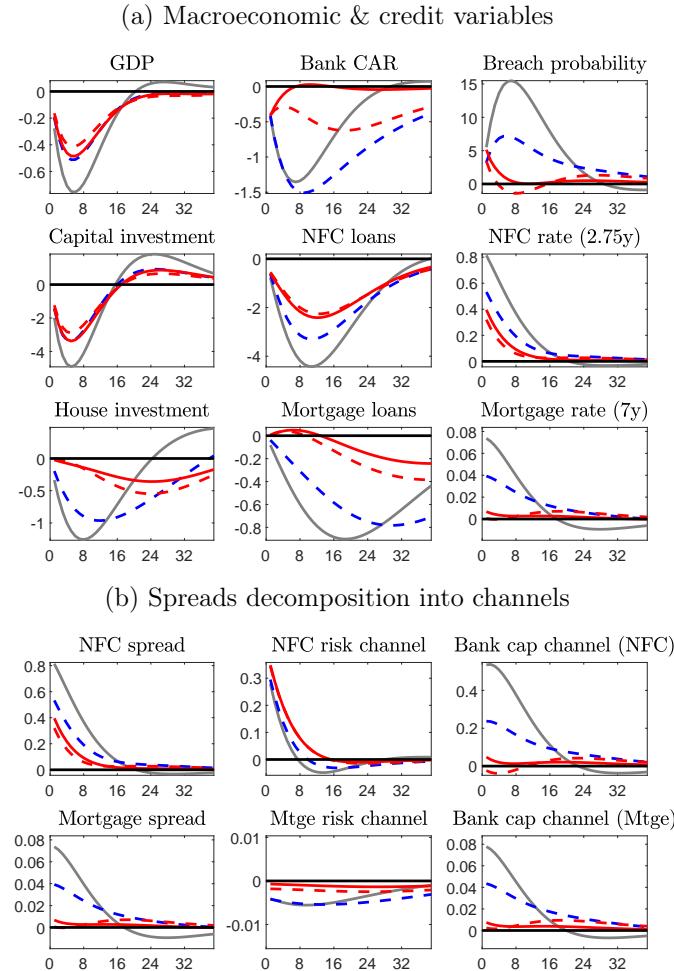


Figure 11: An increase in NFC risks with and without CCyB release

Note: Variables in percentage deviation from steady state. Interest rates, default rates, and spreads annualized. Horizon in quarters. NFC and mortgage rates and spreads apply to new multi-period loans. In the one-period setup, they represent the rates at which new multi-period loans would be granted. Spreads are expressed in terms of a risk-free loan of identical duration. Grey = baseline without CCyB release. Dashed-blue = baseline with CCyB release. Plain-red = one period debts without CCyB release. Dashed-red = one period debts with CCyB release.

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