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Macroprudential regulation and leakage to the shadow banking sector

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Abstract

Macroprudential policies are often aimed at the commercial banking sector, while a host of other non-bank financial institutions, or shadow banks, may not fall under their jurisdiction. We study the effects of tightening commercial bank regulation on the shadow banking sector. We develop a DSGE model that differentiates between regulated, monopolistic competitive commercial banks and a shadow banking system that relies on funding in a perfectly competitive market for investments. After estimating the model using euro area data from 1999 – 2014 including information on shadow banks, we find that tighter capital requirements on commercial banks increase shadow bank lending, which may have adverse financial stability effects. Coordinating macroprudential tightening with monetary easing can limit this leakage mechanism, while still bringing about the desired reduction in aggregate lending. In a counterfactual analysis, we compare how macroprudential policy implemented before the crisis would have dampened the business and lending cycles.

JEL: E32, E58, G23

Keywords: Macroprudential Policy, Monetary Policy, Policy Coordination, Non-Bank Financial Institutions, Financial Frictions

Non-technical summary

In the aftermath of the global financial crisis of 2007/2008, a broad consensus has been reached among scholars and policy makers that a *macroprudential* approach towards financial regulation should focus on systemic developments in financial markets – such as swings in aggregate credit or financial market volatility – and on the role of financial cycles for business cycle movements. Contemporaneously, the development of financial intermediaries in canonical pre-crisis dynamic stochastic general equilibrium (DSGE) models has been central to the research program, with particular attention placed on banking-augmented macro models that allow the assessment of the effectiveness of different macroprudential tools in the presence of financial frictions. However, many models largely abstract from heterogeneity in financial markets, e.g. assuming that regulators reach the entire financial sector.

In this study we develop and estimate a quantitative DSGE model for the euro area that features credit intermediation by different financial institutions: regulated commercial banks and unregulated shadow banks. On the aggregate level, the two intermediaries engage in similar activities, but differ along several dimensions on the micro-level. First, while commercial banks can directly be reached with macroprudential tools, shadow banks are unregulated in the model. In reality, the shadow banking sector comprises a multitude of diverse and highly specialized institutions, such that the implementation of universal macroprudential regulation towards the sector as a whole may prove difficult. Furthermore, while – in line with empirical evidence – commercial banks exert market power, shadow banks are assumed to be subject to market forces and modeled as price takers. Due to lack of regulation, intermediating funds via these institutions is risky, and investors will limit their exposure to shadow banks endogenously. The presence of shadow banking implies a trade-off for regulators, as tighter regulation on commercial banks induces credit leakage towards the unregulated part of the financial system.

How much credit tightening induced by macroprudential regulation will therefore be counteracted by the additional credit take-up of shadow banks? Given the diverse nature of financial firms involved in shadow bank credit intermediation, their regulation falls into the court of various regulatory authorities. This makes consistent and comprehensive regulation more difficult to attain. In the absence of macroprudential regulation of non-bank financial institutions, how can monetary policy react to limit the side effect of leakage from regulated to unregulated intermediaries after adjustments in capital requirements of commercial banks?

We employ ECB data on euro area shadow and commercial banks in a full-information Bayesian estimation exercise and employ the quantitative model for policy analyses. Overall credit fluctuation in response to monetary policy and banking regulation shocks is dampened, as shadow bank credit movements counteract deviations of commercial bank lending to some degree, resulting from the credit leakage mechanism. Furthermore, monetary policy can mitigate unintended credit leakage to the shadow banking sector in response to unanticipated increases in macroprudential regulation, as changes in short-term interest rates affect both commercial and shadow bank credit. Finally, we show in a counterfactual analysis how the level of regulatory capital would have evolved if the regulator had imposed counter-cyclical requirements already since 1999.

1 Introduction

A macroprudential approach towards financial regulation focuses on systemic developments in financial markets like swings in aggregate credit or financial market volatility, as well as on the role of financial cycles for business cycle movements.[1] While a lot of regulation has focused on the commercial banking sector[2], comprehensive regulation of the non-bank financial sector has proven to be more difficult to attain. Since non-bank financial institutions might take up some of the lending that banks have been prohibited from extending due to macroprudential policies[3], understanding the interaction between commercial bank regulation and non-bank financial institutions is crucial for the assessment of macroprudential policies.

We analyze the implications of considering non-bank financial intermediaries, or *shadow banks*, in the conduct of macroprudential regulation of the commercial banking sector. The shadow banking sector comprises a set of diverse institutions conducting highly specialized tasks in the financial system. Observed from an an aggregate level, the shadow banking sector intermediates funds from savers to borrowers in a similar fashion to the commercial banking system, but without being subject to macroprudential policies. How much of the credit tightening induced by macroprudential regulation will therefore be counteracted by the additional credit take-up of shadow banks? Given the diverse nature of financial firms involved in shadow bank credit intermediation, their regulation falls into the court of various regulatory authorities. This makes consistent and comprehensive regulation more difficult to attain. In the absence of macroprudential regulation of non-bank financial institutions, how can monetary policy react to limit the side effects?

To answer these questions, we derive a dynamic stochastic general equilibrium (DSGE) model with savers and borrowers, and two types of financial institutions that intermediate funds between these two groups: commercial banks and shadow banks. Both types of intermediaries are based on distinct microeconomic foundations that allow for structural differences with respect to regulatory coverage and market structure in the two sectors. We then apply Bayesian techniques and rely on economic and financial data for the euro area to estimate the parameters of our model.

We contribute to the literature in several ways. On the technical side, we derive a heterogeneous financial system by combining elements of two canonical frameworks for

[1] See Borio and Shim (2007), or Borio (2009, 2011) for a detailed description of the macroprudential approach.

[2] Rules laid down in the latest round of Basel accords on banking regulation (*Basel III*) strongly focus on supervisory and regulatory tools targeting macro developments in credit and risk-taking, such as rules on interbank lending, cyclical adjustments of capital requirements, and supervision on bank interconnectedness.

[3] See Cizel et al. (2019).

modeling financial frictions in DSGE models: our commercial banking sector is based on the work by Gerali et al. (2010), whereas our shadow banking sector is modeled similar to the financial sector in Gertler and Karadi (2011). This is the first paper to model both approaches in one consistent setting with heterogeneous financial markets.[4] The second contribution is the inclusion of data on euro area shadow bank lending in the estimation procedure, which has so far been limited to other jurisdictions. Third, we contribute to the policy discussion around unintended consequences of macroprudential measures and interaction with monetary policy: the presence of shadow banks can affect the setting of macroprudential policy, even if not directly enforceable on all financial intermediaries.

Effective and targeted macroprudential policy is often considered to be the first-best response in reaction to financial instability concerns (see for instance Rubio and Carrasco-Gallego, 2015). We challenge this view in the face of a growing non-bank financial sector in the euro area (see Figure 1) that remains sparsely regulated, and a potential for macroprudential and monetary policy coordination. Our approach is therefore intended as a caveat to work that considers financial stability issues of the aggregate financial sector or commercial banking sector only instead of differentiating between banking and non-bank finance. Changes in macroprudential regulation for banks can trigger *credit leakage* towards unregulated institutions, and neglecting such changes in the composition of credit can impede the efficacy of such policies.[5]

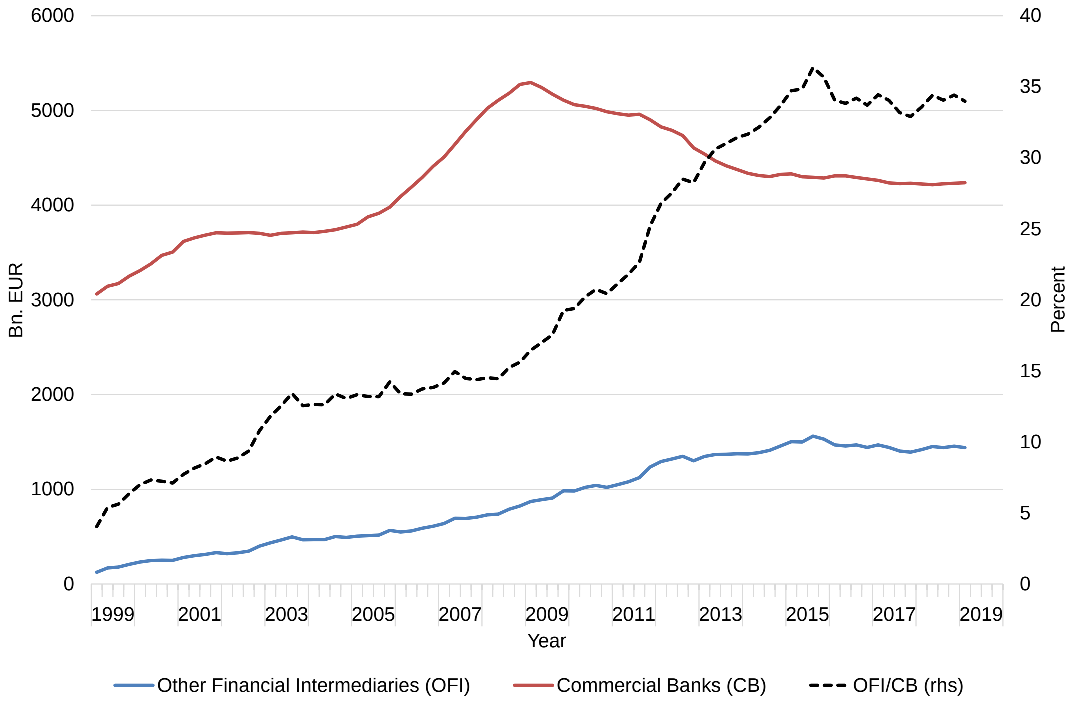
The explicit policy tool we consider in this study is capital requirement regulation, which under Basel III represents a key macroprudential tool regulators can apply to the commercial banking system to prevent banks from engaging in excessive leverage and risk-taking. Countercyclical capital requirements can be raised to avoid excessive credit growth in boom times, and lowered whenever credit developments are subdued. In a subsequent policy exercise we assess the ability of a coordinated monetary policy response in combination with macroprudential policy to limit the leakage mechanism while still bringing about the desired reduction in aggregate lending.

In the following section, we review the literature on both the current state of financial market-augmented macroeconomic models and on studies evaluating macroprudential regulation and coordination with other policy areas. We then introduce the full DSGE

[4]The updated version of the ECB's New Area Wide Model (NAWM II) depicts another example of a model where elements of both the Gerali et al. (2010) and the Gertler and Karadi (2011) framework are combined, see Coenen et al. (2019). However, the "wholesale" and "retail" banks motivated by the two frameworks are part of a representative bank holding group in this model, whereas both bank types will be separate entities in our setup.

[5]Increasing intermediation by non-bank financial institutions does not *per se* depict an undesirable development. In some circumstances, technological advances as well as lower dependency on regulatory and institutional provisions of non-bank financial institutions can increase the efficiency in the intermediation process and increase overall welfare in the economy (Buchak et al., 2018; Ordonez, 2018). However, higher shares of intermediation being conducted by unregulated shadow institutions, which may exploit regulatory arbitrage, potentially increases risks to financial stability, which is our concern here.

Figure 1: Commercial and Shadow Bank Loans to Non-Financial Corporates



Note: Outstanding amount of loans of commercial and shadow banks (OFI) to non-financial coprorates (billions of euro). Source: Euro Area Accounts and Monetary Statistics (ECB).

model in Section 3.[6] Section 4 introduces the data we use and discusses the econometric procedure we employ to derive estimates of key parameters of the model. In Section 5, we use our model to simulate the effects of neglecting shadow bank intermediation in macroprudential policy, before we conclude in Section 6.

2 Literature

The literature on DSGE models including financial intermediaries and frictions has been growing rapidly in the past years. The approach developed in Gertler and Karadi (2011) and Gertler and Kiyotaki (2011) introduces financial frictions based on an agency problem arising between banks and households, as banks are allowed to divert household funds away from investment projects for private benefits. Given that households are aware of potential misconduct, the ability of banks to obtain funding via deposits is limited.

A second strand of macro models incorporating financial frictions focuses on the role of collateral that borrowers have to place with lenders in return for funding. Iacoviello

[6] We highlight the key mechanism entailing credit leakage towards shadow banks in the wake of tighter commercial banking regulation in a simplified two-period version of the model available in the separate Online Appendix which can be found here.

and Guerrieri (2017) and Iacoviello (2005) introduce housing as collateral and relate the amount of borrowing by impatient households to movements in the value of collateral. Extending the approach, Gerali et al. (2010) introduce a banking sector in a canonical New Keynesian model for the euro area and locate the collateral friction between borrowers and banks. By modeling the banking sector explicitly, they are able to incorporate specific characteristics of the euro area banking sector, such as market power and sluggish adjustment of bank interest rates in response to changes in the monetary policy rate.

Focusing on macroprudential regulation[7], Angelini et al. (2014) implement collateral constraints and capital requirements set according to a simple rule in an estimated euro area New Keynesian DSGE model. They find that macroprudential policy is particularly effective in times of financial distress, i.e. when shocks affecting credit supply hit the economy. By employing a modeling framework based on the Holström and Tirole (1997) intermediation setup with rule-based policy makers in place, Christensen et al. (2011) find that countercyclical regulatory policies can stabilize the economy in response to shocks originating in the banking sector.

Some studies evaluate the optimal degree of coordination between macroprudential policy makers and monetary policy in banking-augmented macro models. Within a class of simple policy rules, Angeloni and Faia (2013) find that the best combination includes countercyclical capital ratios and a response of monetary policy to asset prices or bank leverage. Gelain and Ilbas (2017) introduce a central bank and a macroprudential regulator in a Smets and Wouters (2007) New Keynesian DSGE model augmented by a Gertler and Karadi (2011) financial intermediary. They find that in a fully cooperative scenario, a higher weight placed by the regulator on output gap stabilization – which depicts a joint policy objective – is beneficial for reducing macroeconomic volatility. In a non-cooperative setup, a higher weight on credit growth stabilization by the macroprudential regulator is beneficial. In a similar approach, Bean et al. (2010) find that a combination of monetary and macroprudential policies appears to be more effective as a means of leaning against the wind than relying on traditional monetary policy alone. Evaluating different policy regimes, Beau et al. (2012) find that, over the business cycle, conflicts among both policy makers should be limited. By deriving jointly optimal Ramsey policies, Collard et al. (2017) focus on different types of lending and show that limited liability and deposit insurance can cause excessive risk-taking in the financial sector. Silvo (2019) evaluates Ramsey-optimal policies in a New Keynesian framework augmented by Holström and Tirole (1997). In line with Angelini et al. (2014), she finds that macroprudential policies play a modest stabilizing role in response to aggregate supply shocks, but are highly

[7] Banking-augmented macro models are frequently employed in the evaluation of different aspects of financial stability, such as bank runs (Gertler and Kiyotaki, 2015; Gertler et al., 2016) or the effectiveness of (un-)conventional fiscal and monetary policies in times of financial distress (Gertler and Karadi, 2011; Cúrdia and Woodford, 2010a,b, 2011).

effective when the financial sector is the source of fluctuations.

In all of the above studies, financial intermediaries are modeled as homogeneous representative agents. Gertler et al. (2016) augment the canonical Gertler and Karadi (2011) framework by introducing a heterogeneous banking system with wholesale as well as retail banks. Wholesale banks represent the shadow banking part of the financial system engaged in interbank funding, whereas retail banks collect household deposits to lend to both the wholesale banks and the non-financial sector.[8] Meeks and Nelson (2017) use a calibrated model to show how the interaction between shadow banks and commercial banks can affect credit dynamics and that securitization in combination with high leverage in the shadow banking sector can have adverse effects on macroeconomic stability. Verona et al. (2013) develop a model where shadow banks directly engage in credit intermediation between households and firms. In contrast to our model, they assume that shadow banks act under monopolistic competition to derive a positive spread between the lending rate of shadow banks and the risk-free rate. They show that incorporating shadow banks increases the magnitude of boom-bust dynamics in response to an extended period of loose monetary policy. Mazelis (2016) develops a model including traditional banks, shadow banks, and investment funds and studies the relevance of different types of credit for macroeconomic volatility. He concludes that a more equity-based financial system can mitigate the credit crunch during recessions when the economy is stuck at the effective lower bound of nominal interest rates (ELB).

Closest to our study, Begenau and Landvoigt (2016) and Fève and Pierrard (2017) evaluate how the existence of shadow banks can alter the effectiveness of capital requirements. Studying the US case, the former study shows that tightening regulation for commercial banks can result in a shift of intermediation away from safer commercial banks towards unregulated and more fragile shadow banks, such that the net benefit of raising capital requirements for commercial banks only depends on the initial level of fragility in the financial system. Similarly, Fève and Pierrard (2017) estimate a real business cycle model with US data and identify a leaking of intermediation towards shadow banks. They conclude that the degree of stabilization due to higher capital requirements for commercial banks can be dampened when more funds are channeled via the shadow banking sector.[9] Aikman et al. (2018) discuss the role of credit intermediation by market-based financial institutions that do not represent traditional banks for optimal coordination between monetary and macroprudential policies.

[8] The notion of a wholesale banking sector has already been introduced in Gertler and Kiyotaki (2015). Furthermore, Gertler and Kiyotaki (2011) discuss interbank borrowing. However, no distinct separation between wholesale and retail banks has been undertaken in these studies.

[9] Alternative microfoundations for the leakage of credit towards shadow bank institutions in response to rising capital requirements were derived in the theoretical banking literature. See for instance Ordonez (2018), Farhi and Tirole (2017), Plantin (2015), or Harris et al. (2014).

3 A Sketch of the DSGE Model

In this Section, we introduce shadow banking into a DSGE model akin to the euro area banking model developed by Gerali et al. (2010) and Gambacorta and Signoretti (2014).[10] We furthermore provide a detailed description of the implication of introducing shadow banks for the effectiveness of commercial bank regulation in a stylized two-period model presented in the Online Appendix of this study. In the DSGE model, patient households serve as savers and provide funds to impatient entrepreneurs that act as borrowers, implemented by different values for the discount factor used in the utility functions of both agents. Households cannot directly provide funds to borrowing firms, but have to place deposits in financial intermediaries that then provide loans to firms, which use the funds for production.[11] Households can allocate savings between two types of intermediaries: shadow banks and commercial banks. Commercial banks face regulatory capital requirements, whereas shadow banks are not obliged by regulation to back a minimum of assets with equity. As in Gerali et al. (2010), commercial banks exert market power when setting interest rates on loans and deposits and adjust these rates incompletely in response to policy changes.

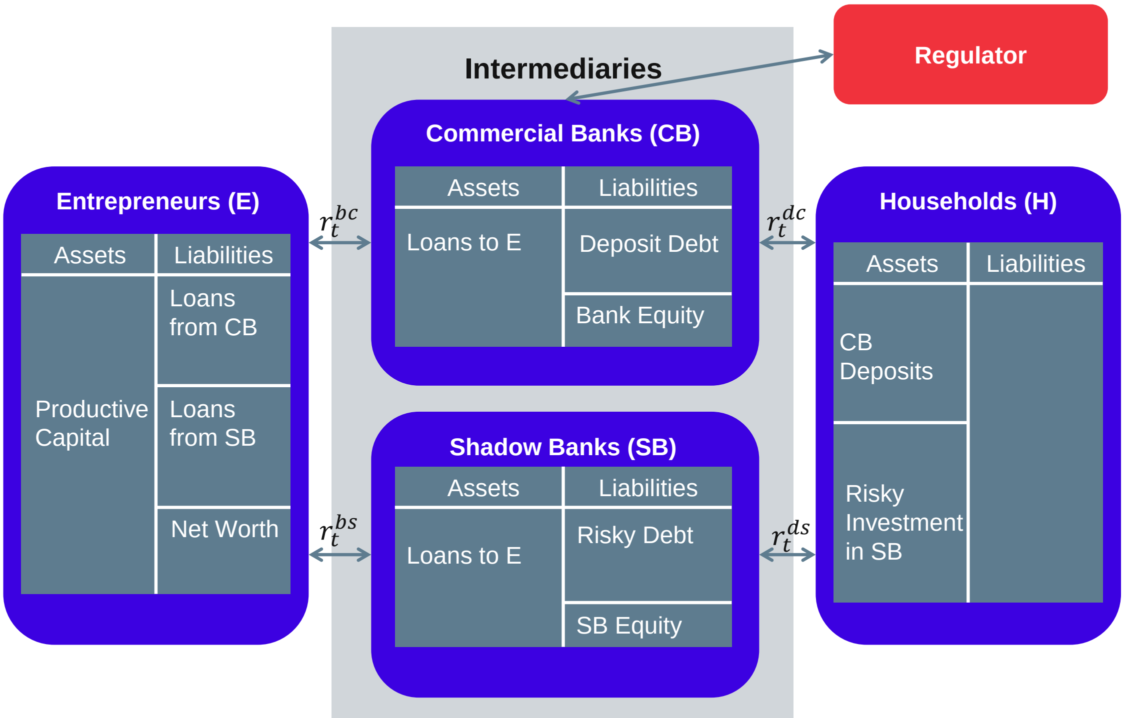
In contrast to commercial banks, shadow banks act under perfect competition. They are neither subject to macroprudential regulation, nor do they have recourse to government support schemes such as deposit insurance and central bank liquidity facilities. Consequently, saving in shadow banks is more risky from the household perspective. Default risk can thus result in a positive spread between the rates households demand from shadow banks compared to commercial banks. To capture the dependence of shadow banks on market funding, we draw on the incentive constraint in Gertler and Karadi (2011). We assume that the lack of regulation is akin to the risk that shadow bankers can divert a share of funds, defaulting on the remaining liabilities in the process. Whenever the benefits from doing so exceed the returns from behaving honestly, shadow bankers face an incentive to disappear from the market and leave investors with losses on their investments. Households are aware of this risk and limit their funding to an amount that motivates the shadow banker of continuing operations rather than diverting a share and defaulting on the rest. The implicit default risk the household faces when placing funds in shadow banks thus results in a spread between shadow bank and commercial bank deposit rates, as households demand higher compensation when placing funds in these institutions.

On the loan market, regulation only applies with respect to commercial banks, as

[10] The complete nonlinear DSGE model is presented in Appendix A.

[11] As in Gambacorta and Signoretti (2014), we assume that all debt contracts are indexed to current inflation. In this respect, we deviate from the framework in Gerali et al. (2010) and Iacoviello (2005) by eliminating the *nominal debt channel* from the model. This channel potentially affects the redistribution of funds between borrowers and savers and thus macroeconomic developments in response to unexpected changes in the price level, which we do not consider here.

Figure 2: Relationship Between Intermediaries, Savers and Borrowers



Note: Overview of model relationships between agents involved in financial intermediation.

entrepreneurs have to fulfil an externally set loan-to-value ratio when demanding funds from commercial banks. Consequently, entrepreneurs can only borrow up to a certain amount of their collateral value at hand, which is given by the stock of physical capital that they own and use for production purposes. However, they can use their remaining collateral for borrowing from shadow banks.[12] An overview of the relationships between savers, borrowers and the two intermediaries is given in Figure 2.

Households provide labor to entrepreneurs and either consume or save in financial intermediaries. Entrepreneurs produce intermediate goods and sell them on a competitive market to retailers that differentiate, repackage and sell them on in a monopolistically competitive market, resulting in a final goods price that includes a mark-up on the marginal cost. Furthermore, capital goods producers are introduced to derive a market price for capital. The central bank conducts monetary policy by setting the nominal short-term interest rate according to a Taylor rule.[13]

In the baseline model, macroprudential regulation is determined exogenously, before we introduce a macroprudential regulator that follows a countercyclical policy rule for capital

[12] Details on the microfoundation of the entrepreneur's credit constraints and the superiority of commercial bank credit are provided in the Online Appendix.

[13] In this model, we abstract from any unconventional monetary policy and assume that the economy is not at the effective lower bound (ELB) of nominal interest rates.

requirements in Section 5. In this respect, our baseline model used in the estimation procedure of Section 4 reflects the regulatory framework in the euro area in place before the introduction of Basel III. Under the preceding Basel II regulations, countercyclical adjustments of capital requirements for commercial banks were not set systematically.

3.1 Households

The representative patient household i maximizes the expected utility

$$\max_{c_t^P(i), l_t^P(i), d_t^{P,C}(i), d_t^{P,S}(i)} E_0 \sum_{t=0}^{\infty} \beta_P^t \left[(1-a^P)\varepsilon_t^z log(c_t^P(i) - a^P c_{t-1}^P) - \frac{l_t^P(i)^{1+\phi^P}}{1+\phi^P} \right] \quad (1)$$

subject to the budget constraint

$$c_t^P(i) + d_t^{P,C}(i) + d_t^{P,S}(i) \leq w_t l_t^P(i) + (1+r_{t-1}^{dC}) d_{t-1}^{P,C}(i) + (1+r_{t-1}^{dS}) d_{t-1}^{P,S}(i) + t_t^P(i) \quad (2)$$

where $c_t^P(i)$ depicts current consumption and lagged aggregate consumption is given by c_{t-1}^P. Working hours are given by l_t^P and labor dis-utility is determined by ϕ^P. Preferences are subject to a disturbance ε_t^z affecting consumption. The flow of expenses includes current consumption and real deposits to be made to both commercial and shadow banks, $d_t^{P,C}(i)$ and $d_t^{P,S}(i)$. Resources consist of wage earnings $w_t^P l_t^P(i)$ (where w_t^P is the real wage rate for the labor input of each household), gross interest income on last period deposits $(1+r_{t-1}^{dC}) d_{t-1}^{P,C}(i)$ and $(1+r_{t-1}^{dS}) d_{t-1}^{P,S}(i)$, and lump-sum transfers t_t^P that include dividends from firms and banks (of which patient households are the ultimate owners).

3.2 Entrepreneurs

Entrepreneurs use labor provided by households as well as capital to produce intermediate goods that retailers purchase in a competitive market. Each entrepreneur i derives utility from consumption $c_t^E(i)$, which it compares to the lagged aggregate consumption level of all entrepreneurs. They maximize expected utility

$$\max_{c_t^E(i), l_t^P(i), b_t^{E,C}(i), b_t^{E,S}(i)} E_0 \sum_{t=0}^{\infty} \beta_E^t log(c_t^E(i) - a^E c_{t-1}^E) \quad (3)$$

subject to the budget constraint

$$\begin{aligned} & c_t^E(i) + w_t l_t^P(i) + (1+r_{t-1}^{bc}) b_{t-1}^{E,C}(i) + (1+r_{t-1}^{bs}) b_{t-1}^{E,S}(i) + q_t^k k_t^E(i) \\ & = \frac{y_t^E(i)}{x_t} + b_t^{E,C}(i) + b_t^{E,S}(i) + q_t^k (1-\delta^k) k_{t-1}^E(i) \quad (4) \end{aligned}$$

with δ^k depicting the depreciation rate of capital, q_t^k the market price for capital in terms of consumption, and x_t determining the price markup in the retail sector.

Entrepreneurs face a constraint on the amount they can borrow from commercial banks which depends on the value of collateral the firm holds. The collateral value of the entrepreneurs is determined by their expected physical capital stock in the period of repayment $(t+1)$, which is given by $E_t[(1-\delta^k)k_t^E\Pi_{t+1}]$.[14] Whereas a regulatory loan-to-value (LTV) ratio m_t^C applies for funds borrowed from commercial banks, shadow bank funding is not prone to regulation. As outlined in detail in the Online Appendix, due to a positive spread between interest rates charged for shadow bank and commercial bank loans, entrepreneurs have an incentive to borrow from commercial banks first and turn to shadow bank lending only whenever the possible amount of commercial bank funds, determined by $m_t^C k_t^E(i)$, is reached. Further borrowing can be obtained from shadow banks by using capital holdings not reserved for commercial bank funds, $(1-m_t^C)k_t^E(i)$. Thus, the two respective borrowing constraints are given by

$$(1+r_t^{bc})b_t^{E,C}(i) \le m_t^C E_t[q_{t+1}^k(1-\delta^k)k_t^E(i)], \tag{5}$$

$$(1+r_t^{bs})b_t^{E,S}(i) \le (1-m_t^C)E_t[q_{t+1}^k(1-\delta^k)k_t^E(i)] \tag{6}$$

where the LTV ratio for commercial banks m_t^C is set exogenously by the regulator and follows an exogenous AR(1) process.

We follow Iacoviello (2005) and assume that the borrowing constraints bind around the steady state such that uncertainty is absent in the model.[15] Thus, in equilibrium, entrepreneurs face binding borrowing constraints, such that Equations 5 and 6 both hold with equality.

3.3 Financial Intermediaries

Both commercial banks and shadow banks intermediate funds between households and firms. While they both engage in intermediation in a similar fashion, we assume the two types of agents to be structurally different along various dimensions.

First, we assume that commercial banks are covered by banking regulation, which implies that they have to fulfill requirements on the amount of capital they have to hold

[14] In Iacoviello (2005), entrepreneurs use commercial real estate as collateral. However, we follow Gerali et al. (2010) by assuming that creditworthiness of a firm is judged by its overall balance sheet condition where real estate housing only depicts a sub-component of assets.

[15] Iacoviello (2005) discusses the deviation from the certainty equivalence case in Appendix C of his paper.

compared to the size of their balance sheet. Second, they are eligible for central bank liquidity assistance and government guarantees such as deposit insurance schemes.[16] Thus, for households and firms, commercial banks depict safe deposit institutions, given that they are both covered by regulation and have access to government support schemes. We furthermore assume market power in the loan and deposit markets for commercial banks,[17] and model it using the same Dixit-Stiglitz framework as employed in Gerali et al. (2010). Thus, in both loan and deposit markets, commercial banks are able to charge some markup on loan rates and pay deposit rates conditional on a markdown. In line with Gerali et al. (2010), we model commercial banks by distinctively separating a single bank into three units: two retail branches responsible for retail lending and retail deposits, respectively, and one wholesale branch that manages the bank capital position. While the two retail branches operate under monopolistic competition, we assume lending and deposit taking between retail and wholesale units to operate perfectly competitively.

Shadow banks, in contrast, face no regulatory burden but in turn are not covered by structural support schemes. Consequently, the shadow banking sector increasingly depends on creditor trust, which is captured by a moral hazard problem that governs the degree of leverage of shadow bank institutions. Whereas commercial banks' charter values as well as their funding opportunities via central banks provide a buffer in case of illiquidity, shadow banks are exposed to funding pressures that can lead to instantaneous exit from participation in the market. Reduced regulatory burdens in the establishment of shadow banking operations supports regular inflow to this market. As a consequence, while we assume commercial banks to be infinitely lived in our model, we allow for frequent entry to and exit from the shadow banking system.

3.3.1 Commercial Banks

In the following, we discuss the maximization problem of the wholesale unit of the commercial bank as the capital requirement set by regulators applies directly to this branch of the commercial bank.[18] Due to space limitations, we will not discuss the maximization problems of the retail deposit and loan branches here as they are identical to the problems outlined in Gerali et al. (2010) and we refer to their study.

Wholesale Unit The wholesale branches of commercial banks operate under perfect competition and are responsible for the capital position of the respective commercial bank.

[16] Even though not explicitly modeled, the assumption of an existing insurance scheme lies behind the idea of shadow bank deposits being more risky than deposits placed with commercial banks.

[17] The existence of market power in the euro area was indicated in various empirical studies, see for instance Fungáčová et al. (2014) or De Bandt and Davis (2000).

[18] Thus, the modeling of the wholesale unit closely resembles the commercial bank outlined in Section 1.3.1. in the Online Appendix.

On the asset side, they hold funds they provide to the retail loan branch, b_t^C, and these retailers ultimately lend the funds to entrepreneurs as credit $b_t^{E,C}$. As retailers act under monopolistic competition, the retail rate r_t^{bc} comprises a markup over the wholesale loan rate r_t^C. On the liability side, the wholesale unit combines commercial bank net worth, or capital, k_t^C, with wholesale deposits, d_t^C, that are provided by the retail deposit branch, but originally stem from deposits placed in the retail branch by patient households ($d_t^{P,C}$). Furthermore, the capital position of the wholesale branch is prone to a regulatory capital requirement ν_t^C. Moving away from the regulatory requirement imposes a quadratic cost to the bank, which is proportional to the outstanding amount of bank capital and parameterized by κ_k^C.

The wholesale branch maximization problem can be expressed as

$$\max_{b_t^C,\, d_t^C} \; r_t^C b_t^C - r_t^{dC} d_t^C - \frac{\kappa_k^C}{2}\left(\frac{k_t^C}{b_t^C} - \nu_t^C\right)^2 k_t^C \tag{7}$$

subject to the the balance sheet condition

$$b_t^C = k_t^C + d_t^C. \tag{8}$$

The first-order conditions yield the following expression:

$$r_t^C = r_t^{dC} - \kappa_k^C\left(\frac{k_t^C}{b_t^C} - \nu_t^C\right)\left(\frac{k_t^C}{b_t^C}\right)^2. \tag{9}$$

As the commercial bank has access to central bank funding in the model, we assume that the rate paid on wholesale deposits gathered from the retail deposit unit of the commercial bank (and so originally from households and firms) has to be equal to the risk-free policy rate, r_t, via arbitrage:

$$r_t^{dC} = r_t$$

such that the spread between the loan and deposit rates on the wholesale level is given by

$$r_t^C = r_t - \kappa_k^C\left(\frac{k_t^C}{b_t^C} - \nu_t^C\right)\left(\frac{k_t^C}{b_t^C}\right)^2. \tag{10}$$

This expression indicates that the marginal benefit from further lending, the spread earned on intermediation at the margin, has to be equal to the marginal costs from doing so in equilibrium. This marginal cost increases whenever the deviation of commercial bank capital holdings from the regulatory requirement increases.

Assuming symmetry between banks and reinvestment of profits in banks, aggregate bank capital K_t^C is accumulated from retained earnings only:

$$K_t^C = (1 - \delta^C)K_{t-1}^C + J_{t-1}^C \tag{11}$$

where J_t^C depicts aggregate commercial bank profits derived from the three branches of the bank, see Gerali et al. (2010). Capital management costs are captured by δ^C.

3.3.2 Shadow Banks

In contrast to the commercial banking sector, shadow banks do not operate under monopolistic competition. The shadow banking sector is assumed to consist of a multitude of differentiated and specialized business entities, which, taken together, engage in similar intermediation activity as commercial banks. Given the flexibility and the heterogeneity of the shadow banking system, we assume shadow banks operate under perfect competition.

Instead of being constrained by regulation, as commercial banks are, shadow banks' ability to acquire external funds is constrained by a moral hazard problem that limits the creditors' willingness to provide external funds. To avoid excessive equity capital accumulation – and eventually exclusive financing via equity rather than debt – shadow bankers are assumed to have a finite lifetime: Each shadow banker faces an i.i.d. survival probability σ^S with which they will be operating in the next period. This exit probability functions in the maximization problem of the shadow banker as an additional discount factor, which ensures that they are always net debtors to the households. To make up for the outflow, every period new shadow bankers enter with an initial endowment of w^S they receive in the first period of existence. The number of shadow bankers in the system remains constant.[19]

As long as the real return on lending $(r_t^{bS} - r_t^{dS})$ is positive, it is profitable for the shadow bank to accumulate capital until they exit the intermediation sector. Thus, the shadow bank's objective to maximize expected terminal wealth, $v_t(j)$, is given by

$$v_t(j) = \max E_t \sum_{i=0}^{\infty} (1 - \sigma^S){\sigma^S}^i {\beta^S}^{i+1} k_{t+1+i}^S(j). \tag{12}$$

We introduce a moral hazard problem that leads to the possibility of positive spreads earned by shadow banks.[20] We allow for the possibility that shadow banks divert a fraction of available funds, θ^S, and use them for private benefits at the beginning of each period. Households can consequently only recover the leftover share $(1-\theta^S)$ afterwards. However,

[19] The complete derivation of the shadow bank problem and a deeper discussion of the approach used is presented in Section A.3.2 of Appendix A.

[20] See Section 2 in the Online Appendix.

diverting funds and "running away" is equivalent to declaring bankruptcy for the shadow bank, such that it will only do so if the return of declaring bankruptcy is larger than the discounted future return from continuing operations:

$$v_t(j) \geq \theta^S q_t^k b_t^{E,S}(j). \tag{13}$$

Equation 13 depicts the incentive constraint the shadow banker faces when trying to acquire funds from households.[21] As we assume some shadow bankers to exit each period and new bankers to enter the market, aggregate capital k_t^S is determined by the capital of continuing shadow bankers, $k_t^{S,c}$, and the capital of new bankers that enter, $k_t^{S,n}$

$$k_t^S = k_t^{S,c} + k_t^{S,n} \tag{14}$$

and combining the expressions for $k_t^{S,c}$ and $k_t^{S,n}$ derived in Appendix A yields the following law of motion for shadow bank capital:

$$k_t^S = \sigma^S[(r_{t-1}^{bS} - r_{t-1}^{dS})\phi_{t-1}^S + (1 + r_{t-1}^{dS})]k_{t-1}^S + \omega^S q_t^k b_{t-1}^{E,S}. \tag{15}$$

The shadow bank balance sheet condition

$$q_t^k b_t^{E,S}(j) = d_t^{P,S}(j) + k_t^S(j) \tag{16}$$

in combination with the demand for shadow bank credit by borrowers given by Equation 6 determines shadow bank lending $b_t^{E,S}(j)$.

Finally, we assume a non-negative spread between the interest rates earned on shadow bank deposits, r_t^{dS}, and on the deposits households can place with commercial banks, r_t^{dC}, which is determined by the parameter τ^S, with $0 \leq \tau^S \leq 1$. In Section 1.1. of the Online Appendix, we provided a microfoundation for the existence of a positive spread, and use the results to incorporate a relationship between the two deposit rates similar to the relation stated in Equation 4 in the two-period model:

$$1 + r_t^{dS} = \frac{1 + r_t^{dC}}{1 - \tau^S \varepsilon_t^{\tau}}. \tag{17}$$

As in the two-period version of the model, the parameter τ^S determines the spread

[21] Compared to Equation 37 in the Online Appendix, the interest rate term on the right-hand side is missing here. In the DSGE model, we do not have fixed shadow bank capital, but interest returns from the previous period are booked into shadow bank capital at the end of a respective period. In the infinite-horizon case, the timing of events is such that at the beginning of any period t, shadow banks use net worth $k_t^S(j)$ together with deposits $d_t^{P,S}(j)$ to lend out financial claims $b_t^{E,S}(j)$. Afterwards, the shadow banker decides whether to run away or not. In case of behaving honestly, they receive net returns $r_t^{bS} - r_t^{dS}$ on intermediation at the end of period t, and these returns are then part of the capital stock in the next period, $k_{t+1}^S(j)$.

between the gross rates on both deposit types and is implicitly related to the default probability of shadow banks. As a shortcut, we calibrate τ^S and assume the existence of a spread shock ε_t^τ following an auto-regressive process to motivate exogenous swings in the spread on interest rates earned on the two deposit types.

4 Estimation

4.1 Data

All economic variables used in the estimation exercise are drawn from the European System of Accounts (ESA 2010) quarterly financial and non-financial sector accounts, provided by the ECB and Eurostat.[22] For the real and nominal economy, we include information on real gross domestic product, real consumption, real investment, and consumer price as well as wage inflation. Information on commercial bank balance sheets – commercial bank deposits held by private households and commercial bank loans granted to the non-financial corporate sector – is gathered from the data set in "Monetary Financial Institutions" (MFIs) collected by the ECB. Data on commercial bank interest rates on household deposits and firm loans are drawn from different sources within the ECB Statistical Data Warehouse and harmonized in line with the procedure recommended by Gerali et al. (2010). We also use the short-term EONIA rate as a quarterly measure of the policy rate. For shadow bank variables, we use information provided in the ECB data base on different monetary and other financial institutions, as discussed in detail in Appendix B.

We apply full-information Bayesian techniques to estimate some of the model parameters. Our baseline sample covers the period between 1999:Q1 and 2013:Q4, as we assume that the effective lower bound (ELB) on nominal interest rates in the euro area was reached in 2014.[23] Furthermore, as the effective implementation of the Basel III framework under the Capital Requirements Directive IV (CRD IV) of the European Union took place from 2014:Q1 onward, we estimate our baseline model reflecting the regulatory landscape under Basel II for the period before the implementation of the new framework.[24]

In total, we use eleven time series,[25] and we apply the Metropolis-Hastings algorithm

[22] See Appendix B for a detailed description of the data set.

[23] See for instance Coeuré (2015) for a discussion of the beginning of the ELB period in the euro area. We conduct a robustness analysis using a different sample period in Appendix C.

[24] In the euro area, the implementation of Basel III is governed by the Capital Requirements Directives IV (CRD IV) and the subsequent Regulation on Prudential Requirements for Credit Institutions and Investment Firms (CRR), which came into force on January 1, 2014. Thus, as euro area countries did not implement the policy measures put forward under Basel III before the beginning of 2014, we are effectively covering the pre-Basel III era of banking regulation in the euro area with our sample for the baseline estimation.

[25] See charts in Figure 10 of Appendix B.

to derive draws from the posterior distribution, by running five chains with 500,000 draws each in the baseline estimation. We evaluate convergence in the estimation by considering the approach of Brooks and Gelman (1998). We furthermore check for the identification of parameters following Ratto and Iskrev (2011).[26]

4.2 Calibration and Prior Distributions

Table 1 depicts calibrated parameters. In most cases, we apply the calibration used by Gerali et al. (2010). We adjust parameters on the loan (deposit) rate markup (markdown) for commercial bank lending ε^{bE} (ε^{d}) to match the mean spreads in our extended sample. As the loan rate markup (deposit rate markdown) is given by $\frac{\varepsilon^{bE}}{\varepsilon^{bE}-1}$ ($\frac{\varepsilon^{d}}{\varepsilon^{d}-1}$), we set parameters to match the average annualized loan rate spread (deposit rate spread) with respect to the EONIA of 240 basis points (35 basis points) in our extended sample.[27]

In addition, by incorporating shadow banks and macroprudential regulation in the model, we introduce three new parameters: τ^S, θ^S, and σ^S. Given our broad definition of shadow banks, finding empirical equivalents to shadow bank deposit returns is not straightforward. The shadow bank aggregate we consider covers institutions with highly diverse investment portfolios, different types of investors placing funds, and ultimately highly varying returns on the specific activity they are engaged in. We calibrate τ^S such that the implied default probability of shadow banks is approximately five percent per quarter and the resulting annualized spread between shadow bank and commercial bank deposit rates is approximately two percentage points in steady state.

Furthermore, we ensure in the calibration that the share of shadow bank intermediation in total intermediation is approximately one-third in steady state and that the size of the average shadow bank loan portfolio is three times the size of shadow bank capital. These values are comparable to statistical figures derived in empirical studies on the euro area shadow banking sector based on similar data (Bakk-Simon et al., 2012; Malatesta et al., 2016) and resemble average values in our data set. The latter calibration allows us to treat σ^S as a transformed parameter in the estimation, and the resulting post-estimation value is given by 0.944. Our value of θ^S, the share of divertible funds, turns out to be lower than the calibrated value in Gertler and Karadi (2011), where the authors settled on a value of 0.381 in the calibration of the US model.[28] Furthermore, we set the steady-state commercial bank capital requirement, $\overline{\nu^C}$, equal to 8 percent, which resembles the

[26] Details on convergence statistics and identification tests are available upon request.

[27] In Gerali et al. (2010), the retail deposit rate spread is stated to be 125 basis points. However, we include the period after 2008 in our sample, where bank market power was adversely affected by the global financial crisis and the debt crisis in Europe and thus lending and deposit margins for commercial banks were reduced significantly.

[28] An economic interpretation of the lower share that intermediaries can divert in the euro area could be given by a higher degree of creditor protection.

Table 1: Calibrated Parameters

Parameter	Description	Value
τ^S	Deposit Rate Spread Parameter	0.05
θ^S	SB Share of Divertible Funds	0.2
σ^S	SB Survival Probability	0.944
$\overline{\nu^C}$	Steady-State Capital Requirement	0.08
ϕ^P	Inverse Frisch Elasticity of Labor Supply	1
β_P	Discount Factor Households	0.9943
β_E	Discount Factor Entrepreneurs	0.975
$\overline{m^C}$	Steady-State LTV Ratio vs. Commercial Banks	0.3
α	Capital Share in Production Function	0.2
ε^d	Deposit Rate Markdown Given by $\frac{\varepsilon^d}{\varepsilon^d-1}$	-0.9
ε^{bE}	Loan Rate Markup Given by $\frac{\varepsilon^{bE}}{\varepsilon^{bE}-1}$	2
ε^y	Goods Market Markup Given by $\frac{\varepsilon^y}{\varepsilon^y-1}$	6
ε^l	Labor Market Markup Given by $\frac{\varepsilon^l}{\varepsilon^l-1}$	5
δ^k	Depreciation Rate Physical Capital	0.025
δ^b	Bank Capital Management Cost	0.1049

overall level of capital-to-asset holdings demanded from commercial banks under Basel II. The steady-state LTV ratio for commercial banks $\overline{m^C}$ is calibrated following Gerali et al. (2010), implying relatively strict regulation on collateral and a significant scope for shadow bank lending based on collateral criteria.[29]

For the prior distributions, we mostly follow Gerali et al. (2010) for the parameters originally estimated in their study. As we apply a Calvo (1983) pricing framework instead of Rotemberg (1982), we rely on a prior distribution similar to those introduced by Smets and Wouters (2003, 2007) for the Calvo parameter θ^p. We choose a slightly tighter prior distribution for the Taylor-rule parameter on inflation and change the distribution on the respective output parameter to a Beta distribution compared to the Normal distribution used in the original study. We thus give preference to a prior distribution that does not, even theoretically, allow for negative values of the parameter. Table 2 reports prior and posterior distributions for structural parameters as well as parameters describing exogenous processes. As in Gerali et al. (2010), we take the posterior medians as parameter estimates, and report estimates derived in their study for comparability.

For the parameter that governs the cost of deviation from the capital requirement, κ_C, we assume a uniform distribution ranging from 0 to 25. Since this parameter is difficult to identify in an observable empirical counterpart, the non-informative nature of this prior in principle allows sufficient flexibility for the posterior to assume a broad range of values depending on the highest likelihood of the entire model and parameter set.

We finally use the same priors for all exogenous process parameters, including the

[29] Changing the LTV ratio to higher levels does not change the estimation results dramatically.

parameters related to the two newly introduced shocks to the spreads between shadow bank and commercial bank returns (ε_t^τ), as can be seen in Table 2.

4.3 Posterior Distributions

In Table 2 we also report summary statistics of the posterior distributions for the model parameters. We furthermore provide marginal densities of the prior and posterior distributions for the structural parameter estimates in Figure 11 in Appendix B.

Even though the mode of the posterior for the Calvo parameter turns out to be slightly lower than the estimate derived in Smets and Wouters (2003), price stickiness is a significant feature in the model. The posterior mode for the investment adjustment cost parameter κ^i turns out to be of similar magnitude as the parameter derived in Smets and Wouters (2003), whereas Gerali et al. (2010) report a larger value for this parameter.

Sluggish interest rate adjustment appears particularly strong in the market for commercial bank deposits, indicated by high posterior mode and median values for the deposit rate adjustment cost parameter κ^d. Furthermore, loan rates adjust more rapidly to changes in the policy rate compared to commercial bank deposit rates. Commercial banks therefore appear to react to changes in monetary policy by a more flexible adjustment of loan rates in response to competition from shadow banks which operate under perfect interest-rate pass through, compared to a situation where shadow banking is absent.

As indicated in the previous section, the uniform prior for the commercial bank capital requirement adjustment cost parameter κ_k^C was selected due to a weak identification problem, and the resulting estimated median turns out to be slightly lower than in Gerali et al. (2010).[30] Parameters related to monetary policy are broadly in line with results derived for instance in Gerali et al. (2010) and Smets and Wouters (2003), with our estimated posterior modes for the Taylor rule parameters ϕ^π, ϕ^y and ϕ^r taking on values in-between the estimated parameters derived in these studies. Finally, household habit formation is slightly weaker than in Gerali et al. (2010). For all shock processes, persistence turns out to be relatively high, with the processes for commercial bank deposit rate markdown shocks and price markup shocks depicting exceptions.

[30] We conducted a sensitivity analysis to evaluate the robustness of the estimation and found that model dynamics are unchanged when this parameter is varied.

Table 2: Prior and Posterior Distributions

		Prior Distribution			Posterior Distribution				GNSS (2010)
		Distribution	Mean	Std.Dev.	5 Perc.	Median	95 Perc.	Mode	(Median)
Structural Parameters									
θ^p	Calvo Parameter	Beta	0.5	0.10	0.83	0.87	0.90	0.86	-
κ^i	Investment Adjustment Cost	Gamma	2.5	1.0	2.98	3.98	5.14	3.67	10.18
κ^d	Deposit Rate Adjustment Cost	Gamma	10.0	2.5	10.00	13.26	16.72	12.62	3.50
κ^{bE}	Loan Rate Adjustment Cost	Gamma	3.0	2.5	4.84	8.34	14.23	7.56	9.36
κ_k^C	CCR Deviation Cost	Uniform	0.0	25.0	0.01	10.05	21.32	24.71	11.07
ϕ^π	TR Coefficient π	Gamma	1.5	0.25	1.44	1.87	2.30	1.75	1.98
ϕ^y	TR Coefficient y	Gamma	0.20	0.05	0.14	0.24	0.34	0.20	0.35
ϕ^r	Interest Rate Smoothing	Beta	0.75	0.10	0.84	0.88	0.91	0.88	0.77
a^P	HH Habit Formation	Beta	0.50	0.10	0.70	0.77	0.84	0.77	0.86
Exogenous Processes (AR Coefficients)									
ρ^τ	Deposit Rate Spread	Beta	0.8	0.1	0.62	0.81	0.95	0.85	-
ρ^z	Consumer Preference	Beta	0.8	0.1	0.82	0.87	0.92	0.87	0.39
ρ^a	Technology	Beta	0.8	0.1	0.31	0.42	0.52	0.42	0.94
ρ^{mE}	Entrepreneur LTV	Beta	0.8	0.1	0.91	0.94	0.97	0.95	0.89
ρ^d	Deposit Rate Markdown	Beta	0.8	0.1	0.27	0.36	0.46	0.36	0.84
ρ^{bE}	Loan Rate Markup	Beta	0.8	0.1	0.51	0.63	0.75	0.64	0.83
ρ^{qk}	Investment Efficiency	Beta	0.8	0.1	0.33	0.46	0.58	0.49	0.55
ρ^y	Price Markup	Beta	0.8	0.1	0.25	0.36	0.47	0.37	0.31
ρ^l	Wage Markup	Beta	0.8	0.1	0.64	0.71	0.77	0.71	0.64
ρ_k^C	Commercial Bank Capital	Beta	0.8	0.1	0.93	0.96	0.99	0.97	0.81
Exogenous Processes (Standard Deviations)									
σ^τ	Deposit Rate Spread	Inverse Gamma	0.01	0.05	0.002	0.007	0.016	0.005	-
σ^z	Consumer Preference	Inverse Gamma	0.01	0.05	0.008	0.011	0.014	0.011	0.027
σ^a	Technology	Inverse Gamma	0.01	0.05	0.025	0.029	0.033	0.028	0.006
σ^{mE}	Entrepreneur LTV	Inverse Gamma	0.01	0.05	0.006	0.008	0.009	0.007	0.007
σ^d	Deposit Rate Markdown	Inverse Gamma	0.01	0.05	0.002	0.002	0.002	0.002	0.032
σ^{bE}	Loan Rate Markup	Inverse Gamma	0.01	0.05	0.002	0.002	0.003	0.002	0.063
σ^{qk}	Investment Efficiency	Inverse Gamma	0.01	0.05	0.001	0.002	0.002	0.002	0.019
σ^r	Monetary Policy	Inverse Gamma	0.01	0.05	0.001	0.001	0.002	0.001	0.002
σ^y	Price Markup	Inverse Gamma	0.01	0.05	0.001	0.002	0.002	0.001	0.598
σ^l	Wage Markup	Inverse Gamma	0.01	0.05	0.035	0.041	0.047	0.040	0.561
σ_k^C	Commercial Bank Capital	Inverse Gamma	0.01	0.05	0.003	0.003	0.004	0.003	0.031

Note: Results are based on 5 chains with 500,000 draws each based on the Metropolis-Hastings algorithm. GNSS (2010) refers to the results reported in Gerali et al. (2010).

5 Policy Analyses

We use our estimated model to evaluate whether disregarding credit intermediation via the shadow banking sector in macroprudential policy decisions has quantitative implications for policy decisions and the macroeconomy. In this context, we discuss potential implications for policy coordination between central banks and macroprudential regulators. Furthermore, in a counterfactual analysis, we assess how regulators would have set capital requirements under a countercyclical policy rule in the fashion of the Basel III regulatory framework had it been in place throughout the existence of the common currency. To do so, we introduce a policymaker following a countercyclical rule in the pre-Basel III model and simulate the development of capital requirements over the course of the monetary union. We thereby evaluate the implications from policy rules with different target variables. Furthermore, we discuss to what extent the level of implied capital requirements would have changed if regulators took not only commercial bank credit, but overall credit into account.

5.1 Macroprudential Regulation

In the following analyses, we discuss different regulatory regimes, depending on the degree of shadow bank consideration. We therefore implement, in the estimated Basel II model, different types of regulators that follow countercyclical rules for adjusting commercial bank capital requirements. We take key elements of the Basel III framework into account: countercyclical adjustment of capital requirements in response to swings in the credit cycle and the primary focus on commercial banking in the application of macroprudential policy. As indicated above, before the implementation of Basel III, the requirement on total capital holdings was 8 percent, and no countercyclical adjustment of requirements was intended. We raise the steady-state capital requirement for all regulator types from 8 percent to 10.5 percent[31] and change the capital requirement equation in the model from an exogenous AR(1) process to a regulation-specific countercyclical rule described in more detail below. We leave the rest of the calibration and estimated parameters unchanged, as they were derived from the estimation using the true regulatory setup and economic data before the implementation of Basel III.

We discuss two different versions of the Basel III macroprudential regulator – in addition to the case without countercyclical capital regulation as under Basel II – that can apply capital requirements only to commercial banks, but cannot enforce regulation on the shadow banking system. The difference between these types emerges from the degree

[31] The Basel III capital requirement consist of different types of buffers banks have to hold: 8 percent (minimum Tier 1+2 capital) plus 2.5 percent (capital conservation buffer), yielding 10.5 percent for total capital.

to which shadow banking is considered when setting capital requirements for commercial banks. We define a *moderate* regulator that only takes variation in commercial bank credit into account when setting capital requirements for commercial banks. In comparison, a *prudent* regulator considers overall credit, which includes both commercial and shadow bank credit.[32]

The macroprudential policy rules we consider resemble the countercyclical capital requirement on commercial bank balance sheets introduced with the Basel III accords. The macroprudential authority raises the requirement on the capital-to-asset ratio whenever a certain credit measure rises above the level perceived as stable, and lowers the requirement whenever the credit gap is negative. We distinguish between four target variables that indicate the credit cycle: credit levels, credit growth, as well as the level and the growth rate of the credit-to-GDP ratio.[33] The regulator thus raises the capital-to-asset ratio ν_t^C above the steady-state level of capital requirements $\overline{\nu^C}$ whenever the respective measure deviates positively from its steady-state value, and vice versa.

5.1.1 The Moderate Regulator

We first evaluate the policy setting of a moderate regulator that only focuses on developments in commercial bank credit when setting capital requirements for commercial banks. The policy rules the moderate regulator follows in each scenario resemble the rule derived in Angelini et al. (2014) where deviations of the respective credit measure from steady state are targeted:

$$\text{Credit Growth Rule:} \quad \nu_t^C = (1-\rho^\nu)\overline{\nu^C} + (1-\rho^\nu)\chi_\nu \Delta \widehat{B}_t^M + \rho^\nu \nu_{t-1}^C + \varepsilon_t^\nu, \tag{18}$$

$$\text{Credit/GDP Growth Rule:} \quad \nu_t^C = (1-\rho^\nu)\overline{\nu^C} + (1-\rho^\nu)\chi_\nu \Delta \widehat{Z}_t^M + \rho^\nu \nu_{t-1}^C + \varepsilon_t^\nu, \tag{19}$$

$$\text{Credit Level Rule:} \quad \nu_t^C = (1-\rho^\nu)\overline{\nu^C} + (1-\rho^\nu)\chi_\nu \widehat{B}_t^M + \rho^\nu \nu_{t-1}^C + \varepsilon_t^\nu, \tag{20}$$

$$\text{Credit/GDP Level Rule:} \quad \nu_t^C = (1-\rho^\nu)\overline{\nu^C} + (1-\rho^\nu)\chi_\nu \widehat{Z}_t^M + \rho^\nu \nu_{t-1}^C + \varepsilon_t^\nu, \tag{21}$$

where

$$\widehat{B}_t^M = b_t^{E,C} - \overline{b^{E,C}},$$
$$\widehat{Z}_t^M = \frac{b_t^{E,C}}{Y_t} - \frac{\overline{b^{E,C}}}{\overline{Y}}$$

[32]Under Basel III, the specific credit measure that should be applied is not stated explicitly in the regulatory statutes, and the primary focus of regulators lies on credit intermediated by commercial banks.

[33]The choice of target variables is inspired by the common measures employed in the DSGE literature on capital requirements. See for instance Rubio and Carrasco-Gallego (2016), Bekiros et al. (2018), Angelini et al. (2014), Angeloni and Faia (2013), and Christensen et al. (2011).

and Δ indicates the difference of a variable compared to its one-period lag. The reaction parameter χ_ν determines the degree of policy sensitivity, and we calibrate it to a value of 7, which is broadly in line with the parameter values derived in Angelini et al. (2014). Furthermore, we allow for exogenous shocks ε_t^ν to the capital requirement, and assume an auto-regressive shock process and smoothing in the adjustment of capital requirements, governed by parameter ρ^ν which we calibrate at a value of 0.9.

5.1.2 The Prudent Regulator

In addition, a prudent regulator is introduced that takes lending by the shadow banking sector into account when setting capital requirements for commercial banks. Despite the lack of a unifying regulatory framework for shadow banks, we assume that the prudent regulator is able to derive estimates of non-bank credit intermediation. The regulator therefore considers not only commercial bank credit, but movements in *overall* credit.[34] The policy rules stated in Equations 18 to 21 are thus altered for the prudent regulator such that:

$$
\begin{aligned}
&\text{Credit Growth Rule:} && \nu_t^C = (1-\rho^\nu)\overline{\nu^C} + (1-\rho^\nu)\chi_\nu \Delta \widehat{B}_t^P + \rho^\nu \nu_{t-1}^C + \varepsilon_t^\nu, && (22)\\
&\text{Credit/GDP Growth Rule:} && \nu_t^C = (1-\rho^\nu)\overline{\nu^C} + (1-\rho^\nu)\chi_\nu \Delta \widehat{Z}_t^P + \rho^\nu \nu_{t-1}^C + \varepsilon_t^\nu, && (23)\\
&\text{Credit Level Rule:} && \nu_t^C = (1-\rho^\nu)\overline{\nu^C} + (1-\rho^\nu)\chi_\nu \widehat{B}_t^P + \rho^\nu \nu_{t-1}^C + \varepsilon_t^\nu, && (24)\\
&\text{Credit/GDP Level Rule:} && \nu_t^C = (1-\rho^\nu)\overline{\nu^C} + (1-\rho^\nu)\chi_\nu \widehat{Z}_t^P + \rho^\nu \nu_{t-1}^C + \varepsilon_t^\nu, && (25)
\end{aligned}
$$

where

$$
\begin{aligned}
\widehat{B}_t^P &= (b_t^{E,C} + b_t^{E,S}) - (\overline{b^{E,C}} + \overline{b^{E,S}}),\\
\widehat{Z}_t^P &= \frac{b_t^{E,C} + b_t^{E,S}}{Y_t} - \frac{\overline{b^{E,C}} + \overline{b^{E,S}}}{\overline{Y}}.
\end{aligned}
$$

5.2 Impulse Response Analysis

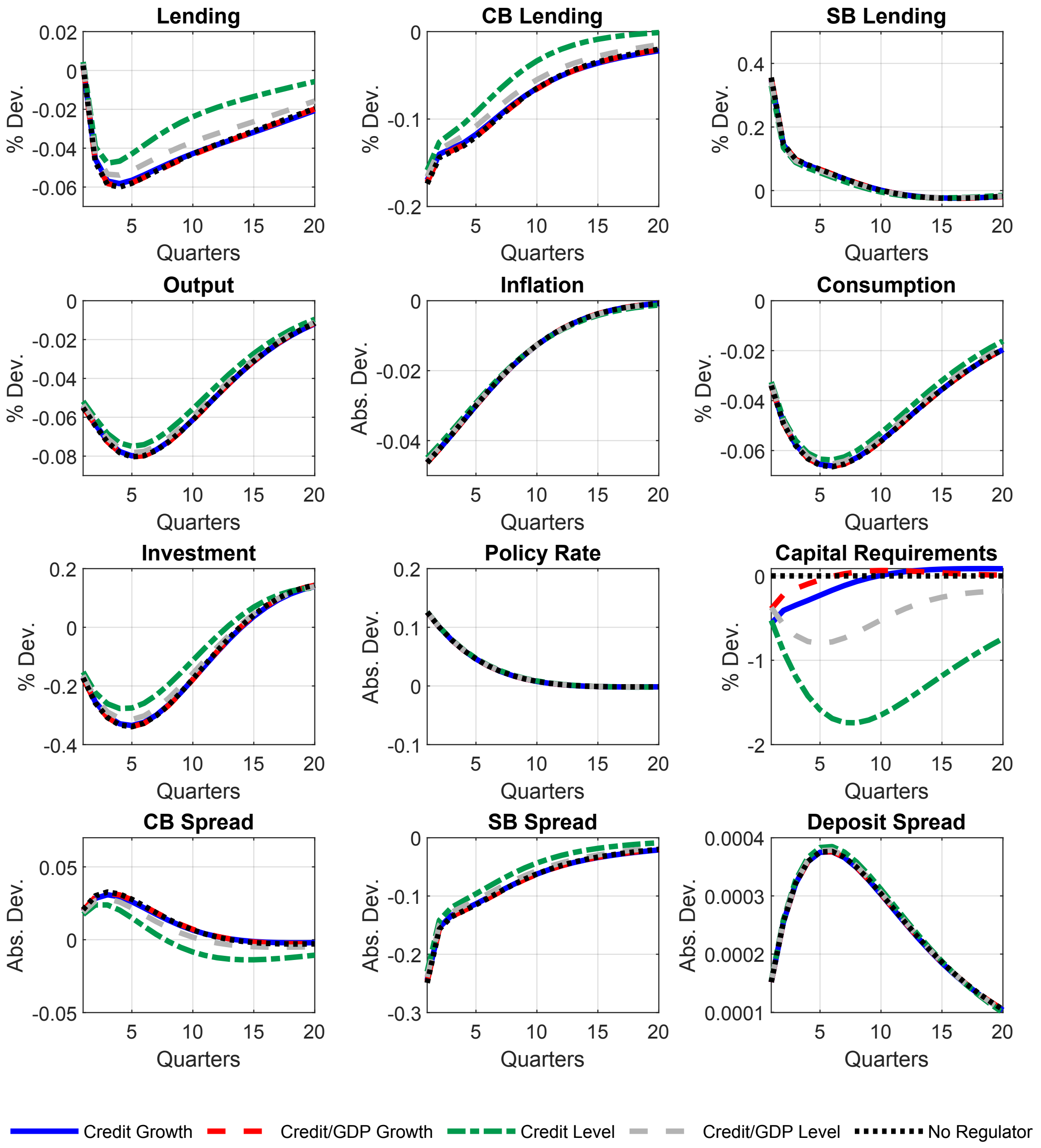
In the following, we derive impulse responses for two policy shocks: a standard monetary policy shock and a shock to commercial bank capital requirements. We analyze the first shock to evaluate whether our model is able to replicate stylized facts from the large literature on monetary policy shocks, and to study potentially differing reactions of commercial bank and shadow bank intermediation. We then evaluate the impact of

[34] The ECB has stressed the importance to consider both commercial bank *and* overall credit in their "scoreboard approach" for macroprudential regulation. See for instance Constâncio et al. (2019) for a review of the ECB's approach towards macroprudential policy and the role of market-based finance in regulatory statutes.

an unanticipated increase of capital requirements to shed light on credit leakage towards shadow bank intermediation in response to tighter commercial bank regulation. We finally discuss the potential of coordination between monetary and macroprudential policies to avoid potentially unintended side effects of tighter commercial bank regulation, i.e. credit leakage towards the shadow banking sector.

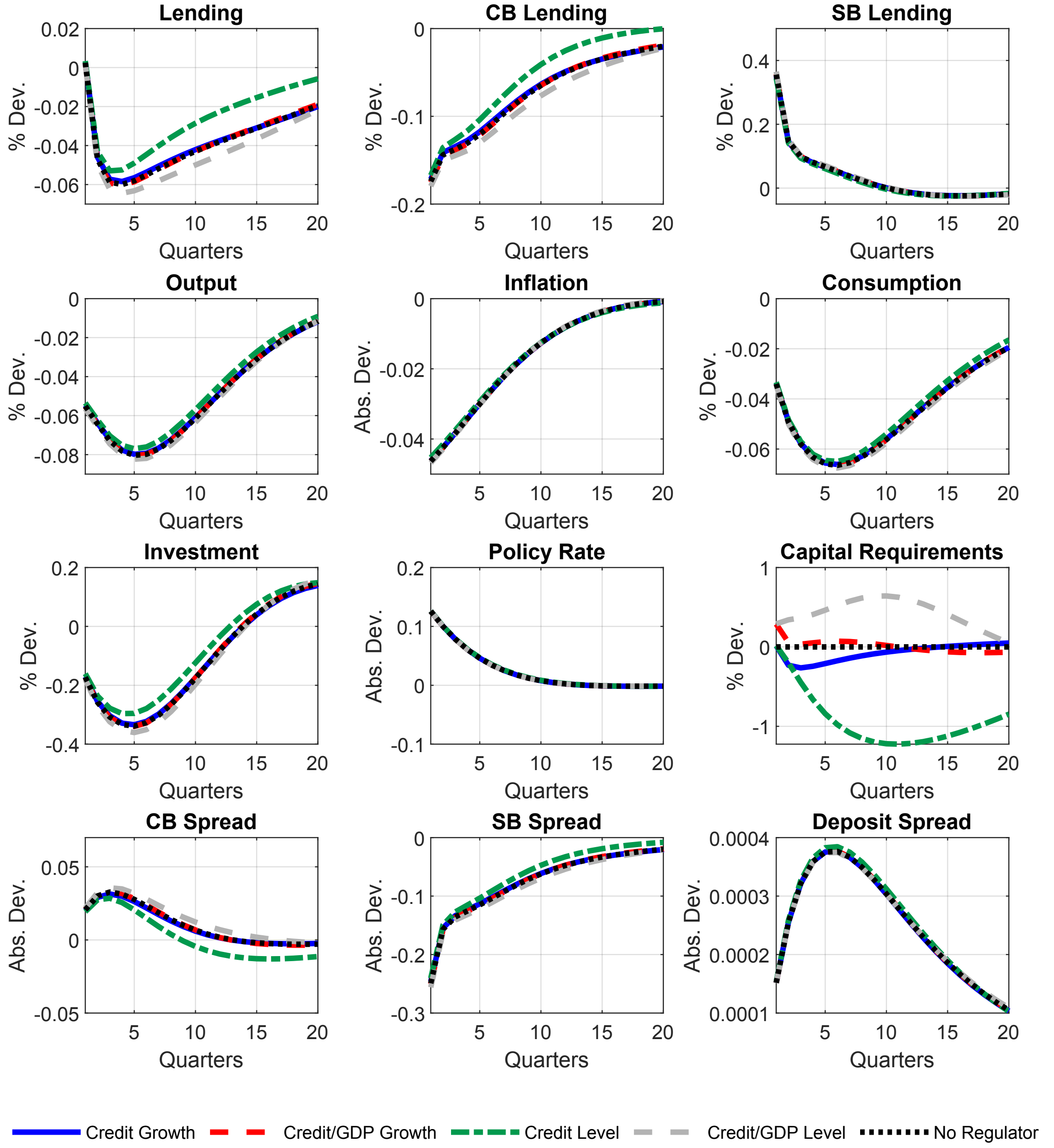
5.2.1 Monetary Policy Shock

Figure 3: Impulse Responses: Monetary Policy Shock – Moderate Regulator



Note: Impulse responses to a one-standard-deviation monetary policy shock. Rates in absolute deviations from steady state, all other variables as percentage deviations from steady state.

Figure 4: Impulse Responses: Monetary Policy Shock – Prudent Regulator



Note: Impulse responses to a one-standard-deviation monetary policy shock. Rates in absolute deviations from steady state, all other variables as percentage deviations from steady state.

Several empirical studies have identified different reactions in credit intermediated within and outside the regular banking system in response to monetary policy shocks. Igan et al. (2017) find that some institutions (money market mutual funds, security broker-dealers) increase their asset holdings after monetary policy tightening, whereas issuers of asset-backed securities (ABS) decrease their balance sheets. Pescatori and Sole (2016) use a VAR framework including data on commercial banks, ABS issuers, and other finance companies as well as government-sponsored entities (GSEs). They find, inter alia, that monetary policy tightening decreases aggregate lending activity, even though the size of the non-bank intermediary sector increases. Similarly, Den Haan and Sterk (2011), using US flow-of-funds data, find that non-bank asset holdings increase in response to monetary tightening, even though overall credit declines or stays relatively flat. Mazelis (2016) distinguishes between commercial banks depending on deposit liabilities, highly levered shadow banks which depend on funding from other intermediaries, and investment funds that draw funding from real economic agents directly. He finds that, whereas commercial bank credit remains relatively flat after monetary tightening and is reduced only in the medium term, shadow banks and investment funds increase lending in response to monetary policy tightening in the short term. Nelson et al. (2018) find similar results when looking at aggregate balance sheets, even though their definition of shadow banks differs from that in Mazelis (2016). For European banks, Altunbas et al. (2009) show that institutions engaged to a large extent in non-bank activities, such as securitization, are less affected by monetary policy shocks.

We report the reaction of model variables to an unanticipated increase in the policy rate by 12.5 basis points in Figures 3 and 4. In line with standard findings, output and its subcomponents – consumption and investment – decline in a hump-shaped manner and inflation falls in response to tighter monetary policy. Total lending is reduced as credit costs increase due to higher interest rates, while aggregate demand deteriorates. Bank intermediation spreads increase, as monopolistic competitive banks raise lending rates to generate profits, which compensates for the decline in lending volume.[35] However, higher commercial bank loan rates increase lending costs for borrowing firms. The collateral constraint 5 indicates that the amount of borrowing firms can obtain from commercial banks is limited by the LTV ratio m_t^C and the value of non-depreciated physical capital $q_{t+1}^k(1-\delta^k)k_t^E(i)$. Due to this borrowing limitation, an increase in the borrowing cost firms face when acquiring loans from commercial banks $1+r_t^{bc}$ causes a decline in the quantity of commercial bank loans $b_t^{E,C}(i)$.

On the margin, borrowers will find it profitable to switch to alternative sources of funding. Shadow banks face higher refinancing costs due to an increasing risk premium, reflected in the widening of the deposit rate spread. They are extending loan supply and accept a decline in the intermediation spread on impact to generate profits. Thus, the decline in commercial bank lending is partly counteracted by an increased intermediation and leverage of shadow banks. Whereas commercial bank credit falls by approximately 0.18 percent in response to higher interest rates in all scenarios, shadow bank credit increases by approximately 0.35 percent. We therefore confirm empirical evidence on the presence of credit leakage towards shadow banks in response to tighter monetary policy

[35]This finding is consistent with studies relying on a homogeneous description of the financial sector, see for instance Gerali et al. (2010).

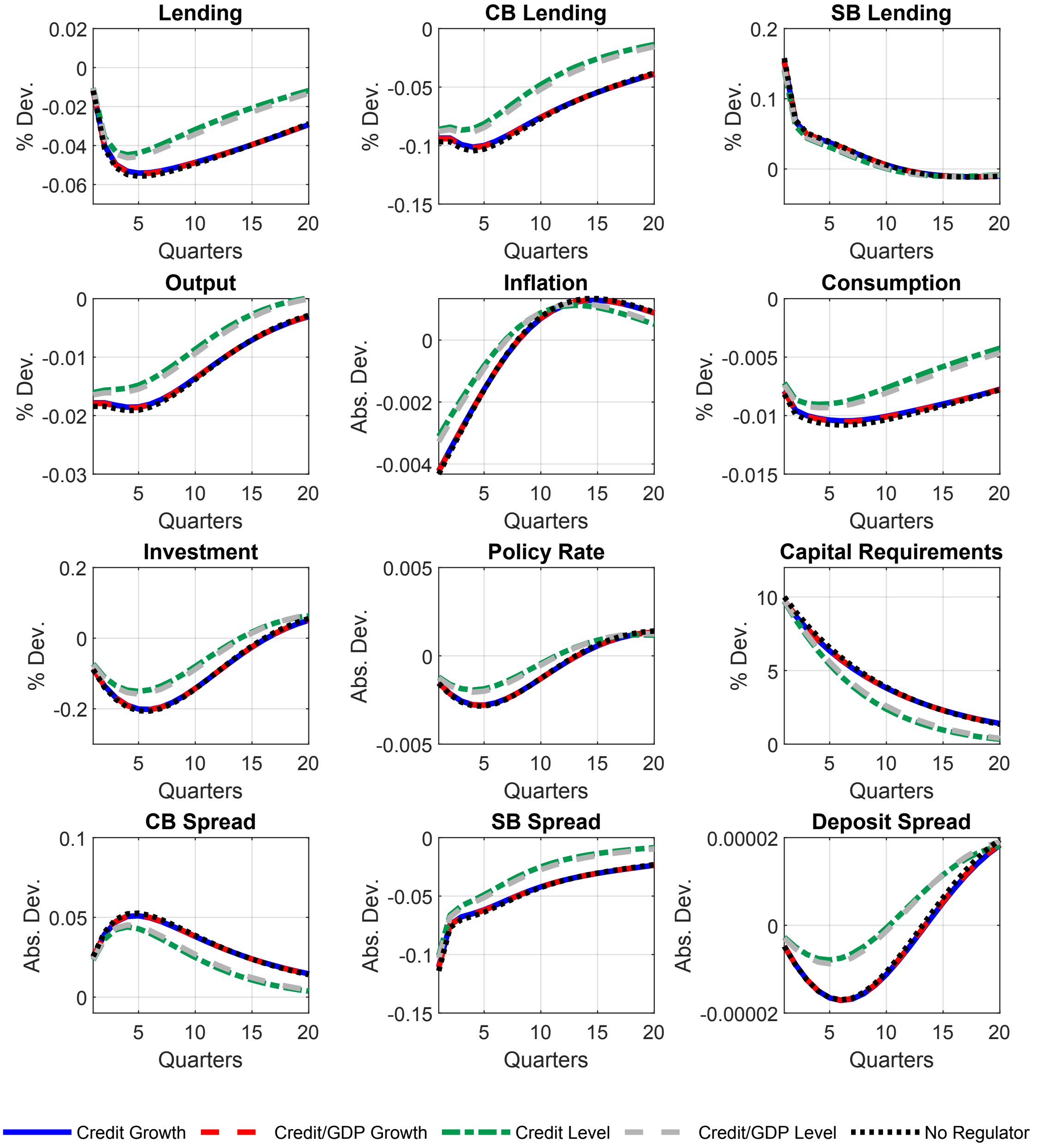
in our model.

For the moderate regulator, the decline in credit and real activity is larger for rules based on growth rates (solid blue and dashed red lines in Figures 3 and 4) than for level rules (dashed green and gray lines). Policy makers relying on level rules lower capital requirements more aggressively in response to a monetary tightening, and thus the overall decline in lending is mitigated. For all types of rules, a moderate policymaker only concerned with developments in the commercial banking sector lowers capital requirements to a larger extent than the prudent counterpart when confronted with higher interest rates. Quantitatively, a moderate regulator cuts capital requirements by half a percent on impact, which depicts a reduction of roughly five basis points compared to the steady-state level of capital requirements. While the requirements are quickly readjusted back to the steady-state level under growth-based rules, capital requirements are eased by up to 1.8 percent, or 19 basis points under the credit level-based rule.

The easing of capital regulation is significantly less pronounced under the prudent regulator (Figure 3). Strikingly, a regulator considering both commercial bank and shadow bank credit would actually increase capital requirements in our stylized simulation exercise whenever the rule is based on the credit-to-GDP (growth) gap. The significant increase in shadow bank credit, and a relatively strong decline in GDP – the denominator of the credit-to-GDP ratio – in response to higher interest rates is sufficient to trigger a slight increase in capital requirements. In turn, the reduction in overall credit is even more pronounced in the prudent regulation case with credit-to-GDP as in the moderate regulator case, and compared to the benchmark situation of no countercyclical policy maker. Also, the reduction in aggregate demand and output is slightly more pronounced in the case of a prudent macroprudential regulator.

We take this finding as indication that a different treatment of shadow banks in policy considerations can lead to different policy prescriptions in response to macroeconomic shocks, with respective consequences for macroeconomic developments and financial stability. Ultimately, the response by regulators depends on the primary objective of macroprudential policy. As we do not explicitly take the effect of shadow banking on financial stability into account, the results here indicate that a regulator concerned with excessive lending by unregulated shadow banks – and a *potentially* resulting increase in financial instability – would prescribe a different policy for commercial banks when developments in the shadow banking sector are taken into considerations.[36]

Figure 5: Impulse Responses: Capital Requirement Shock – Moderate Regulator



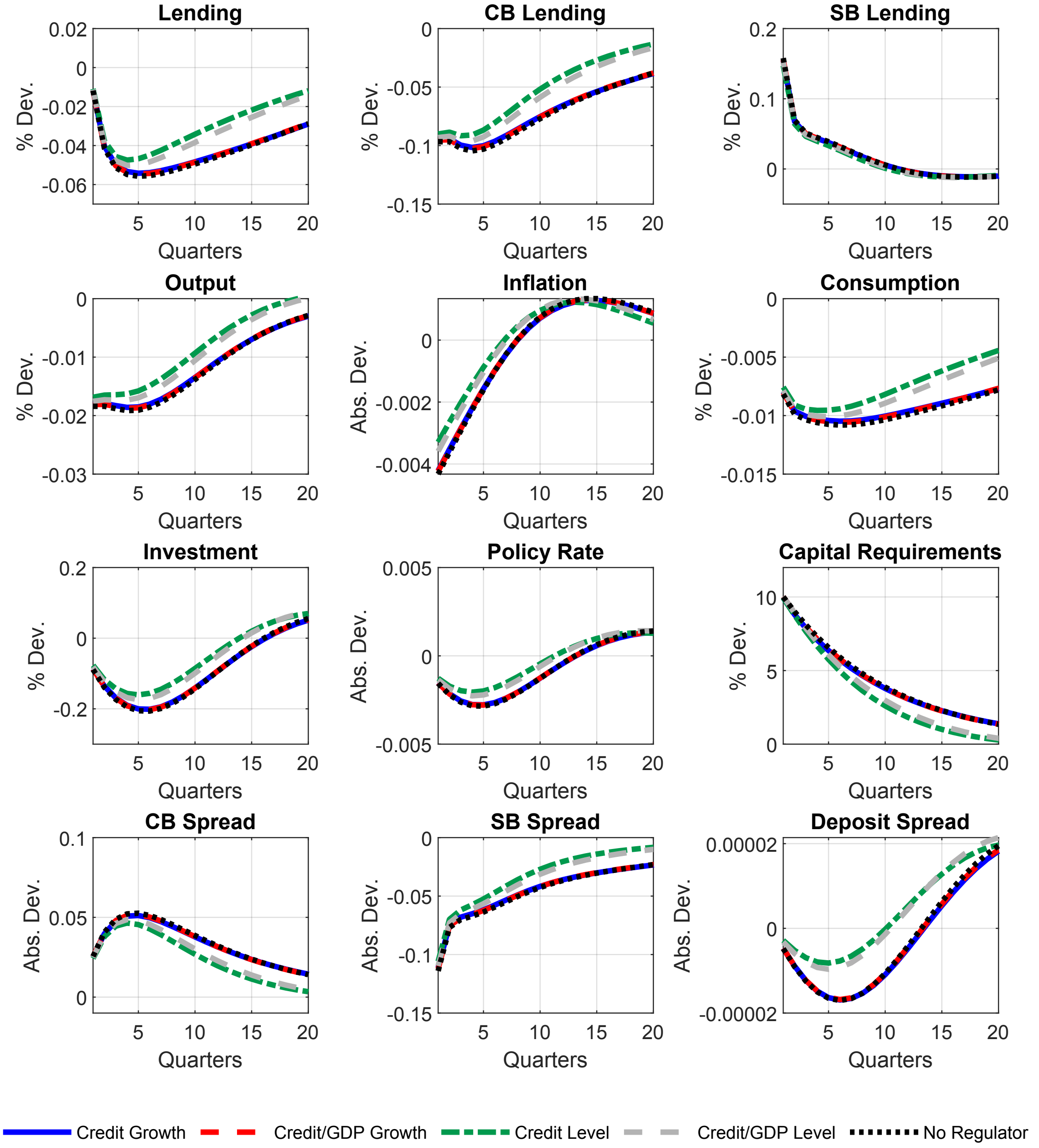
Note: Impulse responses to a one-standard-deviation capital requirement shock. Rates in absolute deviations from steady state, all other variables as percentage deviations from steady state.

5.2.2 Capital Requirement Shock

In the previous section we verify that our model can generate dynamics of commercial and shadow bank credit in response to tighter monetary policy which are qualitatively in line with empirical evidence. Similar evidence on the effects of regulatory changes on credit

[36] As we do not derive welfare implications of shadow banking here, no discussion about the optimality or desirability of different described policy responses can be drawn from the presented results. Gebauer (2020) introduces such a welfare analysis in a simplified version of our model.

Figure 6: Impulse Responses: Capital Requirement Shock – Prudent Regulator



Note: Impulse responses to a one-standard-deviation capital requirement shock. Rates in absolute deviations from steady state, all other variables as percentage deviations from steady state.

intermediation is still relatively scarce, primarily due to issues of identifying unanticipated shocks to capital regulation on the macro level.[37] Irani et al. (2018) use detailed US corpo-

[37]Compared to well-established procedures to identify monetary policy shocks, the empirical identification of macroprudential policy shocks is less straightforward. First, policy decisions are taken in a process that has only started to mature since the financial crisis, while monetary policy has a long history of regular meetings of the monetary policy committees that announce their decisions in a public manner, at least in many developing countries over several decades. Second, as many of the macroprudential tools discussed now were only implemented over the last ten years, time series for respective measures are still short.

rate loan data to evaluate the effect of capital requirement changes on the development of non-bank financial intermediation. Relying on data derived from a supervisory register on syndicated loans, they find that shadow bank credit increases in response to commercial bank capital constraints. Similarly, Buchak et al. (2018) examine data on Fintech lenders in residential mortgage markets. They find that commercial banking contracted due to a higher regulatory burden – such as higher bank capital requirements as well as mortgage market-related regulatory changes – and was partly replaced by unregulated shadow bank intermediation. To evaluate the effect of credit leakage towards shadow banks in response to tighter regulation, we simulate an unanticipated increase in commercial bank capital requirements by one percentage point (resembling a positive ten-percent deviation from steady state) and provide impulse responses in Figures 5 and 6.

Whereas overall lending is reduced by increased bank capital requirements, lower credit intermediation by commercial banks is partly offset by increased shadow bank activity in all scenarios. Due to the leakage mechanism laid out in detail in the Online Appendix, higher capital requirements result in a deviation of actual capital-to-asset ratios held by commercial banks from the regulatory requirement and increase the intermediation cost for commercial banks (Equation 10). In response, both the wholesale and retail loan rates r_t^C and r_t^{bc} increase. As in the case of a monetary policy tightening, due to the collateral constraint 5, the quantity of loans $b_t^{E,C}(i)$ declines. Monopolistically competitive banks raise loan rates and generate profits via retained earnings, and borrowing from shadow banks becomes relatively more attractive. The initially unaffected demand for credit by entrepreneurs eases the shadow bank leverage constraint (Equation 13). In response, the shadow bank lending rate spread declines and shadow bank intermediation and leverage increases.[38] Thus, in response to a macroprudential tightening, borrowers increase the share of relatively costly shadow bank loans which raises the overall cost of borrowing. Finally, tighter macroprudential regulation reduces overall lending activity and ultimately, due to lower credit supply, dampens economic activity. Lower aggregate demand reduces inflation, and monetary policy consequently responds by lowering interest rates.

The different degrees to which macroprudential policymakers take shadow banks into consideration has implications for the development of both credit and macroeconomic variables in the model. Following an unanticipated rise in capital requirements, regulators following level-based rules pursue a path of relative rapid policy normalization compared to the case of growth-based rules, both under moderate and prudent regulation. In return, even though the drop in commercial bank lending is equally pronounced on impact, credit returns to its steady-state level more quickly under level rules. Therefore, the reduction in overall credit is relatively smaller in the case of the level-based regulators, and the de-

[38] A similar rationale for credit leakage effects in response to tighter regulation is provided in Aikman et al. (2018).

scribed losses in aggregate demand are weaker. Inflation is reduced to a lesser extent and monetary policy reacts less aggressively in the case of level-based rules.

5.2.3 Policy Coordination

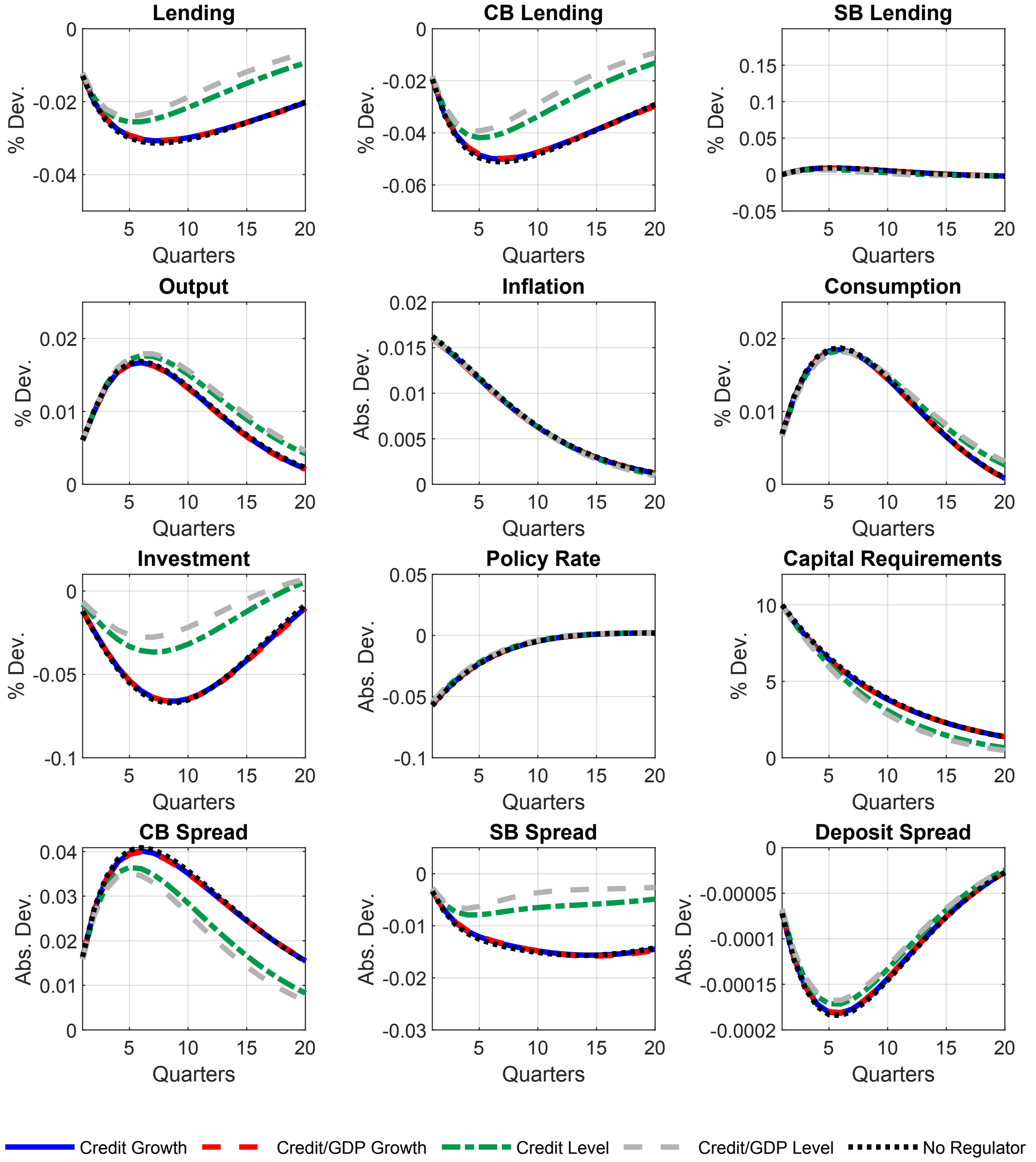
In the two preceding policy exercises, unexpected tightening by one policymaker triggered counteractive measures implemented by the other to mitigate adverse effects on price stability and output. Furthermore, tighter regulation and monetary policy caused leakage towards the shadow banking sector. Both observations indicate a potential role for coordination among policymakers to mitigate dampening macroeconomic implications of tighter regulation and, in particular, to limit the unintended leakage of credit towards the shadow banking sector.

In the following exercise, we evaluate to what extent a coordinated reaction using monetary policy could limit the increase in shadow bank lending in response to tighter bank capital regulation in our model setup. Higher capital requirements indeed reduce lending activity by commercial banks, as shown in the analysis of the previous section. However, the contemporaneous increase in shadow bank lending depicts a limitation of macroprudential policy efficiency. First, the intended reduction in lending activity is partly counteracted by an increase in shadow bank intermediation, resulting in a smaller reduction in overall lending compared to a situation without shadow bank intermediation. Second, an increase in shadow bank lending potentially increases financial instability as a relatively larger share of intermediation is now conducted by unregulated financial institutions.

To discuss benefits from policy coordination in light of the limits on macroprudential regulation emerging from the existence of shadow banks, we evaluate whether monetary policy can be employed to avoid leakage of credit intermediation towards shadow banks. Whereas capital requirements only affect commercial banks, interest rates depict a universal tool that reaches through "all the cracks in the economy" (Stein, 2013). To this end, we apply the monetary policy reaction that is necessary to keep shadow bank intermediation at its steady-state level in response to the capital requirement shock discussed in the previous Section.

Figures 7 and 8 depict impulse responses to an unanticipated increase in commercial bank capital requirements by one percentage point in combination with a contemporaneous response by monetary policy that mitigates the reaction of shadow bank intermediation. In the simulations, the reaction in shadow bank lending is negligible as the central bank lowers interest rates by approximately $5 - 6$ basis points in response to tighter capital requirements. As indicated in Section 5.2.1, commercial bank credit increases in reaction to monetary policy easing, and therefore the decrease in commercial bank lending is less pronounced in Figures 7 and 8 compared to the respective reductions in Figures 5 and 6.

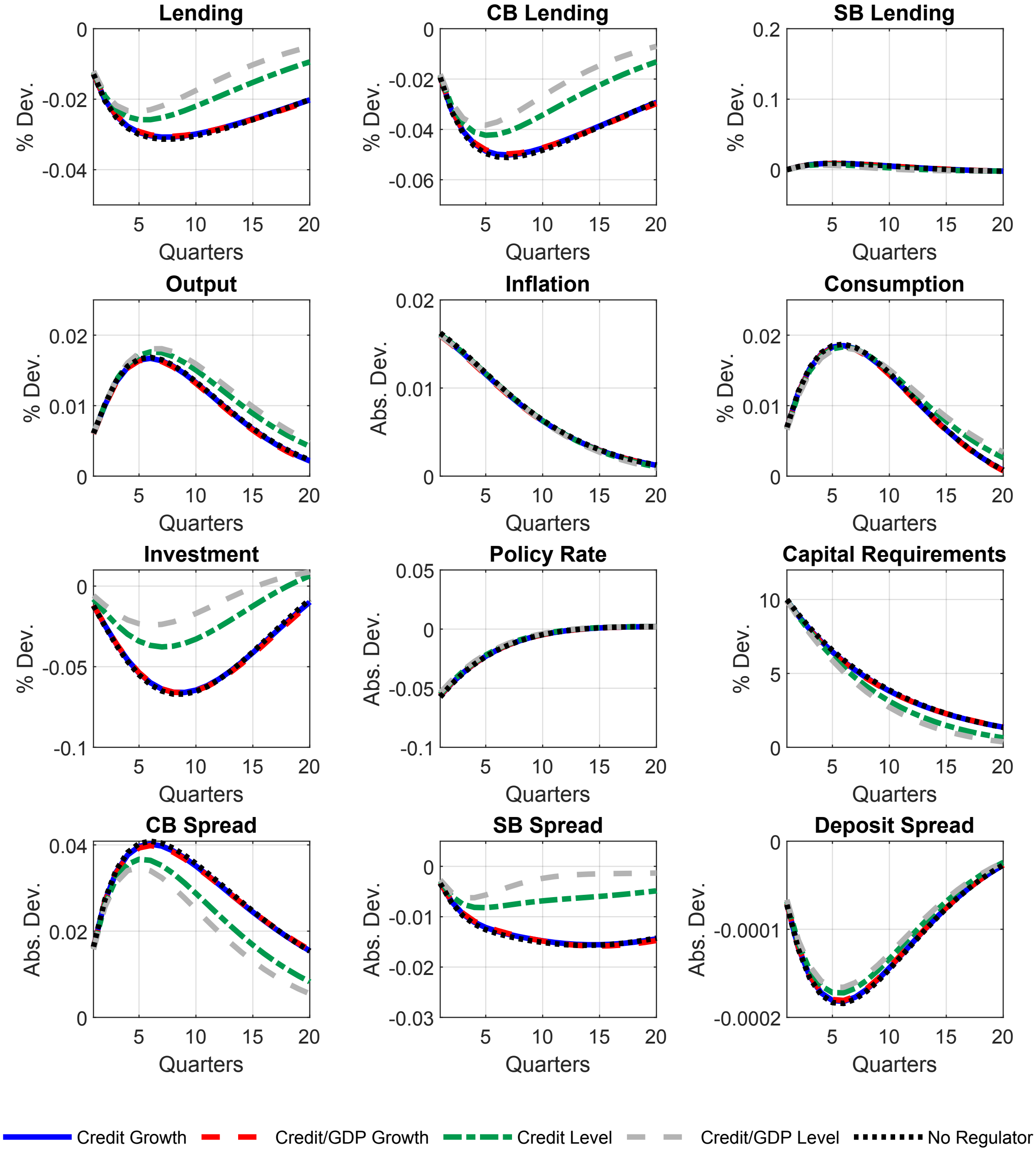
Figure 7: Impulse Responses: Policy Coordination – Moderate Regulator



Note: Impulse responses to a combination of capital requirement and monetary policy shocks. Rates in absolute deviations from steady state, all other variables as percentage deviations from steady state.

Therefore, even though monetary policy easing partly counteracts the intended reduction in overall lending stemming from an increase in capital requirements, it can help to mitigate potentially undesired leakage towards shadow banks as a side effect of tighter commercial bank regulation.

Figure 8: Impulse Responses: Policy Coordination – Prudent Regulator

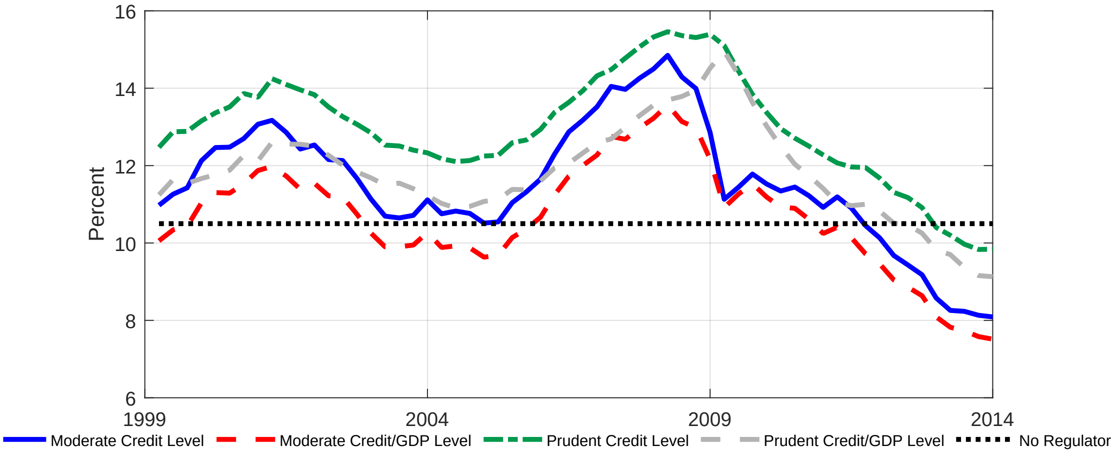


Note: Impulse responses to a combination of capital requirement and monetary policy shocks. Rates in absolute deviations from steady state, all other variables as percentage deviations from steady state.

5.3 Counterfactual Simulation

Finally, we evaluate how euro area regulators would have set capital requirements under Basel III, if the framework would have been in place already in 1999 and throughout the existence of the common currency. For all regulatory regimes, we use the estimated baseline model (Section 4) to filter the data and simulate the evolution of endogenous model variables over the period 1999 – 2014 in a counterfactual analysis. In the counterfactual simulation we allow for endogenous feedback between capital requirements and macroeconomic and financial variables. We focus on hypothetical capital requirements that the regulator would have set in response to macroeconomic and financial shocks under the growth-based rules of Equations 18–19 and 22–23, reported in Figure 9.[39]

Figure 9: Counterfactual Analysis: Different Regulatory Regimes



Note: Simulated path of capital requirements based on shock series identified in estimation of Section 4 and for different regulators of Section 5.1.

Independent of the rule type, both the moderate and the prudent regulator would have applied some form of countercyclical regulation by reducing capital requirements in times of financial distress and by raising requirement in times of excessive lending. All rules would have prescribed a sharp tightening of credit standards from the mid-2000s onward, in response to massive credit growth in the European financial sector. Over the course of the global financial crisis starting in 2008 and the European debt crisis, both regulators would have prescribed a reduction in capital requirements due to subdued lending activity in the euro area.

Thereby, the moderate regulators only concerned with commercial bank credit would have set lower capital requirements relative to their prudent counterparts throughout the sample period. Also, they would have raised capital requirements more aggressively prior to the 2008 financial crisis, as commercial bank credit grew rapidly in these years (Figure 1). Prudent regulators on the other hand would have eased requirements later and less strongly in response to the financial crisis: In the years 2008-2009, shadow bank credit continued to grow further while the increase in commercial bank lending stalled. If the leakage channel would have been taken into account by the regulator, the migration of credit to the shadow banking system at a time when financial stability considerations take

[39] We focus on the growth-based rules to avoid taking a stance on the steady-state level of credit, which would be required to construct the level-based rules, Equations 20–21 and 24–25.

center stage may have led to yet different dynamics.[40]

These findings indicate that the existence of shadow banking and the resulting credit leakage requires a detailed understanding of the exact transmission mechanism of financial regulation. Considering non-bank financial intermediation in regulation for commercial banks as depicted by the prudent regulator can, on the one hand, result in lower capital requirements and a resulting lower leakage of credit to unregulated intermediaries. On the other hand, giving a stronger weight to the developments in *overall credit* relative to the leakage motive, can, as in our simulation, lead to higher requirements for commercial banks. Furthermore, as shown in Section 5.2.3, monetary policy can play an active role in mitigating shadow bank intermediation. Thus, it can play a crucial part whenever leakage concerns limit the scope for tighter commercial banking regulation.

Table 3: Differences in Variation Under Different Policy Regimes

	Moderate Regulator		**Prudent Regulator**	
	Credit	Credit/GDP	Credit	Credit/GDP
GDP	-5.85	-5.16	-5.74	-4.72
Consumption	-3.20	-2.46	-2.81	-1.70
Investment	-25.14	-23.77	-25.77	-23.70
Inflation	-1.98	-2.00	-2.20	-2.24
Policy Rate	-2.12	-2.19	-2.35	-2.47
Total Lending	-4.12	-4.23	-4.56	-4.74
CB Lending	-5.43	-5.35	-5.67	-5.56
SB Lending	-5.10	-4.39	-4.37	-3.29

Note: Percentage difference in the variance of macroeconomic and financial variables, compared to the variation under the baseline scenario without cyclical regulation. For variable X, the percentage difference ΔX is defined as $\Delta X = [Var(X^{Reg}) - Var(X^{NoReg})]/Var(X^{NoReg})$.

In Table 3, we report the percentage difference in the variance of simulated variables when considering macroprudential rules compared to the baseline scenario without cyclical capital requirements. We find that the growth-based rules in Figure 9 would have been effective at reducing macroeconomic volatility. Moderate regulators are particularly successful in reducing volatility in real macroeconomic variables, as the variance reduction in GDP and consumption is largest under this set of regulators. Investment volatility also declines slightly more under moderate regulation if growth in the credit-to-GDP gap is used as the target variable. In turn, prudent regulators are better equipped at stabilizing nominal variables and overall lending.

[40] Implications of the leakage channel for optimal capital regulation are further explored in Gebauer (2020). He shows that under optimal policy, credit leakage provides a motive for mitigating the regulatory response to commercial bank credit whenever commercial and shadow bank credit move in the *same* direction in response to macroeconomic disturbances.

6 Conclusion

We develop a DSGE model featuring two different types of financial intermediaries: regulated commercial banks and unregulated shadow banks. Methodologically, we combine two seminal strands of the literature for modeling financial frictions that were independently developed in recent years. In doing so, we exploit differences with respect to market power and regulatory coverage in the two frameworks and argue that they can be applied to structurally different financial institutions.

We highlight the key mechanism of bank capital requirements and evaluate how tighter regulation of commercial bank credit intermediation can result in higher intermediation activity by unregulated shadow banks. We estimate the structural parameters of the model via Bayesian methods using euro area data on both commercial and shadow banks.

We use our estimated model to evaluate quantitative responses of macroeconomic variables to unexpected changes in macroprudential and monetary policy. We find that macroprudential tightening leads to a reduction in commercial bank credit, but increases intermediation by shadow banks. If a macroprudential rule is employed, this leakage mechanism can be reduced, but not eliminated.

Whereas capital requirements can only be employed with respect to commercial banks, interest rates depict a universal tool to reach though "all the cracks in the economy" (Stein, 2013). We evaluate whether monetary policy can be employed to counteract the leakage mechanism in a coordinated macroprudential and monetary policy interaction scenario. Even though monetary easing partly counteracts the intended reduction in overall lending stemming from an increase in capital requirements, it can help to mitigate potentially undesired leakage towards shadow banks as a side effect of tighter bank regulation.

We furthermore evaluate in a counterfactual analysis how regulation would have been set had it followed Basel III rules, and how this would have affected macro indicators through the global financial crisis and the sovereign debt crisis. We find macroprudential tightening during episodes of credit increases, and easing during credit crunches. Furthermore, regulators only concerned with commercial bank credit would have raised capital requirements more strongly in the years preceding the global financial crisis, when growth in commercial bank lending was particularly pronounced. However, more 'prudent' regulators taking both commercial and shadow bank credit into consideration would have generally applied higher levels of capital requirements. Also, these prudent regulators would have eased requirements only later and less strongly after the outbreak of the financial crisis, as shadow bank credit continued to grow thereafter.

We therefore highlight the need for understanding credit leakage and the emerging trade-off for regulators taking lending by both regulated and unregulated intermediaries into account when lending by both intermediaries increases. On the one hand, an increase in overall credit might indicate the need for tighter regulation. On the other hand, tighter regulation on the regulated entity only fuels credit leakage to the unregulated entity, with potential implications for financial stability. This paper develops a framework for financial regulators to think of such trade-offs, and take them into account when making macroprudential decisions, potentially by including a role for policy coordination with the monetary authority, which requires further investigation.

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A Appendix: The Full Nonlinear DSGE Model

A.1 Households

The representative patient household i maximizes the expected utility

$$E_0 = \sum_{t=0}^{\infty} \beta_P^t \left[(1-a^P)\varepsilon_t^z log(c_t^P(i) - a^P c_{t-1}^P) - \frac{l_t^P(i)^{1+\phi^P}}{1+\phi^P} \right] \tag{A.1}$$

which depends on current individual consumption $c_t^P(i)$ as well as lagged aggregate consumption c_t^P and working hours l_t^P. Labor dis-utility is parameterized by ϕ^P. Preferences are subject to a disturbance affecting consumption, ε_t^z. Household choices are undertaken subject to the budget constraint:

$$c_t^P(i) + d_t^{P,C}(i) + d_t^{P,S}(i) \leq w_t l_t^P(i) + (1+r_{t-1}^{dC})d_{t-1}^{P,C}(i) + (1+r_{t-1}^{dS})d_{t-1}^{P,S}(i) + t_t^P(i) \tag{A.2}$$

The flow of expenses includes current consumption and real deposits to be made to both commercial and shadow banks, $d_t^{P,C}(i)$ and $d_t^{P,S}(i)$. Due to the difference in the discount factor for households (β_P) and entrepreneurs (β_E), households only place deposits, but do not borrow any funds from financial market agents. Resources consist of wage earnings $w_t^P l_t^P(i)$ (where w_t^P is the real wage rate for the labor input of each household), gross interest income on last period deposits $(1+r_{t-1}^{dC})d_{t-1}^{P,C}(i)$ and $(1+r_{t-1}^{dS})d_{t-1}^{P,S}(i)$, and lump-sum transfers t_t^P that include dividends from firms and banks (of which patient households are the ultimate owners). First-order conditions yield the consumption Euler equation and labor-supply condition:

$$\frac{\varepsilon_t^z}{c_t^P(i)} = \beta_P^t E_t \left[\frac{1+r^{dC}}{c_{t+1}^P(i)} \right] \tag{A.3}$$

$$l_t^P(i)^{\phi^P} = \frac{w_t}{c_t^P(i)} \tag{A.4}$$

A.2 Entrepreneurs

Entrepreneurs use labor provided by households as well as capital to produce intermediate goods that retailers purchase in a competitive market. Each entrepreneur i derives utility from consumption $c_t^E(i)$, which it compares to the lagged aggregate consumption level of all entrepreneurs. He maximizes expected utility

$$E_0 \sum_{t=0}^{\infty} \beta_E^t log(c_t^E(i) - a^E c_{t-1}^E) \tag{A.5}$$

by choosing consumption, the use of physical capital k_t^E, loans from both commercial and shadow banks ($b_t^{E,C}$, $b_t^{E,S}$), and labor input from households. He faces the following budget constraint:

$$\begin{aligned} c_t^E(i) + w_t l_t^P(i) + (1 + r_{t-1}^b) b_{t-1}^{E,C}(i) + (1 + r_{t-1}^b) b_{t-1}^{E,S}(i) + q_t^k k_t^E(i) \\ = \frac{y_t^E(i)}{x_t} + b_t^{E,C}(i) + b_t^{E,S}(i) + q_t^k (1 - \delta^k) k_{t-1}^E(i) \end{aligned} \tag{A.6}$$

with δ^k depicting the depreciation rate of capital and q_t^k the market price for capital in terms of consumption. As we assume that intermediate goods are sold on a wholesale market at price P_t^w and are transformed by retailers in a composite final good whose price index is P_t, we define $x_t \equiv \frac{P_t}{P_t^w}$ as the price markup of the final over the intermediate good. We thus express output y_t^E produced by the entrepreneur in terms of the relative competitive price of the wholesale good, given by $\frac{1}{x_t}$ and which is produced according to the Cobb-Douglas technology

$$y_t^E(i) = A_t^E k_{t-1}^E(i)^\alpha l_t^E(i)^{1-\alpha} \tag{A.7}$$

where the (stochastic) total factor productivity (TFP) is given by A_t^E.

Entrepreneurs face constraints on the amount they can borrow from commercial and shadow banks as discussed in Section 3:

$$(1 + r_t^{bc}) b_t^{E,C}(i) \leq m_t^C E_t[q_{t+1}^k (1 - \delta^k) k_t^E(i)] \tag{A.8}$$

$$(1 + r_t^{bs}) b_t^{E,S}(i) \leq (1 - m_t^C) E_t[q_{t+1}^k (1 - \delta^k) k_t^E(i)] \tag{A.9}$$

where the LTV ratio for commercial banks m_t^C is set exogenously by the regulator and follows an exogenous AR(1) process.

A.3 Financial Intermediaries

In our model, we have two financial market agents that intermediate funds between households and firms: commercial banks and shadow banks. While they both engage in intermediation in a similar fashion, we assume the two types of agents to be structurally different along various dimensions, as discussed in Section 3.

A.3.1 Commercial Banks

In the following, we discuss the maximization problem of the wholesale unit of the commercial bank as the capital requirement set by regulators applies directly to this branch of the commercial bank. Due to space limitations, we will not discuss the maximization problems of the retail deposit and loan branches here as they are identical to the problems outlined in Gerali et al. (2010) and refer to their study.

Wholesale Unit The wholesale branches of commercial banks operate under perfect competition and are responsible for the capital position of the respective commercial bank. On the asset side, they hold funds they provide to the retail loan branch, b_t^C, which ultimately lends these funds to entrepreneurs at a markup in the form of loans, $b_t^{E,C}$. On the liability side, it combines commercial bank net worth, or capital, k_t^C, with wholesale deposits, d_t^C, that are provided by the retail deposit branch, but originally stem from deposits placed in the retail branch by patient households ($d_t^{P,C}$). The wholesale bank balance sheet is thus given by

$$b_t^C = k_t^C + d_t^C. \tag{A.10}$$

Furthermore, the capital position of the wholesale branch is prone to a regulatory capital requirement, ν_t^C. Moving away from the regulatory requirement imposes a quadratic cost c_t^C to the bank, which is proportional to the outstanding amount of bank capital and parameterized by κ_k^C:

$$c_t^C = \frac{\kappa_k^C}{2}\left(\frac{k_t^c}{b_t^C} - \nu_t^C\right)^2 k_t^C. \tag{A.11}$$

The wholesale branch thus maximizes the discounted sum of real cash flows:

$$\begin{aligned}\mathcal{L}^w = \max_{b_t^C,\, d_t^C} \; E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \Big[& (1+r_t^C)b_t^C - b_{t+1}^C\Pi_{t+1} + d_{t+1}^C\Pi_{t+1} - (1+r_t^{dC})d_t^C + \\ & + (k_{t+1}^C\Pi_{t+1} - k_t^C) - \frac{\kappa_k^C}{2}\left(\frac{k_t^C}{b_t^C + b_t^S} - \nu_t^C\right)^2 k_t^C \Big]\end{aligned} \tag{A.12}$$

where we assume the net wholesale loan rate r_t^C and the deposit rate r_t^{dC} to be given from the perspective of the maximizing bank. We can use the objective together with the balance sheet constraint A.10 to get:

$$r_t^C b_t^C - r_t^{dC} d_t^C - \frac{\kappa_k^C}{2}\left(\frac{k_t^C}{b_t^C} - \nu^C\right)^2 k_t^C.$$

We can thus express the maximization problem as:

$$\mathcal{L}^w = \max_{b_t^C,\, d_t^C} \; r_t^C b_t^b - r_t^{dC} d_t^C - \frac{\kappa_k^C}{2}\left(\frac{k_t^C}{b_t^C} - \nu_t^C\right)^2 k_t^C. \tag{A.13}$$

The first-order conditions yield the following expression:

$$r_t^b = r_t^{dC} - \kappa_k^C \left(\frac{k_t^C}{b_t^C} - \nu_t^C\right)\left(\frac{k_t^C}{b_t^C}\right)^2 \tag{A.14}$$

As the commercial bank has access to central bank funding in the model, we assume that the rate paid on wholesale deposits gathered from the retail deposit unit of the commercial bank (and so originally from households and firms) has to be equal to the risk-free policy rate, r_t, by arbitrage:

$$r_t^{dC} = r_t$$

such that the spread between the loan and deposit rates on the wholesale level is given by

$$r_t^b - r_t = -\kappa_k^C \left(\frac{k_t^C}{b_t^C} - \nu_t^C\right)\left(\frac{k_t^C}{b_t^C}\right)^2. \tag{A.15}$$

Assuming symmetry between banks and reinvestment of profits in banks, aggregate bank capital K_t^C is accumulated from retained earnings only:

$$K_t^C = (1 - \delta^C) K_{t-1}^C + J_{t-1}^C \tag{A.16}$$

where J_t^C depicts aggregate commercial bank profits derived from the three branches of the bank, see Gerali et al. (2010). Capital management costs are captured by δ^C.

A.3.2 Shadow Banks

The balance sheet of each shadow bank j in each period is given by

$$q_t^k b_t^{E,S}(j) = d_t^{P,S}(j) + k_t^S(j) \tag{A.17}$$

where the asset side is given by the funds lend to entrepreneurs, $b_t^{E,S}(j)$, multiplied with the relative price for these claims, q_t^k. Shadow banks' liabilities consist of household deposits $d_t^{P,S}(j)$ and net worth, or shadow bank capital $k_t^S(j)$.

Shadow bankers earn an interest rate on their claims r_t^{bS}. The net profits of shadow banks, i.e. the difference between real earnings on financial claims and real interest payments to depositors, determine the evolution of shadow bank capital:

$$k_{t+1}^S(j) = (1 + r_t^{bS})q_t^k b_t^{E,S}(j) - (1 + r_t^{dS})d_t^{P,S}(j) \tag{A.18}$$

or

$$k_{t+1}^S(j) = (r_t^{bS} - r_t^{dS})q_t^k b_t^{E,S}(j) + (1 + r_t^{dS})k_t^S(j). \tag{A.19}$$

For the shadow banker, as long as the real return on lending, $(r_t^{bS} - r_t^{dS})$ is positive, it is profitable to accumulate capital until it exits the shadow banking sector. Thus, the shadow bank's objective to maximize expected terminal wealth, $v_t(j)$, is given by

$$v_t(j) = maxE_t \sum_{i=0}^{\infty}(1 - \sigma^S){\sigma^S}^i {\beta^S}^{i+1} k_{t+1+i}^S(j) \tag{A.20}$$

or

$$v_t(j) = maxE_t \sum_{i=0}^{\infty}(1 - \sigma^S){\sigma^S}^i {\beta^S}^{i+1}[(r_{t+i}^{bS} - r_{t+i}^{dS})q_{t+i}^k b_{t+i}^{E,S}(j) + (1 + r_{t+i}^{dS})k_{t+i}^S(j)]. \tag{A.21}$$

We introduce a moral hazard problem discussed in Section 3. Diverting funds and "running away" is equivalent to declaring bankruptcy for the shadow bank, such that it will only do so if the return of declaring bankruptcy is larger than the discounted future return from continuing and behaving honestly:

$$v_t(j) \geq \theta^S q_t^k b_t^{E,S}(j). \tag{A.22}$$

Equation A.22 is the infinite-horizon incentive constraint in the two-period model the shadow banker faces when demanding funds from households. Following Gertler and Karadi (2011), we can rewrite it as:

$$v_t(j) = \nu_t^S q_t^k b_t^{E,S}(j) + \eta_t^S k_t^S(j) \tag{A.23}$$

with

$$\nu_t^S = E_t[(1 - \sigma^S)\beta^S(r_t^{bS} - r_t^{dS}) + \beta^S \sigma^S \chi_{t,t+1}^S \nu_{t+1}^S] \tag{A.24}$$

and

$$\eta_t^S = E_t[(1-\sigma^S) + \beta^S\sigma^S z_{t,t+1}^S\eta_{t+1}^S] \tag{A.25}$$

where $\chi_{t,t+i}^S \equiv \frac{q_{t+i}^k b_{t+i}^{E,S}(j)}{q_t^k b_t^{E,S}(j)}$ depicts the gross growth rate in financial claims between t and $t+i$, whereas $z_{t,t+i}^S \equiv \frac{k_{t+i}^S(j)}{k_t^S(j)}$ determines the gross growth rate of shadow bank capital. With these definitions, we can express the incentive constraint as

$$\eta_t^S k_t^S(j) + \nu_t^S q_t^k b_t^{E,S}(j) \geq \theta^S q_t^k b_t^{E,S}(j). \tag{A.26}$$

With constraint A.26 being binding, bank capital determines the amount that the shadow banker can lend out:

$$q_t^k b_t^{E,S}(j) = \frac{\eta_t^S}{\theta^S - \nu_t^S} k_t^S(j) = \phi_t^S k_t^S(j) \tag{A.27}$$

where ϕ_t^S is the asset-to-capital ratio, or the shadow bank leverage ratio. As shadow banks' incentive to divert funds increases with leverage, Equation A.27 limits the shadow bank's leverage ratio to the point where costs and benefits of cheating are exactly leveled. Thus, due to the financial friction, shadow banks, even not facing an externally set capital requirement that limits their leverage, are prone to an endogenous capital constraint that limits their ability to increase leverage.[41]

Rewriting bank capital as

$$k_{t+1}^S(j) = [(r_t^{bS} - r_t^{dS})\phi_t^S + (1 + r_t^{dS})]k_t^S(j) \tag{A.28}$$

we get

$$z_{t,t+1}^S = \frac{k_{t+1}^S(j)}{k_t^S(j)} = (r_t^{bS} - r_t^{dS})\phi_t^S + (1 + r_t^{dS}) \tag{A.29}$$

and

$$\chi_{t,t+1}^S = \frac{q_{t+1}^k b_{t+1}^{E,S}(j)}{q_t^k b_t^{E,S}(j)} = \frac{\phi_{t+1}^S}{\phi_t^S} z_{t,t+1}^S. \tag{A.30}$$

[41]We assume that in the simulations, parameters are set such that the constraint always binds within a local region around steady state in equilibrium. Similarly to condition 41 in the Online Appendix, an equilibrium with a binding incentive constraint is characterized by $0 < \nu_t^S < \theta^S$, which can be shown with Equation A.27.

As none of the components of ϕ_t^S depends on firm-specific factors, we can drop the subscript j by summing across individual shadow bankers to get for total shadow bank lending:

$$q_t^k b_t^{E,S} = \phi_t^S k_t^S \tag{A.31}$$

with $b_t^{E,S}$ depicting aggregate lending/financial claims the shadow banking sector provides and k_t^S being the aggregate capital held by shadow banks in period t.

As we assume some shadow bankers to exit each period and new bankers to enter the market, we know that aggregate capital k_t^S is determined by capital of continuing shadow bankers, $k_t^{S,c}$, and capital of new bankers that enter, $k_t^{S,n}$:

$$k_t^S = k_t^{S,c} + k_t^{S,n}. \tag{A.32}$$

As a fraction σ^S of existing shadow bankers survives each period, we know that at period t, we have for $k_t^{S,c}$

$$k_t^{S,c} = \sigma^S[(r_{t-1}^{bS} - r_{t-1}^{dS})\phi_{t-1}^S + (1 + r_{t-1}^{dS})]k_{t-1}^S. \tag{A.33}$$

For new shadow bankers, we assume that they get some start-up capital from the household the shadow banker belongs to. This start-up value is assumed to be proportional to the amount of claims exiting shadow bankers had intermediated in their final period. With i.i.d. exit probability σ^S, total final period claims of exiting shadow bankers at t are given by $(1-\sigma^S)q_t^k b_{t-1}^{E,S}$. We assume that each period the household transfers a fraction $\frac{\omega^S}{1-\sigma^S}$ of this value to entering bankers, such that in the aggregate, we get:

$$k_t^{S,n} = \omega^S q_t^k b_{t-1}^{E,S}. \tag{A.34}$$

Combining Equations A.32, A.33 and A.34, we get the following law of motion for shadow bank capital:

$$k_t^S = \sigma^S[(r_{t-1}^{bS} - r_{t-1}^{dS})\phi_{t-1}^S + (1 + r_{t-1}^{dS})]k_{t-1}^S + \omega^S q_t^k b_{t-1}^{E,S}. \tag{A.35}$$

Finally, we assume a non-negative spread between the interest rates earned on shadow bank deposits, r_t^{dS}, and on the deposits households can place with commercial banks, r_t^{dC}, which is again determined by the parameter τ^S, with $0 \leq \tau^S \leq 1$. In the Online Appendix, we provide a microfoundation for the existence of a positive spread, and use the results to incorporate a relationship between the two deposit rates similar to the relation stated in the two-period model:

$$1 + r_t^{dS} = \frac{1 + r_t^{dC}}{1 - \tau^S \varepsilon_t^\tau}. \tag{A.36}$$

As in the two-period version of the model, the parameter τ^S determines the spread between the gross rates on both deposit types and is implicitly related to the default probability of shadow banks. As a shortcut, we will calibrate τ^S and assume the existence of a spread shock ε_t^τ following an auto-regressive process to motivate exogenous swings in the spread on interest rates earned on the two deposit types.

A.4 Capital Goods Producers and Retailers

Following Gerali et al. (2010), the first-order condition for capital goods producers is given by

$$\begin{aligned} 1 = q_t^k & \left[1 - \frac{\kappa^i}{2}\left(\frac{I_t \varepsilon_t^{q^k}}{I_{t-1}} - 1\right)^2 - \kappa^i \left(\frac{I_t \varepsilon_t^{q^k}}{I_{t-1}} - 1\right)\frac{I_t \varepsilon_t^{q^k}}{I_{t-1}}\right] + \\ & + \beta_E E_t \left[\frac{\lambda_{t+1}^E}{\lambda_t^E} q_{t+1}^k \kappa^i \left(\frac{I_{t+1}\varepsilon_{t+1}^{q^k}}{I_t} - 1\right)\left(\frac{I_{t+1}\varepsilon_{t+1}^{q^k}}{I_t}\right)^2 \varepsilon_{t+1}^{q^k}\right] \end{aligned} \tag{A.37}$$

and capital accumulation is given by

$$K_t = (1 - \delta^k) K_{t-1} + \left[1 - \frac{\kappa^i}{2}\left(\frac{I_t \varepsilon_t^{q^k}}{I_{t-1}}\right)^2\right]. \tag{A.38}$$

We assume price stickiness à la Calvo (1983) in the retail sector.[42] Thus, only a share or retailers indicated by θ^p is able to adjust prices in a given period. Retailers' marginal costs are given by

$$mc_t^E = \frac{1}{x_t}. \tag{A.39}$$

A.5 Monetary Policy and Market Clearing

The central bank sets the policy rate according to a Taylor-type rule given by

[42] In the studies by Gerali et al. (2010) and Gambacorta and Signoretti (2014), price stickiness was modeled using Rotemberg (1982) pricing. However, we decided to use the more convenient Calvo pricing approach in the model.

$$
(1 + r_t) = (1 + r)^{(1-\phi^r)}(1 + r_{t-1})^{\phi^r} \left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi^\pi(1-\phi^r)} \left(\frac{y_t}{y_{t-1}}\right)^{\phi^y(1-\phi^r)} \varepsilon_t^r \tag{A.40}
$$

where the weights on inflation and output growth are given by ϕ^π and ϕ^y, respectively. The steady-state policy rate is given by r and ε_t^r defines a white noise monetary policy shock.

The market clearing condition is given by the aggregate resource constraint

$$
Y_t = C_t + q_t^k(K_t - (1 - \delta^k)K_{t-1}) + \frac{\delta^k K_{t-1}^b}{\pi_t} + AC_t \tag{A.41}
$$

with AC_t determining the overall adjustment costs and composite consumption given by $C_t = c_t^P + c_t^E$.

B Appendix: Data and Estimation

We derive our data set from the European System of Accounts (ESA 2010) quarterly financial and non-financial sector accounts, provided by the ECB and Eurostat. Commercial bank balance sheet data is gathered from the data set on “Monetary Financial Institutions” (MFIs), whereas shadow bank data is based on statistics on “Other Financial Institutions” (OFIs) as well as on data on investment funds and money market funds (MMFs) provided by the ECB. Commercial bank interest rate data is combined from different sources, as indicated below. All variables except for interest rates are seasonally and working day adjusted and expressed in real terms. We furthermore detrend macroeconomic variables (real GDP, real consumption, real investment) and intermediary loans and deposits by applying log-differences. We then subtract the sample means from the data after log-differentiation to arrive at average growth rates of zero for these variables. Interest rates and price and wage inflation variables are also demeaned. A detailed description of each variable is given below, and the final time series used in the estimations are plotted in Figure 10.

B.1 Real Economic and Commercial Bank Data

For the real economy, we include information on real gross domestic product, real consumption, real investment, and consumer price as well as wage inflation. We furthermore use data on commercial bank deposits held by private households, commercial bank loans granted to the non-financial corporate sector, the short-term EONIA rate as a quarterly measure of the policy rate, and measures for interest rates on household deposits and firm loans. We detrend non-stationary seasonally adjusted data (real consumption, real investment, bank deposits and loans) by using demeaned log-differenced data and demean all interest and inflation rates.

Real GDP: Real gross domestic product, euro area 19 (fixed composition), deflated using the GDP deflator (index), calendar and seasonally adjusted data (national accounts, main aggregates (Eurostat ESA2010)).

Real consumption: Real consumption expenditure of households and non-profit institutions serving households (NPISH), euro area 19 (fixed composition), deflated using Consumption deflator (index), calendar and seasonally adjusted data (national accounts, main aggregates (Eurostat ESA2010)).

Real investment: Real gross fixed capital formation (GFCF), euro area 19 (fixed composition), deflated using GFCF deflator (index), calendar and seasonally adjusted data (national accounts, main aggregates (Eurostat ESA2010)).

Inflation: Harmonized index of consumer prices (HICP) overall index, quarterly changes, euro area (changing composition), net inflation rate, calendar and seasonally adjusted data.

Wage inflation: Labor cost index, OECD data, euro area 19 (fixed composition), wages and salaries, business economy, net wage inflation, calendar and seasonally adjusted data.

Nominal interest rate (policy rate): EONIA rate, ECB money market data.

Commercial bank loans: Real outstanding amounts of commercial bank (MFIs excluding ESCB) loans to non-financial corporations, euro area (changing composition), deflated using HICP, calendar and seasonally adjusted data.

Commercial bank deposits: Real deposits placed by euro area households (overnight deposits, with agreed maturity up to two years, redeemable with notice up to 3 months), outstanding amounts, euro area (changing composition), deflated using HICP, calendar and seasonally adjusted data.

Interest rate on commercial bank loans: Annualized agreed rate (AAR) on commercial bank loans to non-financial corporations with maturity over one year, euro area (changing composition), new business coverage. Before 2003: Retail interest Rates Statistics (RIR), not harmonized data. Starting 2003:Q1: MFI Interest Rate Statistics (MIR), harmonized data.

Interest rate on commercial bank deposits: Commercial bank interest rates on household deposits, weighted rate from rates on overnight deposits, with agreed maturity up to two years, redeemable at short notice (up to three months), euro area (changing composition), new business coverage. Before 2003: Retail interest Rates Statistics (RIR), not harmonized data. Starting 2003:Q1: MFI Interest Rate Statistics (MIR), harmonized data.

B.2 Shadow Bank Data

In addition to the variables on commercial bank and real activity, we include data on shadow banks in the euro area in our sample. In comparison to lending provided by commercial banks, we derive a time series on shadow bank lending to non-financial corporates. In doing so, we are able to include an empirical measure of shadow bank credit. Deriving information on the European shadow banking system is challenging since 1) a wide variety of shadow bank definitions are used among scholars and practitioners and 2) euro area data on financial institutions that could be classified as shadow banks is available at a much lower level of detail and in a less structured manner than information on commercial banks. Therefore, one has to compromise between the conceptional definition of shadow banks used and the empirical counterparts that can be analyzed with available data.

In practice, the shadow banking system consist of a multitude of financial institutions partly fulfilling highly specialized task in a prolonged chain of credit intermediation (Adrian, 2014; Adrian and Liang, 2014; Pozsar et al., 2010). Given the diverse nature of non-bank financial institutions, a variety of definitions of shadow banks have been proposed, covering either a particular set of institutions (institutional approach) or a range of activities different entities are jointly engaged in (activity approach). We base our empirical measures of shadow banks on the "broad" definition of the shadow banking system provided by the Financial Stability Board (FSB, 2017, 2011), which states that the shadow banking system is "the system of credit intermediation that involves entities and activities outside the regular banking system" (FSB, 2011, p.2) and that "...this implies focusing on credit intermediation that takes place in an environment where *prudential regulatory standards and supervisory oversight are either not applied or are applied to a materially lesser or different degree than is the case for regular banks engaged in similar activities*" (FSB, 2011, p.3).

More precisely, we follow the institutional approach employed by ECB staff to apply the FSB broad definition to available euro area data (Malatesta et al., 2016; Doyle et al., 2016; Bakk-Simon et al., 2012). The core of this approach depicts the use of the "Other Financial Intermediaries" (OFIs) aggregate in the Eurosystem's financial accounts data. Within the aggregate, all activities of financial intermediaries not classified as "Monetary Financial Institutions" (MFIs) are captured. Thus, the OFI aggregate depicts a residual component and not only includes institutions universally accepted as shadow banks. For instance, the insurance corporations and pension funds sector (ICPFs) is mainly engaged in activities that are not related to shadow bank intermediation, and we therefore exclude balance sheet items of these institutions from our shadow bank aggregates. Furthermore, the OFI aggregate is lacking information on money market funds (MMFs), which are classified as MFIs. However, there is a broad consensus in the literature that MMFs engage in activities that could possibly be counted as shadow bank intermediation,[43] and we therefore include MMF information in the shadow bank aggregate. Our benchmark shadow bank definition (1) therefore closely resembles the broad shadow bank definition by the FSB and covers the whole range of OFIs except for ICPFs, plus MMFs (Scenario 1 in Table 4).[44]

The OFI sector, in line with the broad definition of shadow banks given by the FSB,

[43] See for instance Adrian (2014), Adrian and Liang (2014), Pozsar et al. (2010), or FSB (2017, 2011).

[44] Detailed information on the composition of the OFI sector has only recently been provided by the ECB. For instance, the collection of detailed balance sheet data on investment funds and financial vehicle corporations (FVCs) was only initiated in 2008 and 2009, respectively. Also, harmonized data on MMFs is available only from 2006 onward in the MFI statistics, but can be gathered from other sources for earlier years (see Appendix B). Balance sheet information on these institutions accounts for approximately 50 percent of the total OFI sector, with the rest being characterized by smaller and more heterogeneous entities. As highlighted by Doyle et al. (2016), one should therefore be aware of the fact that not all institutions in the remaining half of the OFI aggregate could unambiguously be declared as shadow banks.

Table 4: Different Definitions of Shadow Banks Based on the OFI Aggregate

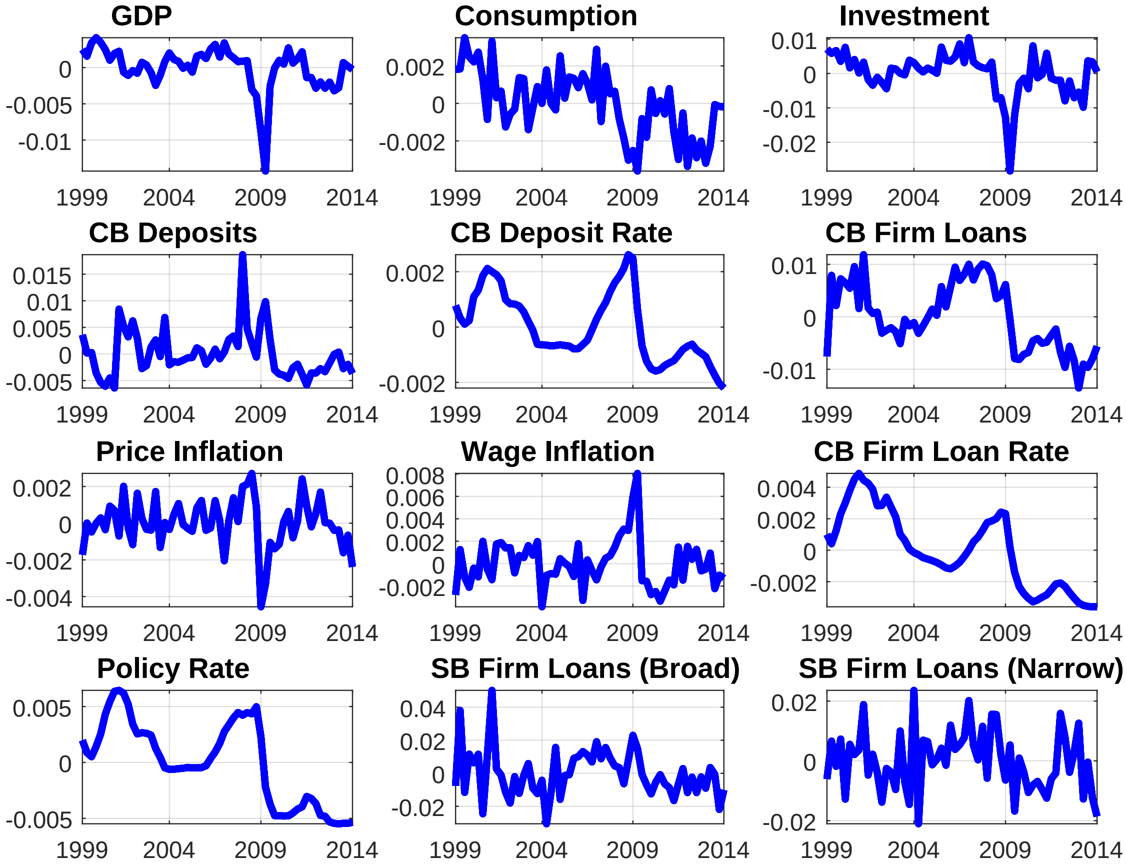
Scenario	Including Investment Funds	Including Money-Market Funds	Lending Counterparties
1	X	X	NFCs
2		X	Total economy

covers non-MMF investment funds. Whereas some studies highlight the increasing role of direct investment fund lending to the non-financial private sector in the euro area since the recent global financial crisis (Doyle et al., 2016), other studies discuss the special role investment funds play in the financial system and question the adequacy of considering these institutions as intermediaries between real economy borrowers and lenders. For instance, Bakk-Simon et al. (2012) argue that investment funds are indeed covered by regulation, even though substantially different than commercial banks. They therefore question whether the definition of shadow banks being intermediaries outside the regulatory system given by the FSB applies to investment funds. Consequently, we use as a robustness check an alternative measure of shadow bank loans that excludes investment funds (Scenario 2 in Table 4). However, we are not able to gather counterparty information for investment fund lending before 2008, and therefore use total lending of the OFI sector less investment fund lending in this second estimation, instead of lending to non-financial corporations only.

Shadow bank loans (including investment funds): Loans of other financial intermediaries (OFI) to non-financial corporations, excluding insurance corporations and pension funds, including investment funds, euro area 19 (fixed composition), deflated using HICP, calendar and seasonally adjusted data.

Shadow bank loans (excluding investment funds): Loans of other financial intermediaries (OFI) to total economy, excluding insurance corporations and pension funds, excluding investment fund assets (deposits, loans, and financial derivatives), euro area 19 (fixed composition), deflated using HICP, calendar and seasonally adjusted data.

Figure 10: Euro Area Observable Time Series Used in Estimation

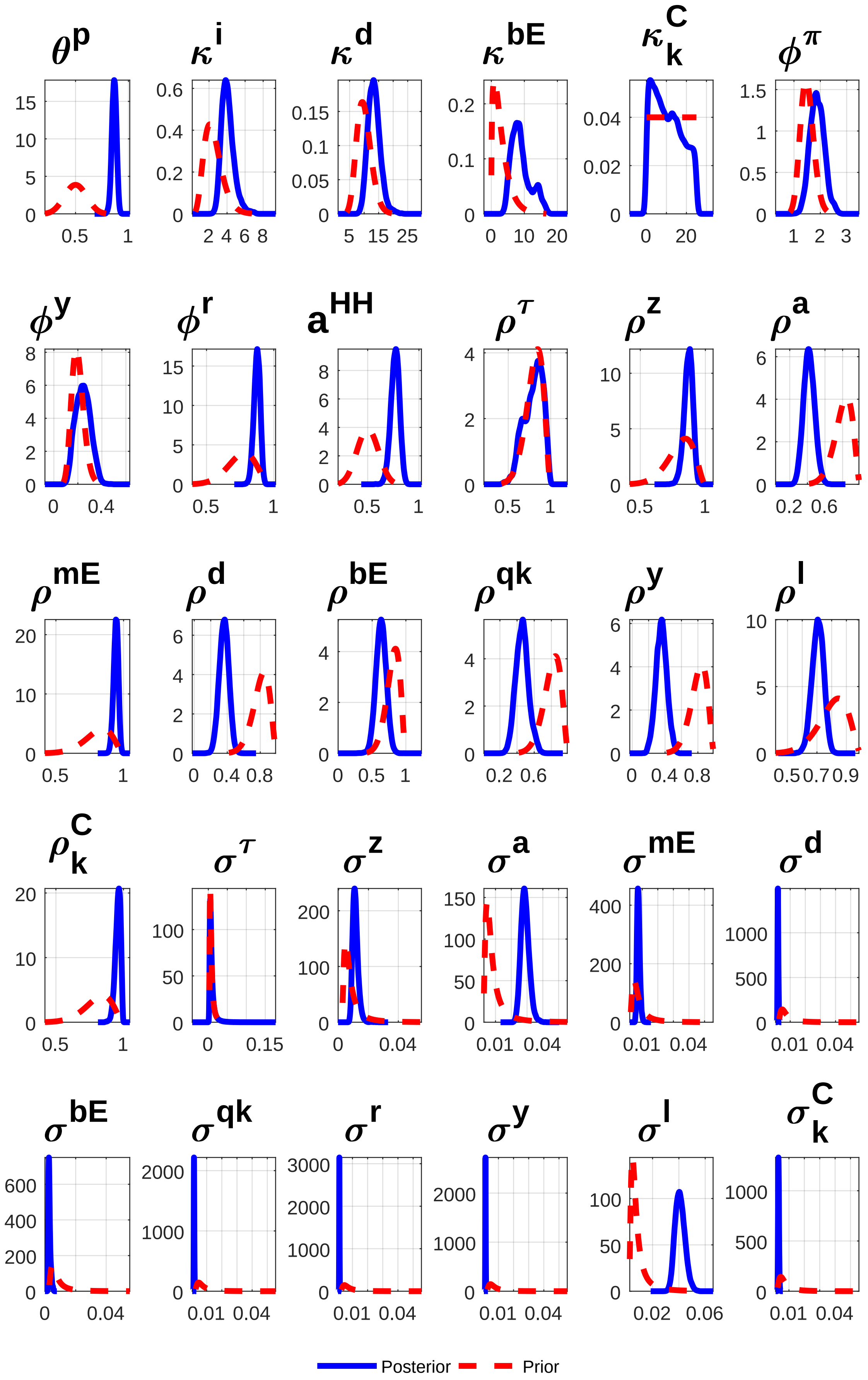


Note: Real stock and volume data (real GDP, real consumption, real investment, loans and deposits by commercial and shadow banks) are expressed as demeaned log-differences. Wage and price inflation and interest rates are quarterly net rates and expressed in absolute deviations from sample means.

B.3 Prior and posterior distributions

Figure 11 reports the prior and posterior distributions for the baseline estimation reported in Table 2.

Figure 11: Prior and Posterior Distributions: Baseline Estimation



Note: Prior and posterior distributions from the baseline estimation reported in Table 2.

C Appendix: Robustness Checks

In the following, we estimate our baseline model on two different specifications of the sample. First, to account for uncertainty around the exact date of the beginning of the ELB phase in the euro area, we provide evidence on estimated parameters when using an earlier end date as in the baseline specification. We are also aware of structural changes in the financial system after the 2007/2008 financial crisis and over the course of the subsequent European debt crisis which potentially altered the role and effectiveness of shadow banking in the euro area. To take these considerations into account, we re-estimate our model for the period of 1999:Q1 to 2008:Q4, thereby excluding both the post-financial crisis and ELB period from the estimation. In addition, excluding the period after 2008 allows for a straightforward comparison of results to Gerali et al. (2010), who used the same period in the estimation. Estimation results are reported in the middle columns of Table 5. In addition, we restate our baseline estimation results for comparison.

Whereas result from the pre-crisis period estimation are qualitatively comparable to the baseline estimates, some slight quantitative differences in parameter estimates can be observed. The mode estimates for the parameter governing investment adjustment costs turns out to be lower in the estimation using the pre-crisis sample. By including the years after 2008 - a period characterized by the aftermath of the global financial crisis and by the subsequent European sovereign debt crisis - the rise in investment adjustment costs could be driven by higher investment volatility - due to a significant fall in investment activity in the post-crisis years and the more moderate growth thereafter - in the post-2008 period. Furthermore, estimates for interest rate adjustment costs are higher in the pre-crisis sample compared to the full sample.

Second, we re-estimate our model by applying a different definition of shadow banks, i.e. by excluding investment funds from the shadow bank aggregate, as discussed in Section 4 and appendix B (Scenario 2 in Table 4). We report parameter estimates in the right columns of Table 5, again in comparison to our baseline estimation. Our baseline results are not substantially affected when investment fund information is excluded. Commercial bank loan rate adjustment costs turn out to be slightly lower when investment fund information is excluded from the estimation, whereas other structural parameters - based on the comparison of posterior modes - do not differ from baseline results.

Table 5: Posterior Distributions: Robustness and Evaluation

Parameter		Posterior Distribution				Pre-Crisis				Excluding Investment Funds			
		5 Perc.	Median	95 Perc.	Mode	5 Perc.	Median	95 Perc.	Mode	5 Perc.	Median	95 Perc.	Mode
Structural Parameters													
θ^p	Calvo Parameter	0.83	0.87	0.90	0.86	0.76	0.81	0.86	0.81	0.83	0.86	0.90	0.86
κ^i	Investment Adjustment Cost	2.98	3.98	5.14	3.67	2.60	3.64	4.83	3.50	2.89	3.79	4.76	3.66
κ^d	Deposit Rate Adjustment Cost	10.00	13.26	16.72	12.62	11.37	15.06	18.99	14.74	9.89	12.94	16.25	12.62
κ^{bE}	Loan Rate Adjustment Cost	4.84	8.34	14.23	7.56	5.11	9.72	15.13	8.81	4.75	7.74	11.00	6.91
κ_k^C	CCR Deviation Cost	0.01	10.05	21.32	24.71	3.32	14.01	25.00	25.00	3.08	14.27	24.99	25.00
ϕ^π	TR Coefficient π	1.44	1.87	2.30	1.75	1.23	1.62	2.03	1.58	1.43	1.87	2.31	1.80
ϕ^y	TR Coefficient y	0.14	0.24	0.34	0.20	0.12	0.20	0.28	0.19	0.12	0.20	0.29	0.20
ϕ^r	Interest Rate Smoothing	0.84	0.88	0.91	0.88	0.79	0.86	0.91	0.86	0.84	0.88	0.91	0.88
a^{HH}	HH Habit Formation	0.70	0.77	0.84	0.77	0.53	0.66	0.78	0.64	0.71	0.78	0.85	0.77
Exogenous Processes (AR Coefficients)													
ρ^τ	Deposit Rate Spread	0.62	0.81	0.95	0.85	0.65	0.81	0.96	0.85	0.65	0.82	0.96	0.85
ρ^z	Consumer Preference	0.82	0.87	0.92	0.87	0.77	0.87	0.95	0.88	0.81	0.87	0.92	0.87
ρ^a	Technology	0.31	0.42	0.52	0.42	0.31	0.42	0.52	0.42	0.32	0.42	0.53	0.42
ρ^{mE}	Entrepreneur LTV	0.91	0.94	0.97	0.95	0.90	0.94	0.98	0.95	0.91	0.94	0.97	0.94
ρ^d	Deposit Rate Markdown	0.27	0.36	0.46	0.36	0.28	0.38	0.49	0.38	0.27	0.37	0.47	0.37
ρ^{bE}	Loan Rate Markup	0.51	0.63	0.75	0.64	0.52	0.67	0.82	0.67	0.50	0.63	0.76	0.64
ρ^{qk}	Investment Efficiency	0.33	0.46	0.58	0.49	0.27	0.40	0.54	0.41	0.34	0.46	0.58	0.47
ρ^y	Price Markup	0.25	0.36	0.47	0.37	0.25	0.38	0.51	0.36	0.24	0.35	0.46	0.34
ρ^l	Wage Markup	0.64	0.71	0.77	0.71	0.62	0.70	0.77	0.69	0.65	0.71	0.77	0.71
ρ_k^C	Commercial Bank Capital	0.93	0.96	0.99	0.97	0.86	0.92	0.97	0.93	0.93	0.96	0.99	0.96
Exogenous Processes (Standard Deviations)													
σ^τ	Deposit Rate Spread	0.002	0.007	0.016	0.005	0.002	0.007	0.018	0.005	0.002	0.007	0.023	0.005
σ^z	Consumer Preference	0.008	0.011	0.014	0.011	0.005	0.008	0.011	0.007	0.008	0.011	0.014	0.011
σ^a	Technology	0.025	0.029	0.033	0.028	0.021	0.025	0.030	0.025	0.024	0.028	0.033	0.028
σ^{mE}	Entrepreneur LTV	0.006	0.008	0.009	0.007	0.004	0.006	0.007	0.005	0.006	0.008	0.009	0.007
σ^d	Deposit Rate Markdown	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
σ^{bE}	Loan Rate Markup	0.002	0.002	0.003	0.002	0.002	0.003	0.004	0.003	0.002	0.003	0.003	0.002
σ^{qk}	Investment Efficiency	0.001	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.001	0.002	0.002	0.002
σ^r	Monetary Policy	0.001	0.001	0.002	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.002	0.001
σ^y	Price Markup	0.001	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.001	0.002	0.002	0.001
σ^l	Wage Markup	0.035	0.041	0.047	0.040	0.029	0.035	0.042	0.035	0.035	0.041	0.047	0.040
σ_k^C	Commercial Bank Capital	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003

Note: Results are based on 5 chains with 500,000 draws each based on the Metropolis-Hastings algorithm. Columns 3 to 6 report the posterior moments from the baseline estimation in Table 2. Columns 7 to 10 report results from the estimation using the sample 1999:Q1 to 2008:Q4, and columns 11 to 14 report results from the estimation using shadow banking data excluding information on investment funds.

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