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Macro to the rescue? – An analysis of macroprudential instruments to regulate housing credit

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Non-technical summary

Research Question

In recent years the number of macroprudential instruments has risen significantly. However, there is still only scarce empirical evidence on their impact. This leaves open questions for policymakers. Which instruments should be activated in which situation? What are the transmission channels of macroprudential policy to both the financial system and the real economy? Moreover, proper evaluation of instruments that have been activated would require a counterfactual analysis, which is hardly feasible with empirical data.

Contribution

This model aims to help gain a deeper understanding of the transmission mechanism and impact of various macroprudential instruments. The model puts a focus on the regulation of mortgage credit, which was at the heart of the last financial crisis. There is a distinct financial sector lending to both households via mortgage credit and corporations via corporate assets. Monitoring costs of credit relationships depend dynamically on macroeconomic developments of corporate credit and mortgage credit. This allows to replicate both procyclical balance sheet expansions as well as asset price dynamics and spill-over effects between both markets. Moreover, three distinct instruments are assessed: a countercyclical capital buffer rule (CCyB), sectoral risk-weights and loan-to-value ratios (LTVs). First, the model allows, to deepen our understanding about potential transmission mechanisms of macroprudential regulation and second, it can function as a valuable tool for evaluating macroprudential policy.

Results

The results show that macroprudential instruments can contribute to dampening credit booms and, thus, mitigate the build-up of financial system vulnerabilities. The effectiveness and efficiency for each instrument depends on the nature of the shock. The CCyB might be more effective and efficient responding to general shocks, where housing credit increases as a side effect of larger credit movements. Sectoral shocks can be dealt with or responded to first with sectoral regulation. In the model the LTV is highly effective in dampening mortgage credit movements, but also causes strong side effects compared to sectoral risk weights. Thus, the model shows that while there are a variety of effective instruments available, there is no one-size-fits-all policy.

Nichttechnische Zusammenfassung

Fragestellung

In den vergangen Jahren ist die Zahl der verfügbaren makroprudenziellen Instrumente stark angestiegen. Allerdings liegt nur geringe empirische Evidenz über die Auswirkungen dieser Instrumente vor. Für Regulierer gibt es daher offene Fragen hinsichtlich der Anwendung makroprudenzieller Instrumente: Welche Instrumente sollten in welcher Situation angewandt werden? Wie erfolgt die Transmission makroprudenzieller Politik in das Finanzsystem und die Realwirtschaft? Auch nachdem Instrumente aktiviert wurden, würde deren Evaluierung eine kontrafaktische Analyse benötigen, die mit empirischen Daten kaum möglich ist.

Beitrag

Das vorliegende Modell soll das Verständnis über die Wirkungsweise und Auswirkung verschiedener makroprudenziellen Instrumenten verbessern. Der Fokus liegt hierbei auf Immobilienkrediten, die in der Finanzkrise eine wichtige Rolle spielten. Es wird ein Finanzsektor modelliert wird, der Beziehungen sowohl zu Haushalten (über Immobilienkredite) als auch Unternehmen (mittels Unternehmensfinanzierung) unterhält. Die Kosten der Überwachung von Kreditbeziehungen verlaufen dynamisch in Abhängigkeit makroökonomischer Entwicklungen, getrennt für Unternehmens- und Immobilienkredite. Das Modell erlaubt die Nachbildung von zyklischen Bilanzausweitungen sowie von Marktpreisdynamiken und Übertragungseffekten zwischen den Märkten für Immobilien und Unternehmensaktiva. Es werden drei makroprudenzielle Instrumente untersucht: eine Regel im Stile eines antizyklischen Kapitalpuffers (CCyB), sektorale Risikogewichte sowie eine Obergrenze für den Beleihungsauslauf (LTV). Das Modell erlaubt nicht nur ein tieferes Verständnis für mögliche Transmissionskanäle, sondern dient auch - über eine kontrafaktische Analyse - als Evaluierungsinstrument.

Ergebnisse

Die Ergebnisse zeigen, dass makroprudenzielle Regulierung in der Tat dazu beitragen kann, dem Aufbau von Verwundbarkeiten durch das Dämpfen von Kreditzyklen entgegenzuwirken. Allerdings ist nicht jedes Instrument gleichermaßen dazu geeignet, auf die verschiedenen Schocks zu reagieren. So zeigt das Modell, dass allgemeine Schocks, bei denen übermäßige Anstiege von Immobilienkrediten relativ zum Bruttoinlandsprodukt (BIP) eher als Nebenwirkung größerer Kreditentwicklungen auftreten, am besten mit dem CCyB als Beschränkung für ein allgemeines Kreditwachstum adressiert werden; gegebenenfalls können auch sektorale Risikogewichte zum Abschwächen übermäßiger sektoraler Entwicklungen verwendet werden. Sektorale Schocks hingegen werden in dem Modell am besten mit sektoralen Instrumenten adressiert. In dem Modell hat die LTV-Obergrenze eine hohe Effektivität, ruft aber starke Nebenwirkungen hervor. Die vorliegende Analyse zeigt somit auch, dass Regulierer zwar ein breites Instrumentarium besitzen, jedoch kein Instrument das Beste für alle Umstände ist.

BUNDESBANK DISCUSSION PAPER NO 25/2019

Macro to the Rescue? - An Analysis of Macroprudential Instruments to Regulate Housing Credit*

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Abstract

This paper builds a macro model with a financial sector and a housing market to understand the transmission and effects of macroprudential instruments addressing mortgage credit. The model compares the introduction of a loan-to-value ratio (LTV), a countercyclical capital buffer (CCyB)-style rule and sectoral constraints similar to sectoral risk weights. The results show that instruments work largely as intended and are to different extents suitable to dampen credit booms. Moreover, there is a trade-off between effectiveness, i.e. the extent to which instruments are able to dampen credit booms, and efficiency, i.e. the extent to which instruments might exhibit unintended consequences for the financial sector or real economy. General shocks, where housing credit increases as a side effect of larger movements, might warrant the use of the CCyB or also sectoral risk weights to correct for sector specific developments. Simple sectoral shocks can be dealt with or responded to first with sectoral risk weights. The LTV is much more effective than sectoral risk weights in confining credit growth, but shows less efficiency due to strong substitution effects.

Keywords: Macroprudential Regulation, Mortgage Markets, Housing Markets, Asset Markets, Waterbed Effects

JEL classification: E31, G21.

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1 Introduction

The G20 reform agenda has largely been implemented. Thus, the topic of evaluation becomes more and more important among policymakers (FSB, 2017).[1] The literature assessing G20 reforms is also growing among academics.[2] Since 2008 the number of macroprudential measures has increased considerably (Cerutti, Claessens, and Laeven, 2017), and there have been efforts to build up databases on macroprudential policy (Cerutti, Correa, Fiorentino, and Segalla, 2017; Vandenbussche, Vogel, and Detragiache, 2015). Empirical evidence on the application of macroprudential instruments is still scarce and mostly restricted to recent episodes or emerging market economies. Prominent examples are the application of the countercyclical capital buffer (CCyB) in Switzerland or the increase of risk weights for mortgage credit in Sweden (Crowe, Dell'Arriccia, Igan, and Rabanal, 2013). Concerning housing markets that have been a key location of distress during the financial crisis, the effectiveness and efficiency of the instruments applied appears to be mixed in general (Akinci and Olmstead-Rumsey, 2015; Kuttner and Shim, 2013; Lim, Columba, Costa, Kongsamut, Otani, Saiyid, Wezel, and Wu, 2011).

Policymakers that want to take action, such as introducing new macroprudential measures, face *ex ante* a dilemma of incomplete information. The effectiveness and efficiency of any regulation depends on its *ex post* implementation (Buch, Vogel, and Weigert, Buch et al.). Is the regulation working effectively and does it achieve its intended objectives or are there any potential unintended consequences?[3] A major obstacle in assessing the effectiveness and efficiency of specific measures is to derive a proper "counterfactual scenario" (Bruno, Shim, and Shin, 2017). In particular, in order to derive and understand potential transmission channels of macroprudential policy, granular data is required that is still not broadly available. Therefore, we develop a macro model in order to allow a structural assessment of the use of macroprudential instruments. We compare a baseline scenario calibrated to US data without any macroprudential instruments to a counterfactual scenario with macroprudential instruments active.

The model introduces financial intermediaries which have relationships to both the household and the corporate sector and which are subject to monitoring costs, similar to the balance sheet adjustment costs as in Gerali, Neri, Sessa, and Signoretti (2010)

[1]For example, in 2017 the FSB published an evaluation framework and launched the first evaluation projects on central clearing of OTC derivatives and infrastructure financing.

[2]Current examples are Loon and Zhong (2016) on the Dodd-Frank Act, Abbassi and Schmidt (2018) and Abbassi, Iyer, Pedro, and Soto (2018) on regulatory reporting, or Acosta-Smith, Ferrara, and Rodriguez-Tous (2018) and Kotidis and van Hooren (2018) who investigate the impact of the Basel 3 Leverage Ratio.

[3]For instance, confining growth by curbing beneficial lending activities or evoking "waterbed effects" where credit flows to less regulated segments (Bank of England, 2011; Deutsche Bundesbank, 2013).

or Iacoviello (2015).[4] These monitoring costs depend on factors affecting the risk of credit, such as the state of the economy or debtor and housing market developments. The model shows that these "risk-sensitive" monitoring costs increase the procyclicality of key economic variables compared to a model without or with only static monitoring costs. In particular, credit extension relative to output is more volatile compared to a model with static monitoring costs. There are three distinct macroprudential instruments. A broad capital based rule similar to the countercyclical capital buffer (CCyB), a rule mimicking sectoral risk weights and a loan-to-value (LTV) ratio. The instruments are calibrated using examples from actual regulation. The underlying assumption is that strong deviations from credit relative to GDP could increase vulnerabilities of the financial system to shocks (Drehmann, Borio, and Tsatsaronis, 2011; Drehmann and Gambacorta, 2012).

We assess the instruments in two dimensions. First, does an instrument achieve its desired objective (effectiveness)? Second, are there any potentially unwanted side effects (efficiency)? We rely on the results from comparative statics of volatility and procyclicality of key variables as well as on impulse response function (IRF) analysis. We put special emphasis on the overall credit and mortgage granted relative to GDP as target variables to approximate credit booms. The results indicate that macroprudential instruments work largely as intended. They can be effective tools to dampen credit booms and decrease the procyclicality of credit. There are also differences in terms of effectiveness. LTVs, as quantity restrictions, are more effective compared to price-based instruments such as macroprudential risk weights or the CCyB; the CCyB is more effective compared to the sectoral risk weights in dampening credit extension relative to output.

However, instruments might trigger unintended consequences such as substitution effects or might even affect output and other real economy variables. Too strong regulation might also curb beneficial credit activity. Sectoral instruments, in particular, might evoke strong substitution effects towards other sectors ("waterbed effect"). This might even endanger financial stability if regulation increases incentives for financial intermediaries to push into riskier activities (Bank of England, 2011; Deutsche Bundesbank, 2013) or even impact the output of the economy (Claessens, Kose, and Terrones, 2014). Thus, rules aiming at housing markets might also affect other asset markets. As the model features two distinct asset markets and lending relationships, we are able to investigate these issues.

The results indeed suggest some inefficiencies. The CCyB as a broad instrument reduces overall credit independent of the nature of the shock. Meanwhile, the LTV and the risk weights imply substitution effects from housing credit to corporate assets. The LTV might even have significant impact on overall output and asset prices. The nature

[4]The idea that lending is a costly process for banks and subject to monitoring or agency cost is spelled out in Diamond (1984) or Carlstrom and Fuerst (1997).

of the shock plays an important role. While a CCyB activation appears to be a suitable response to overall increases in credit, sectoral shocks should be addressed with sectoral instruments such as the LTV or risk weights. But there is also a trade-off between the LTV and risk weights facing sectoral shocks. The LTV is much more effective compared to sectoral risk weights in confining credit growth. Yet, the LTV shows less efficiency compared to the risk weights due to strong substitution effects. There is also a distinct impact on macro variables and asset price volatility. Therefore, the risk weights might be a valuable alternative at the brink of mortgage credit booms or rather small shocks hitting in particular housing credit.

Calibration of the instruments is an important aspect. In a sensitivity analysis we compare a varying degree of policy intensity. The analysis shows that more regulation might not be more effective in all cases. For most key variables there is some point where increasing intensity only yields marginal changes in the comparative statics. Policymakers, therefore, are required to carefully balance the activation of various instruments in view of the nature of shocks to financial stability and the economic environment.

The connection with the existing literature is twofold. First, there is a distinct role for the financial sector in the spirit of Goodfriend and McCallum (2007), Gertler and Karadi (2011), or Gerali et al. (2010). Prior models have usually introduced financial intermediaries only implicitly, e.g. the financial accelerator approach of Aoki, Proudman, and Vlieghe (2004) or the collateral constraints of Iacoviello (2005) or Iacoviello and Neri (2010). In this model we follow the path of a financial sector lending to two different sectors using different assets.

Second, the paper adds to the theoretical and empirical literature on policy evaluation. Akram (2014) estimates the effects of higher capital requirements on lending rates. In a counterfactual scenario the introduction of a counter-cyclical capital buffer would have a large impact on house prices and credit. As regards macro models, Angeloni and Faia (2013) find that modest anti-cyclical capital requirements and a central bank that is willing to lean against the wind, i.e. responds to asset prices or bank leverage, are an optimal policy mix. Gertler, Kiyotaki, and Queralto (2012) introduce a revenue neutral combination of a tax on bank debt (deposits) and a subsidy on bank equity in order to approximate countercyclical capital buffers. Their results show that macroprudential policy, while reducing the negative impact of banking crises, also reduces credit growth in tranquil times, implying lower welfare levels during an upturn. Finally, several contributions find countercyclical LTV rules to tame mortgage credit cycles (Gelain, Lansing, and Mendicino, 2013; Lambertini, Mendicino, and Punzi, 2013; Rubio and Carrasco-Gallego, 2014). The paper is also close to the analyses of Rubio and Carrasco-Gallego (2016) and Clerc, Derviz, Mendicino, Moyen, Nikolov, Stracca, Suarez, and Vardoulakis (2015), who investigate the effects of the three Basel capital requirement levels on overall credit extensions of banks. Clerc et al. (2015) incorporate two types of credit granted to both households and non-financials subject to default risk into a real business cycle model, while Rubio and Carrasco-Gallego (2016) focus on a single asset. Both confirm that a better capitalized financial system is more stable compared to less capitalized financial systems. However, this study puts less emphasis on capital levels, and focuses more on the qualitative implications of shocks on the portfolio structure of the financial system. By including multiple assets and instruments, the model thus allows a better assessment of transmission mechanisms and potential unintended consequences.

The paper is structured as follows. Section 2 presents the basic model components and its calibration, while section 3 describes the modeling and calibration of macroprudential policy. Section 4 discusses the results of the positive analysis of various macroprudential instruments using comparative statics and impulse response analysis. Section 5 presents some sensitivity analysis, before section 6 concludes.

2 The Benchmark Model

Figure 1 describes the main components of the model in a stylized manner. The model builds on the seminal contributions of Gertler and Karadi (2011), henceforth GK, and Iacoviello (2005). Both papers are lean and well-known contributions of relevant financial frictions. The GK framework introduces balance sheet fluctuations that are driven by changes in the real economy, while Iacoviello links housing market developments to the financial sector.[5] There are three general sectors: households, industry and financial intermediaries. There are patient households, i.e. net lenders around the steady state, and impatient households as net borrowers. Household borrowing is limited by a housing collateral constraint (Iacoviello, 2005). All savings of patient lenders are funneled via financial intermediaries to impatient households and non-financial corporations that produce intermediary goods; there is no direct lending from the household to the corporate sector. As in GK, banks are constrained by investor scrutiny due to a moral hazard problem. Moreover, they face monitoring cost for credit similar to the risk weights of the Basel rules on capital adequacy. Most importantly, the model contains two distinct asset markets, housing that is used as mortgage collateral and corporate assets.[6] Both entrepreneurs and impatient households rely on external financing of financial intermediaries.

[5] A disadvantage of the GK framework is that leverage is anti-cyclical in the model. Thus, while balance sheet developments are procyclical due to increases in bank net worth, the leverage goes down in booms and goes up in busts. Nevertheless, for an overall credit perspective, the model is a suitable representation for fluctuations in financial cycles.

[6] Corporate assets are considered here as any funding coming from financial intermediaries to entrepreneurs such as stocks, bonds, but also loans. While the model assumes equity-style instruments, the corporate return can also be seen as the average return on both equity and debt instruments.

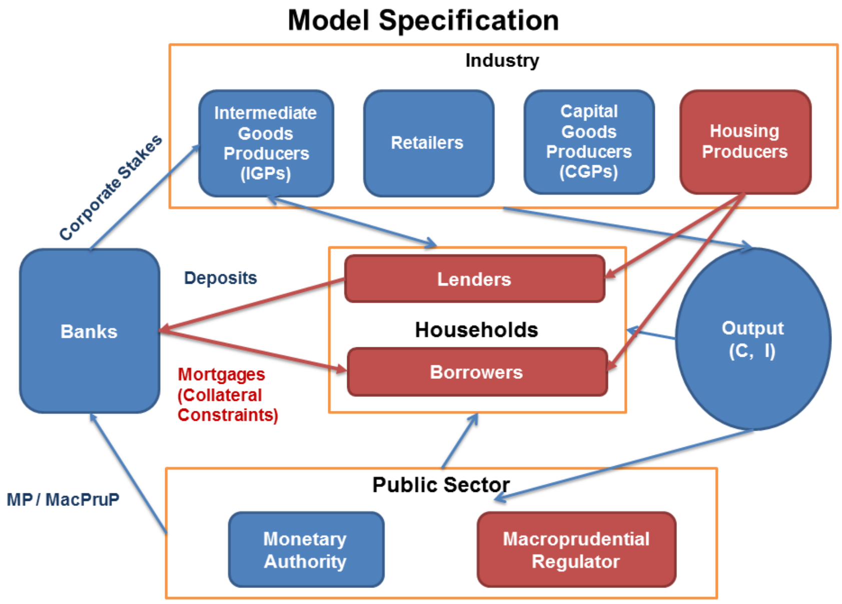

Figure 1: Overview of model building blocks.

2.1 Patient Households

Patient households are lenders to the financial intermediaries in net terms via deposits. They choose optimal non-durable consumption c_t, housing h_t, and labor l_t subject to their budget constraint.[7] There is habit formation in non-durable consumption with parameter a. Households can also choose between investing in houses at real prices Q_{ht} or saving via deposits D_t that are remunerated at the risk-free real rate R_t. They receive wage income $w_t l_t$ from the intermediate goods producers and dividends $\mathcal{D}_t$ from their stakes in financial intermediaries, retailers and capital (housing) goods producers. Their maximisation problem is as follows:

$$\max_{h_{lt},c_t,l_t} E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, h_t, l_t) \text{ s.t.,} \tag{1}$$

$$u(c_t, h_t, l_t) = \log(c_t - ac_{t-1}) + \chi_H \epsilon_{j,t} \log h_t - \frac{\chi_L l_t^{1+\varphi}}{1+\varphi}, \tag{2}$$

$$c_t + Q_{ht}\Delta h_t + D_t = w_t l_t + R_{t-1}D_{t-1} + \mathcal{D}_t, \tag{3}$$

[7] In the following, lower case notation represents sector specific variables that are subject to aggregation.

where χ_H and χ_L represent the weights of housing and labor in the utility function, φ is the inverse of the Frisch elasticity of labor supply, and β is the respective discount factor of lenders. $\epsilon_{j,t}$ is an exogenous housing preference shock following an AR(1) process with iid innovations. This results in the following optimality conditions for consumption, labor and housing choices; λ_t represents the Lagrange multiplier of the lender's budget constraint:

$$\lambda_t = \frac{1}{c_t - ac_{t-1}} - \frac{a\beta_l}{c_{t+1} - ac_t}, \tag{4}$$

$$\lambda_t w_t = \chi_L l_t^{\varphi}, \tag{5}$$

$$Q_{ht} = \beta Q_{h,t+1}\Lambda_{t,t+1} + \frac{\chi_H \epsilon_{j,t}}{h_t \lambda_t}, \tag{6}$$

$$1 = \Lambda_{t,t+1} R_t \beta, \tag{7}$$

where

$$\Lambda_{t,t+1} = \frac{\lambda_{t+1}}{\lambda_t}, \tag{8}$$

is the rate of change of the budget constraint Lagrange multiplier λ_t from period t to $t+1$. The lender's discount factor determines the steady state deposit rate, i.e. $R = 1/\beta$.

2.2 Impatient Households

The impatient households discount the future more heavily compared to lenders, i.e. $\tilde{\beta} < \beta$.[8] They are net borrowers around the steady state. Instead of saving via deposits, they are borrowing via mortgages M_t repayable at the mortgage rate $R_{m,t}$. Borrowing requires collateral determined by the housing stock available: impatient households can only borrow up to an amount such that their repayment in the next period is less than or equal to a fraction m, the LTV, of their future housing wealth. Similar to patient households their preference parameters for housing and labor are $\tilde{\chi}_L$ and $\tilde{\chi}_H$, with $\epsilon_{h,t}$ as

[8] Impatient household variables and parameters are written in tilde notation.

exogenous housing preference shock. The maximisation problem reads:

$$\max_{\tilde{h}_t,\tilde{c}_t,\tilde{l}_t} E_0 \sum_{t=0}^{\infty} \tilde{\beta}^t u(\tilde{c}_t, \tilde{h}_t, \tilde{l}_t) \; s.t. \tag{9}$$

$$u(\tilde{c}_t, \tilde{h}_t, \tilde{l}_t) = \log(\tilde{c}_t - a\tilde{c}_{t-1}) + \tilde{\chi}_H \epsilon_{h,t} \log \tilde{h}_t - \frac{\tilde{\chi}_L \tilde{l}_t^{1+\varphi}}{1+\varphi}, \tag{10}$$

$$\tilde{c}_t + Q_{ht}\Delta\tilde{h}_t + R_{m,t-1}M_{t-1} = \tilde{w}_t\tilde{l}_t + M_t, \tag{11}$$

$$M_t R_{m,t} \leq m Q_{h,t+1}\tilde{h}_t. \tag{12}$$

This results in the following optimality conditions for consumption, labor and housing choices:

$$\tilde{\lambda}_t = \frac{1}{\tilde{c}_t - a\tilde{c}_{t-1}} - \frac{a\tilde{\beta}}{\tilde{c}_{t+1} - a\tilde{c}_t}, \tag{13}$$

$$\tilde{\lambda}_t \tilde{w}_t = \tilde{\chi}_L \tilde{l}_t^{\varphi}, \tag{14}$$

$$Q_{ht} = \tilde{\beta} Q_{h,t+1}\tilde{\Lambda}_{t+1} + \frac{\tilde{\chi}_H \epsilon_{h,t}}{\tilde{h}_t \tilde{\varrho}_t} + \frac{m Q_{h,t+1} \varrho t}{\tilde{\lambda}_{t+1}}, \tag{15}$$

with $\tilde{\varrho}_t$ being the Lagrange multiplier of the borrowing constraint 12.

$$\tilde{\Lambda}_{t,t+1} = \frac{\tilde{\lambda}_{t+1}}{\tilde{\lambda}_t}, \tag{16}$$

The intertemporal choice condition of borrowers is:

$$1 = \tilde{\Lambda}_{t,t+1}\tilde{\beta} R_{m,t} + \frac{\tilde{\varrho}_t R_{m,t}}{\tilde{\lambda}_t}. \tag{17}$$

2.3 Financial Intermediaries

Following the GK literature, bankers are members of the patient households. In order to ensure bankers require external financing there is a probability, $1 - \theta$, that a banker quits the lending business and becomes a worker each period.[9]
The balance sheet of a representative banker consists of patient household deposits D_t and net worth N_t, acquired via retained earnings, that can be interpreted as bank equity.[10]
On the left hand side of the bank balance sheet there is mortgage credit M_t to impatient households, and contingent stakes to non-financial corporations that can be interpreted

[9] However, as each exiting banker is replaced by a new one, their number remains constant.

[10] Gertler and Karadi (2011) show that the bankers can be aggregated, as each banker faces the same prices. This also holds in a two-asset economy. As they also face the same discount factors and borrower demand, each banker wants to hold the same proportion of mortgage credit and corporate stakes.

as a aggregate of stocks, bonds or loans of corporations.[11] Defining total assets of a representative banker as Θ_t, the balance sheet reads:

$$D_t + N_t = M_t + Q_{k,t} S_t = \Theta_t. \tag{18}$$

Bankers accumulate net worth by retaining profits. Thus, net worth depends on the spreads of the return on assets over the deposit rate:

$$N_{t+1} = R_{k,t+1} Q_{k,t} S_t + R_{m,t} M_t - R_t D_t. \tag{19}$$

This can be rewritten using the balance sheet identity and defining the share of mortgages on the bank balance sheet $\sigma_t = \frac{M_t}{\Theta_t}$. The share is time-varying; thus, in the model the portfolio structure of financial intermediaries can vary over time. Portfolio structure is determined both by the return on assets, but also by restrictions such as the availability of housing collateral for credit. Moreover, there is no distinct default in the model. However, the risk of the two assets is implicitly approximated by introducing monitoring costs for surplus returns of mortgages $\psi_{m,t}$ and corporate stakes $\psi_{s,t}$. The riskier an asset, the more monitoring and effort is necessary by bankers. Monitoring costs are a lean way of introducing different levels of mortgage and corporate asset returns in the model economy. Economically, this mechanism is consistent with asset-specific risk weights; actual banks have to hold more costly capital for riskier assets. By implying dynamic risk weights later on, monitoring costs also allow to model differentiated reactions of asset returns after shocks. By altering the cost of credit, monitoring costs might also have real economic impact. Higher monitoring costs might curb overall credit in the model, while decreases in monitoring costs should imply higher credit extension.[12] This yields:

$$N_{t+1} \left[(1 - \sigma_t)(R_{k,t+1} - R_t)(1 - \psi_{s,t}) + \sigma_t (R_{m,t} - R_t)(1 - \psi_{m,t})\right] \Theta_t + R_t N_t. \tag{20}$$

Bankers optimize their terminal wealth, i.e. the net worth accumulated up to the period they exit. As bankers are members of the patient household sector, they have identical discount factors.

$$\begin{aligned} V_t &= \max_{M_t, S_t} = \theta^i \beta^i \Lambda_{t,t+i} \sum_{i=0}^{\infty} N_{t+i} \\ &= \theta^i \beta^i \Lambda_{t,t+i} \sum_{i=0}^{\infty} \left((R_{k,t+i+1} - R_{t+i} + \sigma_{t+i}(R_{m,t+i} - R_{k,t+i+1}))\Theta_{t+i} + R_t N_{t+i} \right). \end{aligned} \tag{21}$$

[11] As the intermediate goods producers issue a stake S_t per unit of capital acquired K_t, arbitrage requires the prices of stakes and capital to coincide: $Q_{k,t} K_{t+1} = Q_{k,t} S_t$.

[12] See also section 3 or B in the appendix.

Following Dedola, Karadi, and Lombardo (2013), terminal wealth with two assets is expressed as a linear combination of the evolution of total bank assets Θ_t and net worth N_t weighted by the respective marginal gain ν_t (η_t) of expanding assets (net worth), holding net worth (total assets) constant.

$$V_t = \nu_t \Theta_t + \eta_t N_t, \tag{22}$$

$$\begin{aligned} \nu_t = {} & (1-\theta)\Lambda_{t,t+1}[(1-\sigma_t)(\beta(R_{k,t+1}-R_t)(1-\psi_{s,t}) \\ & + \sigma_t(R_{m,t}-R_t)(1-\psi_{m,t})] + \beta\theta\Lambda_{t,t+1}\nu_{t+1}x_{t,t+1}, \end{aligned} \tag{23}$$

$$\eta_t = (1-\theta)\Lambda_{t,t+1}R_{t+1}\beta + \beta\theta\Lambda_{t,t+1}\eta_{t+1}z_{t+1} = (1-\theta) + \beta\theta\eta_{t+1}z_{t,t+1}, \tag{24}$$

with $x_{t,t+1}$ ($z_{t,t+1}$) denoting the growth of total wealth (net worth) between periods t and $t+1$. In optimum, bankers choose mortgages and corporate stakes according to the following FOCs:

$$\frac{\delta V_t}{\delta m_t} = (R_{m,t}-R_t)(1-\psi_{m,t}) = 0, \tag{25}$$

$$\frac{\delta V_t}{\delta Q_t S_t} = (R_{k,t+1}-R_t)(1-\psi_{s,t}) = 0. \tag{26}$$

This yields the following relationship between the relative surplus over the risk-free rate of the two assets:[13]

$$(R_{m,t}-R_t) = (R_{k,t+1}-R_t)\frac{1-\psi_{s,t}}{1-\psi_{m,t}}. \tag{27}$$

Thus, the return on mortgages depends on both the return on corporate stakes and the ratio of the share after monitoring costs incurred. It is assumed that monitoring of corporate stakes that are not collateralized is more costly compared to mortgages secured by housing collateral. This also reflects the regulatory environment where risk weights are to reflect the riskiness of underlying assets. In the absence of monitoring costs due to arbitrage reasons, the return of mortgages should equal the return on corporate assets. Thus, monitoring costs introduce an additional friction between the two interest rates.

As in GK an agency problem is introduced that pins down the leverage and balance sheet of banks. Bankers are funding-constrained, as lenders can only recover a certain fraction $1-s$, $s \in [0,1]$, of their investment in case a banker chooses to default and take away the other fraction. Consequently, bankers only receive funds as long as the terminal wealth obtained for running the business V_t is larger than the sums a banker

[13] In the appendix it is shown that this condition is mathematically equivalent to the case that assets are chosen according to risk weighted capital optimization.

obtains when defaulting:

$$V_t = \nu_t \Theta_t + \eta_t N_t \geq s\Theta_t. \tag{28}$$

Assuming efficiency of both bankers and investors, this equation holds equally in the steady state, and the leverage ratio ϕ_t can be pinned down as:

$$\Theta_t = \frac{\eta_t}{s - \nu_t} N_t = \phi_t N_t. \tag{29}$$

Net worth signals a banker's skin in the game and thus correlates positively with the amount of funding a banker can obtain from savers. The leverage depends positively on the marginal gains of both net worth and total assets and negatively on the share of funds intermediaries are able to divert. The rationale is that a profitable bank can obtain more funding, which is self-enforcing. Once profitability starts to improve (deteriorate), more (less) assets can be acquired. The model thus replicates procyclicality of financial intermediaries' balance sheet size (Adrian and Shin, 2010).[14]

Finally, the evolution of total net worth also depends on the share of bankers exiting and entering. Existing bankers' net worth evolves according to the formulas above, while new bankers receive an initial endowment from their families. This endowment amounts to a fraction of $\frac{\omega}{1-\theta}$ of the net worth of exiting bankers. The remaining amount is paid in a lump sum as dividends to the lenders. As the share of exiting and remaining bankers is determined by θ, aggregate net worth evolves according to

$$N_t = \theta N_{e,t} + (1 - \theta) N_{n,t}, \tag{30}$$

$$N_{e,t} = [(1 - \sigma_t) R_{k,t} + \sigma_t R_{m,t} - R_t] \phi_{t-1} N_{t-1} + R_t N_{t-1}, \tag{31}$$

$$N_{n,t} = \frac{\omega}{1 - \theta} \Theta_t. \tag{32}$$

Net worth is accumulated as retained earnings of remaining bankers and the endowment of newly entering bankers. While the retained earnings of existing bankers is driven by their profitability and leverage, the endowment of new bankers is a fixed share of bankers' assets.

2.4 Intermediate Goods Producers

The intermediate goods producers create goods $Y_{w,t}$, which are sold at the wholesale price $P_{w,t}$ to retailers with labor and capital as inputs. They borrow from the financial intermediaries to fund their capital by issuing stakes S_t at price $Q_{k,t}$. Any profits are then paid as a contingent repayment of the return on capital $R_{k,t}$ to the financial interme-

[14]However, as in the original model, the main driver of balance sheet fluctuations is net worth rather than leverage.

diaries. This return can be interpreted as the joint return on outside equity, bonds and loans that are granted to the financial intermediaries as sole investors.

Following Christiano, Eichenbaum, and Evans (2005), intermediate goods producers choose optimal inputs: first, capacity utilization U_t of physical capital that affects the depreciation rate δ_t. Second, labor that is aggregated in a Cobb-Douglas fashion from the labor contributions of patient and impatient households. This functional forms ensures a skill complementarity and reduces substitution effects. The parameter ι governs the wage share or labor intensity of patient households (Iacoviello and Neri, 2010). The value of the intermediate goods producers' capital stock evolves according to $(Q_{k,t+1} - \delta_{t+1})\zeta_{t+1}K_{t+1}$ which assumes that the cost of replacing worn out capital is unity. A_t is a standard technology shock, while ζ_t represents a shock to the quality of the capital stock. This shock alters how efficiently capital can be used and can be interpreted as both financial assets and capital input losing/gaining value immediately. While A_t targets the general productivity, i.e. less capital and labor is required to produce the same amount of output, a shock increasing the quality of capital increases the amount of effective capital.

Goods producers then maximize their profits including the value of the capital stock according to:

$$\max_{U_t, L_t} P_{w,t}Y_{w,t} - w_t l_t - \tilde{w}_t \tilde{l}_t - R_{k,t}Q_{k,t-1}K_t + (Q_{k,t} - \delta_t)\zeta_t K_t, \tag{33}$$

$$\delta_t = \delta_c + \frac{\delta_1 U_t^{(1+\delta_2)}}{1+\delta_2}, \tag{34}$$

$$Y_{w,t} = A_t(\zeta_t U_t K_t)^{\alpha} L_t^{(1-\alpha)}, \tag{35}$$

$$L_t = l_t^{\iota} \tilde{l}_t^{(1-\iota)}. \tag{36}$$

The respective optimality conditions and the return on the rate of capital are

$$\frac{\partial \delta_t}{\partial U_t}\zeta_t K_t = P_{w,t}\frac{\alpha Y_{w,t}}{U_t}, \tag{37}$$

$$w_t = P_{w,t}\frac{(1-\alpha)\iota Y_{w,t}}{l_t}, \tag{38}$$

$$\tilde{w}_t = P_{w,t}\frac{(1-\alpha)(1-\iota)Y_{w,t}}{\tilde{l}_t}, \tag{39}$$

$$R_{k,t+1} = \frac{\frac{\alpha P_{w,t+1}Y_{w,t+1}}{K_{t+1}} + (Q_{k,t+1} - \delta_{t+1})\zeta_{t+1}}{Q_{k,t}}. \tag{40}$$

Wages of households are driven by production output relative to the respective labor input. The return on capital meanwhile is driven by both the effective output per unit of capital and changes in the price of capital after depreciation as well as by changes in capital quality.[15]

2.5 Capital and Housing Goods Producers

Elasticities of investment, i.e. the elasticity of housing supply, play a crucial role for intense price movements (Glaeser, Gyourko, and Saiz, 2008; Caldera and Johansson, 2013). Carlstrom and Fuerst (2010) show that capital and housing investment behave differently over the business cycle, with residential investment being far more responsive to changes in macroeconomic variables. Evidence even suggests that residential investment leads the business cycle and capital goods investment (Peek and Wilcox, 2006). Carlstrom and Fuerst (2010) suggest that separating long-run from short-term elasticities is an important factor in order to achieve hump-shaped responses in investment dynamics after monetary policy shocks. Therefore, the model captures the divergence between short-term and long-term elasticities for both housing and capital via diverging adjustment costs.

Capital (housing) goods producers refurbish depreciated physical capital K_t (aggregate housing H_t), priced unity, and produce new capital (housing) to be sold at price $Q_{k,t}$ ($Q_{h,t}$). The producers are facing both short-term and long-term adjustment costs. The short-term adjustment costs $\Gamma_{ks,t}$ and $\Gamma_{hs,t}$ are flow-based. Meanwhile the long-term adjustment costs $\Gamma_{kl,t}$ and $\Gamma_{hl,t}$ also depend on the level of the prior capital and housing stock:[16]

$$\Gamma_{ks,t} = \frac{\kappa_{ks}}{2}\left(\frac{I_{k,t}}{I_{k,t-1}} - 1\right)^2, \tag{41}$$

$$\Gamma_{hs,t} = \frac{\kappa_{hs}}{2}\left(\frac{I_{h,t}}{I_{h,t-1}} - 1\right)^2, \tag{42}$$

$$\Gamma_{kl,t} = \frac{\kappa_{kl}}{2}\left(\frac{I_{k,t}}{\delta_t K_t} - 1\right)^2 \frac{\delta_t \zeta_t K_t}{I_{k,t}}, \tag{43}$$

$$\Gamma_{hl,t} = \frac{\kappa_{hl}}{2}\left(\frac{I_{h,t}}{\delta_h H_t} - 1\right)^2 \frac{\delta_h H_t}{I_{h,t}}. \tag{44}$$

δ_t represents the depreciation rate depending on the capacity utilization rate as specified above and δ_h the time-invariant housing depreciation rate.[17]

Capital and housing producers thus choose optimal investment $I_{i,t}$, $i \in [k, h]$ in order

[15] A detailed derivation of the rate of return of capital can be found in the appendix.

[16] For instance, Dedola et al. (2013) use both adjustment costs, yet in a comparative manner. See also Christiano et al. (2005).

[17] The time invariance is a result of a constant utilization rate of housing in contrast to capital which is used in the production process.

to maximize

$$\max_{I_{i,t}} E_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left[Q_{i,\tau} I_\tau - (1 + \Gamma_{is,\tau} + \Gamma_{il,\tau}) I_{i,\tau} \right]. \tag{45}$$

This yields the following Q relationship[18] governing investment behavior

$$Q_{i,t} = 1 + \Gamma_{is,t} + \Gamma'_{is,t} \left(\frac{I_{i,t+1}}{I_{i,t}} \right) + \Gamma_{il,t} + \Gamma'_{il,t} - \beta \Lambda_{t,t+1} \Gamma'_{il,t+1} \left(\frac{I_{i,t+1}}{I_{i,t}} \right)^2, \tag{46}$$

subject to the following flow of funds constraints:

$$K_t = (1 - \delta_{t-1}) \zeta_{t-1} K_{t-1} + I_{k,t-1}, \tag{47}$$

$$H_t = (1 - \delta_h) H_{t-1} + I_{h,t-1}. \tag{48}$$

Diverging adjustment cost parameters are then used to model the differences in price responsiveness of capital and housing, as well as varying short-term and long-run elasticities. This allows to bring the model closer to the data and should facilitate estimation of the model. Including both short-term and long-term adjustment costs implies, however, a longer persistence of investment cycles on the one hand. On the other hand, short-term investment dynamics are smoother and less rapid compared to a model with only short-term adjustment costs. As shown in the appendix, there are no qualitative changes in the impulse responses of the main model.[19]

2.6 Retailers

Sticky prices are motivated by a Calvo (1983) pricing problem with price indexation as in GK.[20] Retailers are a continuum of firms that rebrand and resell intermediate output. Only a share of $1-\gamma$ of retailers can adjust to the optimal price of P_t^*, while the remaining share indexes its prices to past inflation at a parameter γ_P. Economy-wide output and prices are formed using Dixit-Stiglitz aggregators with an elasticity among varieties of ϵ and inflation π_t is defined as the change in actual price levels P_t, i.e. $\pi_t = P_t / P_{t-1}$. Retailers maximize their expected profits from setting the optimal prize as follows:

$$\max_{P_t^*} E_t \sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left(\frac{P_t^*}{P_{t+i}} \prod_{j=1}^{i} (1 + \pi_{t+j-1})^{\gamma_P} - P_{w,t+i} \right) Y_{t+i}. \tag{49}$$

[18] Tobin's Q is defined as the ratio of market value of capital (housing) over the replacement cost of capital (housing) which is unity.

[19] See figures 13 to 15 in the appendix.

[20] For price indexation, see also Christiano et al. (2005).

The left part of the discounted sum represents the expected turnover of selling output when the optimal price can be set in period $t + i$. The product in brackets reflects all the prior periods where prices could only be indexed to past inflation. The right part of the discounted sum simply refers to the costs of wholesale output. This results in the following optimality condition:

$$E_t \sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left(\frac{P_t^*}{P_{t+i}} \prod_{j=1}^{i} (1 + \pi_{t+j-1})^{\gamma_P} - \frac{1}{1 - \frac{1}{\epsilon}} P_{w,t+i} \right) Y_{t+i} = 0. \tag{50}$$

GK then show that the optimal price path evolves along

$$P_t = [(1 - \gamma)(P_t^*)^{(1-\epsilon)} + \gamma(\Pi_{t-1}^{\gamma_P} P_{t-1})^{(1-\epsilon)}]^{\frac{1}{1-\epsilon}}, \tag{51}$$

where Π_{t-1} represents the product of past indexed inflation.

2.7 Closing the Model

Closing the model requires market clearing and fulfillment of the aggregate resource constraints. Aggregate output consists of aggregate consumption C_t, and aggregate (gross) investment I_t including adjustment costs:

$$Y_t = C_t + I_t, \tag{52}$$

$$C_t = c_t + \tilde{c}_t, \tag{53}$$

$$I_t = I_{k,t} + \Gamma_{k,t} + I_{h,t} + \Gamma_{h,t}, \tag{54}$$

$$H_t = h_t + \tilde{h}_t. \tag{55}$$

Monetary policy follows a Taylor rule that targets the (nominal) policy rate with interest rate smoothing parameter κ_i. The rule takes into account deviations of the steady state (or rather target) inflation as well as output fluctuations with respective weights κ_π and κ_Y. The nominal rate also determines the real rate via the Fisher equation.

$$i_t = i_{t-1}^{\kappa_i} \left(\pi_t^{\kappa_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\kappa_Y} \right)^{(1-\kappa_i)} \epsilon_i, \tag{56}$$

$$i_t = R_t \pi_t, \tag{57}$$

where $\epsilon_{i,t}$ represents an exogenous monetary policy shock.

2.8 Calibration

The model is calibrated to quarterly data relying on parameters used in the literature around Gertler and Kiyotaki (2010), Gertler and Karadi (2011) and Iacoviello (2005).

As these studies refer to the US economy, the model is calibrated to US data. Table 1 gives a short overview.

Households discount the future with a β of 0.995 yielding an annual risk-free deposit rate of 2%. The housing utility weight of patient households χ_H, the wage share of constrained households ι and the discount rate of impatient households are from Iacoviello and Neri (2010), while the parametrization of the habit persistence a, Frisch elasticity of labor, φ, the disutility parameter of labor χ_L and the parameters of the capital depreciation rate as well as all the parameters related to shocks and Calvo pricing follow Gertler and Karadi (2011), while capital intensity α is set at 0.25 as in Gerali et al. (2010). The housing preference of impatient households $\tilde{\chi}_H$ is calibrated to 0.5.[21] Housing depreciates at a constant quarterly rate δ_h of 0.005, which is equivalent to an annual rate of 2%. The relative ratio of short-to-long-term adjustment cost parameters for housing investment is inspired by results from Caldera and Johansson (2013).[22] Capital investment parameters are then calibrated to ensure a similar pattern, yet a more elastic response of housing investment in line with empirical studies (Carlstrom and Fuerst, 2010). The parameters of the monetary policy rule relies on estimations of Gerali et al. (2010). Finally, the steady state LTV-ratio m is set at 80% in line with literature standards and close to empirical findings.[23] The monitoring costs constants for mortgages and corporate stakes are defined at 0.21 and 0.3, similar to the ratio of risk weight constants under the Basel II standardized approach.[24] Leverage in equilibrium is 6, equaling a capital ratio of around 16%, which is well above regulatory requirements of 8% of risk weighted assets. The calibration of the capital quality, monetary policy and technology shock uses the parameters from GK. The parameters of the capital quality shocks have a lower persistence of 0.66, but larger variance compared to monetary policy and technology that use an autocorrelation of 0.95 with a standard deviation of 0.01.[25] The housing preference shock uses the calibration of Iacoviello and Neri (2010) with an autocorrelation of 0.96 and a SD of 0.04.

All in all, this yields steady state characteristics that are plausible compared to pre-crisis data. The overall consumption share of approximately 76% of GDP, with the major part accounting for lender consumption. Capital investment amounts to 14% of GDP, compared to 10% for residential investment. The amount of mortgages is 0.74

[21]This is higher compared to the lender parameter of 0.12 in order to generate a share of mortgages that copes with empirical data.

[22]The ratio of estimated short-to-long-term supply elasticities relative to the price in the US is $2.5/2 = 1.25$. However, in order to avoid large house price movements, these parameters have been scaled relative to capital.

[23]In the Macroprudential Measures Database of the ESRB there can be found LTVs set between 60% and 100% depending on the type of housing collateral (ESRB, 2018).

[24]The ratio of monitoring costs is 0.7 to 1 similar to the ratio of risk weights that are 35% for mortgages and 50% for corporate loans in the Basel II framework.

[25]Compared to GK, the variance of the capital quality shock is reduced to 0.02 instead of 0.05 to curb the effect of this shock on the overall economy.

Parameter	Value	Description
Financial Intermediaries		
θ	0.965	Probability of remaining a banker
ω	0.002	Endowment share of new bankers
s	0.35	Share of assets bankers can divert
m	0.8	Loan-to-value ratio fixed parameter
ψ_s	0.3	Monitoring costs corporate stakes fixed parameter
ψ_m	0.21	Monitoring costs mortgages fixed parameter
Household Sector		
a	0.815	Habit parameter
β	0.995	Patient household discount factor
$\tilde{\beta}$	0.975	Impatient household discount factor
χ_H	0.12	Housing preference (lenders)
$\tilde{\chi}_H$	0.5	Housing preference (borrowers)
χ_L	3.41	Labor preference parameter
φ	0.276	Inverse Frisch elasticity of labor
ι	0.8	Wage share of lenders
Production Sector		
α	0.25	Capital intensity
δ_c	0.02	Capital depreciation rate constant
δ_1	0.037	Capacity utilization cost parameter
δ_2	7.2	Elasticity of marginal depreciation due to utilization
δ_h	0.005	Housing depreciation rate
κ_{ks}	1	Capital investment adjustment cost, short-term
κ_{kl}	0.5	Capital investment adjustment cost, long-term
κ_{hs}	0.4	Housing investment adjustment cost, short-term
κ_{hl}	0.3	Housing investment adjustment cost, long-term
ϵ	4.167	Elasticity of substitution between output varieties
γ	0.779	Probability of price non-optimization
γ_P	0.241	Degree of indexing to past inflation
Public Sector		
κ_i	0.8	Policy rate inertia
κ_π	1.76	Inflation weight Taylor rule
κ_Y	0.05	Output weight Taylor rule

Table 1: Calibration Parameters.

times annual GDP and approximately 33% of total credit. The annualized interest rate on corporate assets is, at 3.45%, slightly higher than the mortgage rate at 3.02%.

Type	Parameter	Model	Description
Flow	C/Y	0.76	Consumption relative to GDP
	Ik/Y	0.14	Capital Investment relative to GDP
	Ih/Y	0.1	Residential Investment relative to GDP
Stock	$M/(4*Y)$	0.74	Mortgages over annual GDP
	$Credit/(4*Y)$	2.21	Total Credit over annual GDP
	$H/(4*Y)$	4.88	Housing Stock over annual GDP
	$K/(4*Y)$	1.46	Capital Stock over annual GDP
	$M/Credit$	0.34	Mortgage relative to total credit
Prices	Rk^4-1	3.45%	Annualized real loan rate, corporate assets
	Rm^4-1	3.02%	Annualized real mortgage rate
	$1/\phi$	6	Leverage

Table 2: Model steady state characteristics, quarterly basis.

3 Macroprudential Regulation

3.1 Basic Model without Macroprudential instruments

We start with a discussion of the scenario without any macroprudential instruments. The first Basel framework of 1988 required banks to hold a certain amount of their capital to provide for potential losses of their assets. These requirements differentiated only between the categories of assets and did not account for changes in their riskiness.[26] This triggered some criticism, as the framework induced banks to hold more and more risky loans with higher pay-offs (Allen, 2004). The succeeding Basel II framework introduced riskiness of assets as a criterion for the capital requirements within the Internal Ratings Based (IRB) approach. In addition, there was also been the standard approach, which was similar to the functioning of Basel I as it contained fixed risk weights as well.[27]

The IRB approach allows banks to use internal models to estimate default risk of their portfolios. Hence, within IRB the riskiness of assets depended on the estimated loss given default and probabilities of default and could vary over time. At the bank

[26] With regard to mortgages banks were required to back up 50% of their mortgage portfolio with capital irrespective of the underlying credit risk.

[27] For further information on Basel I and II, see Deutsche Bundesbank (2001), Deutsche Bundesbank (2004). Section B in the appendix shows the impact of introducing dynamic compared to static risk weights.

level, this freed capital that could be used for expanding the balance sheet and extending the business at the current stage. Nevertheless, there were also studies warning against cyclical aspects of Basel II and its neglect of the endogeneity of risk (Danielsson, Embrechts, Goodhart, Keating, Muennich, Renault, and Shin, 2001).[28] At the macro level, an increase in procyclicality might become a problem if lower default risk is assumed in the economy on aggregate, extending both upswings and downswings.

Model Implementation

The model incorporates the Basel regulatory frameworks by taking into account agency costs imposed on bankers for monitoring their assets. The riskier an asset is, the more monitoring effort bankers need to exert. This is economically equivalent to risk weights that should mirror the riskiness of certain assets. The riskier assets are considered to be, the more costly capital bankers have to hold on their balance sheet. In the absence of any risk weights or risk-related effort, the implied return of corporate rates and mortgage rates should be equal in equilibrium.[29]

To keep the analysis simple, monitoring efforts in the economy for both corporate stakes and mortgages depend on the business cycle, i.e. GDP. In economic downturns the monitoring effort increases, while in good times the bank internal models predict lower riskiness, i.e. lower monitoring efforts.

$$\psi_{s,t} = \psi_s \frac{Y_t}{\bar{Y}_{ss}}^{\kappa_s}. \tag{58}$$

Additionally, changes in the relative default risk of mortgage credit are calculated from changes in house prices and household income (Campbell and Cocco, 2012; Hott, 2013). Thus, while GDP affects the riskiness of both assets, sector-specific factors ensure that there might be heterogenous developments for the riskiness of both assets. The risk of a mortgage default increases when the value of the house used as collateral for a one-period loan falls, while a higher household income lowers the risk of default.

$$\psi_{m,t} = \psi_m \left(\frac{Y_t}{\bar{Y}_{ss}}\right)^{\kappa_S} \left(\frac{(\tilde{w}_t \tilde{l}_t)}{\tilde{w}l_{ss}}\right)^{\kappa_{wl}} \left(\frac{Q_{h,t}}{1}\right)^{\kappa_{Qh}}. \tag{59}$$

After bankers have chosen optimal mortgages and corporate stakes, the relationship of

[28] Both Kashyap and Stein (2004) and Heid (2007) provide models to shed further light on the issue of cyclicality. See also Brunnermeier and Sannikov (2014) for more on the volatility paradox, i.e. bank risk taking increasing in tranquil times, or see Adrian and Shin (2013) for VaR-implied boom-bust cycles.

[29] In the absence of further restrictions, bankers will always choose the asset with higher returns. Thus, in an equilibrium where banks hold both assets without any regulatory requirements, the respective rates must be equal.

corporate spreads versus mortgages can be described as:

$$\frac{(R_{k,t} - R_t)}{(R_{m,t} - R_t)} = \mathcal{R}_t, \tag{60}$$

where the relative riskiness $\mathcal{R}_t$ is defined as

$$\mathcal{R}_t = \frac{(1 - \psi_{s,t})}{(1 - \psi_{m,t})}, \tag{61}$$

with

$$\frac{\partial \mathcal{R}_t}{\partial Q_{h,t}} < 0, \tag{62}$$

$$\frac{\partial \mathcal{R}_t}{\partial \tilde{w}_t} < 0, \tag{63}$$

$$\frac{\partial \mathcal{R}_t}{\partial \tilde{l}_t} < 0, \tag{64}$$

$$\mathcal{R}_{ss} = \frac{(1 - \psi_s)}{(1 - \psi_m)}. \tag{65}$$

The κ parameters capture the elasticity of changes in income and house prices on the riskiness of mortgage loans. Both constants ψ_m and ψ_s are kept unchanged compared to the model with static risk weights in order to allow for a direct comparison of both specifications.

Dynamic monitoring efforts introduce some form of procyclicality in the economy that was also said to have caused a volatility paradox (Brunnermeier and Sannikov, 2014). In economically benign times, risk is considered low, triggering low risk weights and an increase in riskier assets, while in boom times, risk weights increase. In the model economy with dynamic monitoring costs, economic booms, house price growth or high income of debtors cause the respective monitoring costs to decrease. This implies a credit extension that is *ceteris paribus* larger with dynamic compared to the case without time-varying monitoring costs. This can be shown by comparing the model economy to a Basel I style economy with risk-insensitive monitoring, i.e. fixed risk weights.[30] Figure 2 compares the differential between the impulse response functions for both models responding to a monetary policy, a technology, a housing demand and a capital quality shock. The results show that the risk-sensitive monitoring costs imply stronger credit and mortgage gaps for all models, i.e. more procyclicality.[31] The results show that the model with dynamic risk weights increases the procyclicality of credit variables compared to the economy with constant risk weights: the swings for credit

[30] See appendix B for further details and the actual IRF responses.

[31] The credit (mortgage) gap is defined as the ratio of credit (mortgage) relative to GDP.

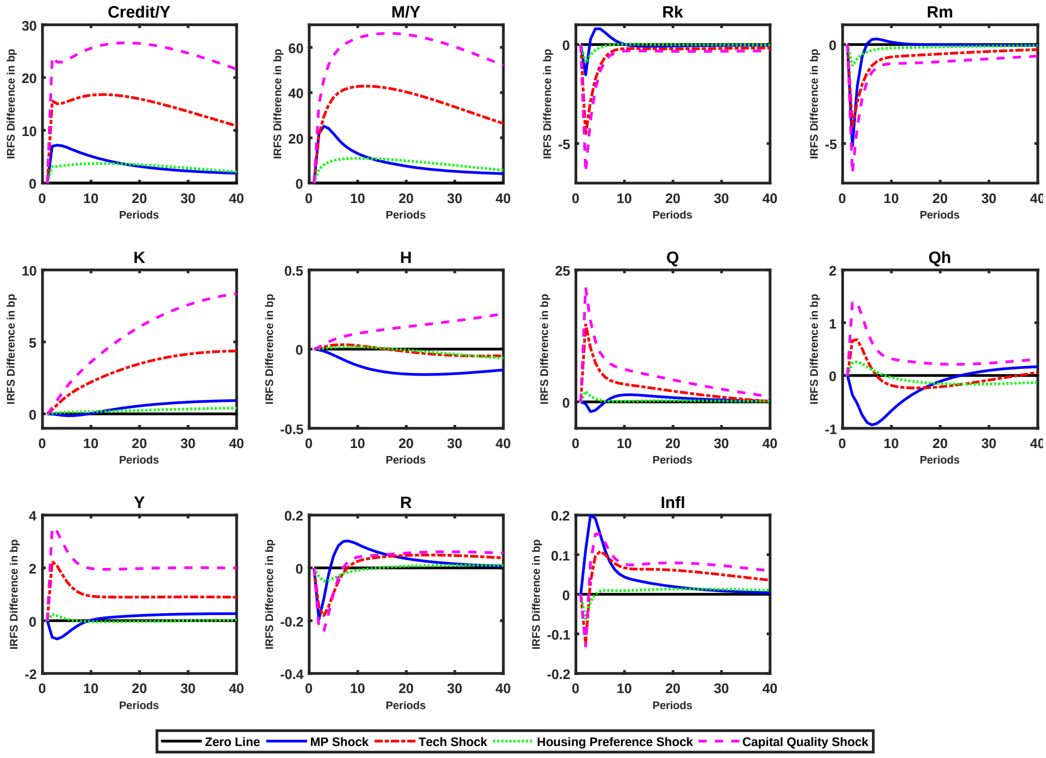

Figure 2: IRF differential between fixed and time-varying monitoring cost for various shocks. Credit and Mortgage Gap is defined as Credit and Mortgage relative to GDP.

and mortgage relative to GDP are more pronounced. Such behavior might be detrimental as a huge debt overhang might increase both the likelihood and severity of financial crises. Also, comparative statics show that for most variables the volatility is higher in the Basel II setup compared to the Basel I setup. The comparison also shows that overall qualitative behavior is not altered. Figures 10, 11 and 12 in the appendix imply, however, that Basel II IRB amplified the swings of impulse responses, but does not alter their qualitative behavior.

3.2 Macroprudential Instruments

The financial crisis showed that the microprudential perspective of regulation might not be sufficient (Borio, 2009). Microprudential regulation puts the focus on the stability of single institutions and the adequacy of individual risk management frameworks, but neglects common asset correlations and the risk of fire sale dynamics in the system as a whole (Hanson, Kashyap, and Stein, 2011). The internal risk based approach of Basel II might even have contributed to the build-up of cyclical systemic risk (Kashyap and Stein, 2004; Heid, 2007; Gehrig and Iannino, 2018) via the volatility paradox: low volatility in boom periods might contribute to a slow increase of risk at the single institutions due to low default rates. Shocks then might trigger a credit contraction that is exacerbated by rising capital requirements and loss provisions due to the rise in default rates and volatility (Adrian and Shin, 2013; Brunnermeier and Sannikov, 2014).[32] As a pillar in the G20 strategy to improve the stability of the financial system, macroprudential instruments have been introduced. An important pillar of the G20 strategy to counteract credit booms has been the introduction of macroprudential regulation in the Basel III regulation (BCBS, 2011). In Europe, the implementation of Basel III is done mainly via the fourth version of the Capital Requirements Directive (CRDIV) and the accompanying regulation (CRR).

At this stage, macroprudential regulation puts the focus on regulating mortgages that have been at the heart of the sub-prime crisis (Brunnermeier, 2009). However, also past crisis episodes have shown the risks of debt-fuelled housing bubbles for the real economy and financial stability.[33] The ESRB recommendation on intermediate objectives and instruments spelled out various instruments to stabilize the financial cycle (ESRB, 2013). Instruments can be broad or target certain exposures. Mortgage regulation falls within the scope of the intermediate objective on containing excessive credit growth. The paper considers the following instruments:

1. Loan-to-value ratio (LTV). This instrument confines the maximum amount of a loan a bank can grant to a borrower relative to the size of the collateral.

2. Sectoral risk weights (RW). Risk weights enable regulators to increase the capital requirements for certain assets for a single bank or a group of financial institutions. A similar instrument might be a sectoral application of the CCyB, which is applied in Switzerland to real estate only.[34]

[32] This should not be interpreted such that the IRB approach is detrimental per se. On the level of an individual institution, risk-sensitive capital requirements might improve the efficiency. Yet at the aggregate level there might be a certain cyclicality that justifies the use of complimentary measures such as macroprudential instruments and backstops such as the leverage ratio.

[33] See Campbell and Cocco (2007) or Case and Quigley (2008) for an overview of how house prices might affect the real economy. Housing collateral ties real estate markets strongly to the market for mortgage credit and other related financial instruments (Campbell, 2012; Musso, Neri, and Stracca, 2011). Evidence shows that the joint impact of bursting housing bubbles and banking crises has resulted in severe downswings. In cases where the peak of a housing bubble was close to the eruption of the banking crisis, Reinhart and Rogoff (2009) report house price declines between 31.7% and 50.4% for four to six years in advanced economies.

[34] RW are in fact a microprudential instrument that is in this case applied uniformly across the financial sector to have a sector wide approach.

3. The countercyclical capital buffer (CCyB) requires banks to hold more capital in general, irrespective of the portfolio composition, once an indicator identifies significant deviations of the credit gap from its long-term trend.[35]

In the model context all instruments are introduced as rules affecting financial variables such as leverage, monitoring costs of households or the maximum amount of mortgage credit granted to borrowers. While there is no official specification of "excessive" credit growth, policy rules usually follow target variables such as the ratio of total credit or mortgages relative to output. The underlying assumption is that strong deviations from credit relative to GDP could increase vulnerabilities of the financial system to shocks (Drehmann et al., 2011; Drehmann and Gambacorta, 2012). The policy intensity determines the strength of the response of the instruments to deviations of the target variables from their steady state values. We therefore confine this analysis to the qualitative results of macroprudential policies dampening credit movements.

CCyB: The CCyB is modelled as a parameter altering the leverage equation of investors. As the CCyB increases capital requirements, any increases in the CCyB immediately reduce bank leverage.[36] The macroprudential authority directly constrains the leverage ratio, via inserting a regulatory weight $\Xi_{CCyB,t}$ that decreases when an target variable declines and vice versa.

$$\Theta_t = \phi_t N_t \Xi_{CCyB,t}, \tag{66}$$

$$\Xi_{CCyB,t} = f(\cdot)^{\kappa_{ccb}}, \tag{67}$$

where κ_{ccb} denotes the responsiveness of the CCyB to the policy function. In line with the literature on the CCyB, the policy functions $f(\cdot)$ are modeled as responding to deviations from the credit gap, i.e. the long-term credit over GDP ratio (Drehmann et al., 2011).[37] For instance, the CCyB level depends on the relation of overall credit, i.e. bank assets Θ_t to GDP:

$$f(\cdot) = \left(\frac{\Theta_t / Y_t}{\Theta_{ss} / Y_{ss}} \right). \tag{68}$$

The CCyB rule is calibrated according to leverage changes relative to an assumed capital ratio of 8% as defined in the CRR. It should also be taken into account that the CCyB rule in the model is a symmetric rule and not bounded. Meanwhile, the actual CCyB is

[35] Measured as credit over GDP. The long-term trend is calculated by applying a Hodrick-Prescott-Filter (Drehmann et al., 2011).

[36] In fact the CCyB in this model can be also seen as a leverage ratio as the model does not introduce an overall balance sheet without risk weighted asset.

[37] For a discussion about the role of credit in financial crises, see Jorda, Schularick, and Taylor (2011).

a buffer that should build up during boom periods. So if there are no buffers present and there is a decline, the actual CCyB is not triggered. Moreover, the CCyB is bounded. There is no additional charge for a credit gap below 2%, and a linear phase-in until the maximum surcharge of 2.5% is reached at a deviation of the credit gap from its long-term value by 10%.[38]

Concerning the calibration of the instrument, the CCyB is assumed to kick in once the credit gap, i.e. credit over GDP, increases more than 2 percent from its long-term trend in a linear manner. That said, if an increase in the credit to GDP ratio from its long-term trend by 10 percentage point should result in an increase of capital requirements by 2.5 percentage point, leverage should decrease by around 24 percentage points. Thus, κ_{ccb} is calibrated to solve $(1.1)^{\kappa_{ccb}} = 0.76$, which results in $\kappa_{ccb} = -2.853$.[39]

LTV: Similarly, the LTV rule modifies equation (12) via replacing the constant LTV m with a time-varying function m_t

$$m_t = m\Xi_{ltv,t}, \tag{69}$$

$$\Xi_{ltv,t} = f(M_t/Y_t)^{\kappa_{ltv}}, \tag{70}$$

where m is the steady state loan-to-value ratio and κ_{ltv} reflects the responsiveness of the LTV rule to changes in the policy rule. As the LTV does not target overall credit, but mortgages only, the rule is calibrated to changes in mortgage credit over GDP. An increase by mortgage over GDP by 10 percentage points from its long-term steady state implies a reduction of the LTV by 5 points (i.e. from 80% to 75%), resulting in a parameter of −0.677. This yields an anti-cyclical loan-to-value ratio, tightening during credit booms, i.e. strong increases of mortgage over GDP deviations from its steady state values.

Sectoral risk weights (monitoring costs): These modify the function for relative risk of mortgages versus corporate stakes $\mathcal{R}_t$ that is determined by monitoring efforts. The regulator thus forces financial intermediaries to put more emphasis on monitoring certain assets relative to others. This is economically equivalent to force banks to hold more capital for certain assets.

$$\mathcal{R}_t = \Xi_{RW,t}\frac{(1-\psi_{s,t})}{(1-\psi_{m,t})}, \tag{71}$$

$$\Xi_{RW,t} = \left(\frac{M_t}{Y_t}\frac{Y_{ss}}{M_{ss}}\right)^{\kappa_{RW}}. \tag{72}$$

[38] See also Drehmann and Gambacorta (2012).

[39] Note that κ_{ccb} takes a negative value to ensure that a rise in the target variable implies a decrease of leverage.

Consequently, an increase in $\Xi_{RW,t}$ changes the banker's desired portfolio structure towards the relatively less risky asset. Mortgages or corporate stakes, respectively, would have to yield a higher rate of return for the banker, everything else being equal. Analogous to the LTV, sectoral risk weights are calibrated to changes in the mortgage gap from its long-term steady state. A 10% increase from the long-term steady state should result in mortgage credit being treated equally to corporate credit in the standard approach. This corresponds to the parameter κ_{RW} equaling 3.74.

4 An Analysis of Macroprudential Regulation

First, we assess comparative statics of four model economies. The baseline scenario is the scenario with dynamic monitoring cost, but no macroprudential regulation. First, we use comparative statics to gauge the impact of activating macroprudential instruments on the volatility and procyclicality of relevant variables. Second, we use impulse response analysis to identify the transmission channels of the three macroprudential instruments. The analysis aims to assess to what extent macroprudential policy can contribute to reduce risks to financial stability by dampening credit and mortgage movements. In line with the key indicators of the CCyB we consider deviations of the credit and mortgage gap from its steady state as indicators of potential risks for financial stability (Drehmann et al., 2011; Drehmann and Gambacorta, 2012). A second objective is to assess their efficiency, i.e. to what extent macroprudential instruments might yield unintended consequences or might negatively affect non-target variables.

4.1 Descriptive statistics

First, we compare the volatility, measured by the variance, and procyclicality, measured by correlation to output, of key variables. The model contains monetary policy, technology, housing demand and a capital quality shock calibrated following table 1. Moments are derived from simulations.[40] As results may depend strongly on the calibration of the instrument intensity, a sensitivity analysis in section 5 shows that the major findings hold when policy intensity is relaxed/tightened.

Volatility: Table 3 shows the variance of key variables in the baseline scenario, normalized by the variance of the output. For output and the target variables the non-standardized variance is reported.[41] A lower volatility of credit might result in less pronounced boom-bust-cycles. Moreover, high levels of asset price volatility could be detrimental to financial stability as this might point to higher uncertainty about asset prices. We expect that households prefer low volatility of consumption relative to GDP as they seek to stabilize their consumption path over the business cycle.

In general, the baseline scenario shows that the volatility is more pronounced for price and financial variables compared to real economic variables such as consumption, which is in line with expectations. In general, the use of all macroprudential instruments dampens the volatility of both mortgages and overall credit compared to the baseline scenario. Also the non-standardized target variables are reduced compared to the baseline. The LTV is the most effective instrument, achieving the most pronounced reduction on mortgage volatility compared to the baseline case with a reduction by around 87%

[40]Number of simulations has been set to $100,000$ to safeguard consistency of the results.

[41]However, to facilitate comparison values are scaled by $10,000$, i.e. to bp, as volatility numbers are very low.

(credit volatility: −56%), followed by the CCyB with −78% (−72%). Part of this effect might be driven by higher output volatility in the LTV and CCyB case compared to the baseline scenario, yet table 6 in the appendix reveals that this effect also holds without the standardization. Risk weights reduce the standardized volatility of mortgage credit by around 11% (−6%).

The nature of broad and sectoral instruments is also mirrored in the comparative statics. The CCyB reduces overall credit by 72% compared to 55% of the LTV and 6% of risk weights. Moreover, the CCyB also reduces the volatility of the other credit variables such as mortgages and corporate assets as well as the volatility of both target variables. While there is a small increase in house price volatility, asset price volatility decreases. Monetary policy is only marginally affected. Meanwhile, both sectoral instruments achieve a reduction in total credit and mortgage volatility at the cost of higher corporate asset volatility. In general, the sectoral instruments are also far more effective in reducing mortgage volatility compared to overall credit volatility. The LTV also strongly drives up asset price volatility by approximately 50%. RW appear to be very efficient as – with the exception of corporate assets – there is hardly any effect on variables other than mortgages or the two target variables. Concerning overall output and consumption there are some distributive issues for the CCyB and the LTV. While the CCyB activation appears to drive up lender volatility and drive down borrower volatility, the LTV works the other way round, benefitting lenders.

Correlation: Table 4 shows that, leaving aside the policy rate, all key variables have a positive correlation with output, i.e. are procyclical. In the baseline scenario, output is slightly more correlated with credit compared to consumption. There is also a higher correlation of house prices compared to asset prices. Concerning the use of macroprudential instruments, the CCyB drives up procyclicality of consumption, while reducing procyclicality of mortgages and corporate assets. Meanwhile, the LTV drives down procyclicality of consumption, in particular borrower consumption, while slightly driving up procyclicality of credit and house and asset prices.

The correlation numbers confirm that price-related regulation such as the CCyB decrease procyclicality of asset prices, while quantity restrictions such as the LTV increase procyclicality of house prices and, in particular, asset prices. Concerning procyclicality of consumption, only the LTV brings down correlation with output significantly. On the credit variables, only the CCyB achieves a significant reduction in correlation for mortgages and corporate stakes, while there is hardly any impact by sectoral regulation. Overall, however, there is hardly any effect of the risk weights in both terms of effectiveness and efficiency.

Persistence: The impact of macroprudential regulation on the persistence of shocks to key variables is measured by the sum of the AR(5)-coefficients. Higher values indicate that shocks persist for a longer time. As can be expected, table 5 shows that con-

Variance	Baseline	CCB	RW	LTV
Consumption relative to Output				
Total	0.340	0.377	0.336	0.255
Lender	0.258	0.354	0.255	0.210
Borrower	3.075	1.223	3.003	3.805
Credit relative to Output				
Total	21.778	6.028	20.420	9.635
Mortgages	97.151	21.598	86.013	12.657
Corporate Assets	5.053	3.800	5.129	7.553
Prices and Rates relative to Output				
House Prices	3.176	3.434	3.050	2.624
Asset Prices	5.957	3.440	5.848	8.926
Policy Rate	0.644	0.591	0.638	0.510
Inflation	0.225	0.210	0.228	0.148
Output and Target Variables (absolute, scaled by $10,000$*)*				
Output	3.282	3.312	3.332	4.180
Credit Gap	48.306	8.894	45.326	21.620
Mortgage Gap	268.701	52.525	238.907	33.048

Table 3: Variance of key variables relative to Output (Second Order Approximation).

Correlation	Baseline	CCB	RW	LTV
Consumption				
Total	0.79	0.84	0.80	0.67
Lender	0.75	0.80	0.75	0.72
Borrower	0.60	0.74	0.63	0.18
Credit and Assets				
Total	0.86	0.88	0.86	0.88
Mortgages	0.83	0.73	0.83	0.81
Corporate Assets	0.84	0.78	0.85	0.86
Prices and Rates				
House Prices	0.80	0.77	0.79	0.85
Asset Prices	0.29	0.14	0.31	0.49
Policy Rate	-0.62	-0.57	-0.61	-0.69
Inflation	0.63	0.54	0.63	0.65

Table 4: Correlation to Output (Second Order Approximation).

sumption and credit, overall, tend to have a higher persistence compared to prices that can adapt more swiftly. Macroprudential regulation hardly affects lender consumption as well as policy and inflation rates. Moreover, the comparative statics for the different instruments also show similar results as to those above. While the CCyB tends to increase the persistence of output, overall credit and corporate assets as well as asset prices, there is a reduced persistence of mortgage credit and housing prices. This points to the effect of the CCyB on overall credit and – via investment – on asset prices. Sectoral instruments again point to substitution effects, with the effects of the risk weights being more of a subtle nature. The LTV, meanwhile, increases persistence of shocks to borrower consumption, mortgage credit and house prices, while reducing the persistence of shocks to overall output and corporate assets. The LTV also slightly affects persistence of policy rates and inflation, although at a rather low level.

Summing up, the numbers imply that macroprudential regulation has the desired effect on the targeted variables. Yet it might not be a free lunch. The CCyB is able to reduce overall procyclicality and volatility of credit. Meanwhile, sectoral regulation might trigger "waterbed" effects: lower volatility in the targeted sector might re-direct funds to the less regulated sector (Bank of England, 2011; Deutsche Bundesbank, 2013). Following sectoral regulation of mortgage credit, there is higher volatility and procyclicality of asset prices and corporate stakes relative to output. This is consistent with tighter sectoral regulation of mortgage credit increasing the attractiveness of corporate financing *ceteris paribus*.

Persistence	Baseline	CCB	RW	LTV
Consumption				
Total	2.99	3.00	2.98	3.10
Lender	3.13	3.13	3.13	3.13
Borrower	2.81	2.54	2.78	3.20
Credit				
Total	1.16	1.51	1.15	0.94
Mortgages	1.31	1.20	1.26	1.62
Corporate Assets	1.42	2.00	1.46	0.81
Prices and Rates				
House Prices	0.49	0.64	0.48	0.58
Asset Prices	1.05	1.97	1.05	0.76
Policy Rate	0.23	0.26	0.23	0.30
Inflation	0.56	0.51	0.55	0.65
Output and Target Variables				
Output	1.68	1.99	1.69	1.46
Credit Gap	1.13	1.33	1.10	0.83
Mortgage Gap	1.33	1.16	1.27	1.89

Table 5: Persistence of AR(5) Process (Second Order Approximation).

4.2 Impulse Response Analysis

The following section uses impulse response analysis to shed light on the transmission mechanisms subject to different macroprudential regimes. We compare the impact of macroprudential instruments to the baseline economy with dynamic monitoring efforts (NoMacPru). We look at three distinct shocks. First, the classic monetary policy and technology shock as examples of a demand- and supply-side shock. Second, a housing demand shock to shed light on the role of regulation in response to sectoral shocks.[42]

Monetary Policy Shock: The baseline case of an expansionary monetary policy shock is classic text book. The lower interest rates push up investment, consumption and GDP, but also inflation in the short term. The capital and housing stock increase. The strong residential investment also implies increases in asset and house prices as well as a balance sheet extension of banks in both corporate securities and mortgage credit, implying an overall increase in the credit gap, i.e. the amount of overall credit relative to GDP, by around 5% compared to the baseline. There is a slight increase in output by up to 100 bp. The mortgage gap, i.e. mortgage credit relative to output, likewise grows significantly, by 12%.

How does macroprudential regulation alter this picture? Similar to the housing demand shock, activating the CCyB curbs overall credit including mortgages relative to GDP. By restricting the amount of credit available, there is a strong increase in the corporate and mortgage spread, increasing the income of lending households and decreasing the income of borrowing households. Due to the stronger demand by households for housing and consumption, there is hardly an impact on overall output and investment. The transmission mainly works through increasing the price of credit, which also equals an increase in interest income for lending households. Overall, the output is achieved less through credit financing relative to GDP.

Tightening risk weights for mortgages leads to higher prices and lower demand for mortgage credit in relative terms. There are modest substitution effects from mortgages towards corporate stakes and housing to capital investment. Overall, there is a positive impact on GDP similar to the CCyB.

The impact of the LTV on the mortgage gap is pronounced. The direct restriction of credit to borrowing households funnels relatively more credit to the corporate sector. The LTV – as corporate stakes are the only unrestricted investment opportunity for intermediaries – pushes down the corporate spread. By confining mortgage credit, borrowing households invest relatively less in houses and relatively more in consumption goods; moreover, the LTV relatively drives down the premium borrowing households have to pay on mortgages compared to the baseline case. The strong confinement to capital investment also drives up asset prices in the short term, but also implies a stronger

[42] The appendix also contains an example of a capital quality shock as the classic GK model specification, see figure 9.

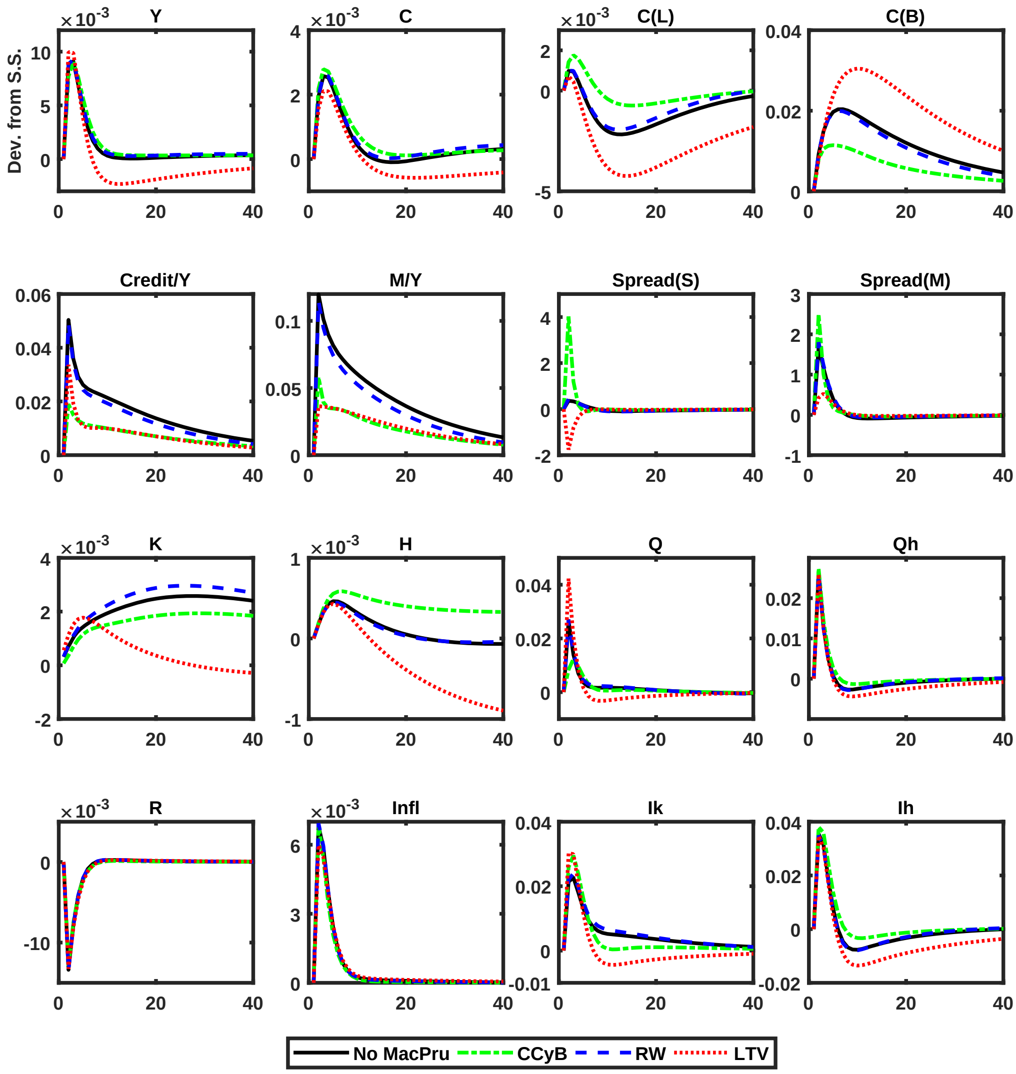

Figure 3: IRF after monetary policy shock lowering the policy rate. Comparison of no macroprudential policies, Countercyclical Capital Buffer (CCyB), Macroprudential Risk Weights (RW) and LTV rule (LTV).

decline of asset prices compared to the baseline case. This is in line with the comparative statics of the previous section. As the LTV channels more money to the productive sector in the short term, GDP grows strongly in the short term compared to the baseline case. Restricting credit implies lower interest income for lending households, resulting in a relatively lower impulse response for output after the first five periods. In general, there is hardly any effect on monetary policy variables. Only the LTV decreases the IRF of inflation relative to the baseline scenario by curbing overall output.

Technology shock: Baseline transmission of the positive technology shock causes higher productivity while lowering required capital and labor inputs. This implies a fall in the inflation rates due to under-capacities in the economy. Meanwhile, the surge in GDP is accompanied by higher credit provision to both households via mortgages and corporate stakes in terms of GDP. Due to the negative shock to inflation, the central banks only react with a very small increase in interest rates in the short-term and a lowering of the interest rate compared to the steady state after five periods, fueling the boom period further.

The CCyB activation confines credit gap and mortgage gap, i.e. the increase in the credit variables over GDP is much weaker compared to the baseline case. The confinement of investment opportunities while investment is increasing also results in an increase in the corporate spread and reverts the baseline reaction. This implies both higher income for lending households and higher borrowing costs for impatient households in the short term. The lower corporate stake quantity drives up asset prices more strongly compared to the baseline case and also drives up gross investment for both housing and capital. Overall, corporate securities even slightly increase compared to the baseline scenario, yet are more than offset by the growth in GDP. The CCyB tames both the credit and the mortgage gap, while pushing up house prices slightly, while implying a less pronounced shock to asset prices for the economy.

As above, risk weights are more modest, but imply substitution effects from residential to capital investments. The impact on the credit gap is lower and there is hardly any impact on absolute corporate stakes. Also, spreads and other economic variables are only modestly changed. Similar to the CCyB, risk weights as a price instrument imply higher income for lenders and higher costs for borrowers in the short term. Thus, while there are some modest substitution effects and the effectiveness of the risk weight is lower compared to the CCyB and the LTV, the efficiency is also higher, as substitution effects are less severe and transmission processes are hardly altered compared to the baseline case.

The LTV again shows signs of a brute-force sectoral regulation that implies strong substitution effects from mortgages to corporate securities. Overall, the credit gap is also reduced, as there is also slightly higher GDP in the short term and a strong reduction of mortgages. Both house and asset prices strongly increase in the short term due to the significant quantity restrictions of mortgages and high investment in the capital sector, respectively. The effect on housing stock is twofold. First, higher house prices make buying more houses more costly, while the higher price of houses implies more houses to be built, so there is both a lower demand and a higher supply that drive down house prices below the baseline after some periods. Housing stock and capital shrink after some time, implying a lower GDP compared to the baseline case. Therefore, the ensuing decline in asset and house prices is also more pronounced in line with a higher volatility in the LTV case compared to the baseline scenario. Borrowing household consumption benefits from both lower borrowing costs, but there is also less opportunity to invest in housing as there are collateral restrictions. Therefore, households consume more in the LTV scenario rather than build up their housing stock.

Housing Demand Shock: In the baseline case a housing demand shock increases the housing preference parameter of both lenders and borrowers, inducing them to buy more houses at the cost of relatively lower overall consumption *ceteris paribus*. This is largely driven by an increase in housing investment. The central bank reacts to the boom by raising the policy rate, resulting in a small decline in inflation. The mild decrease in overall consumption is driven by different outcomes for both households. While borrowing households consume less in response to the shock to buy more houses, the consumption of lending households increases as they have more income due to the policy rate hike.

A surge in residential investment is the main driver of an accompanying rise in output and intermediary goods evoking a mild rise in capital investment, too. Yet, the opposing effects of overall consumption and investment result in only modest changes of real model variables such as consumption or GDP. The impact of the sectoral housing demand shock on the overall economy is less significant compared to the broad monetary policy and technology shock of the previous section.

Compared to the baseline scenario, the CCyB curbs overall credit relative to GDP and slows down the increase of the capital stock and as the bank balance sheets. As a price-based instrument, the CCyB drives up the spread of both corporate credit and mortgage credit, resulting again in higher consumption of lenders and lower consumption of borrowers compared to the baseline scenario. Meanwhile, mortgage relative to GDP is also slowed down, yet less severe compared to the overall credit gap. House prices are mainly demand-driven, so there is hardly any impact of the CCyB or any other macroprudential instrument. There is higher corporate investment in the short term that is accompanied by higher depreciation and capacity utilization.

Risk weights imply a similar effect on mortgage credit and mortgage rates relative to GDP, yet more modest. However, there are small substitution effects that channel funds to the corporate sector. The subsequent increase in productive capital results in a slightly higher GDP compared to the benchmark case, resulting in higher capital investment and capital stock. There is hardly an impact on house prices and investment as well as on the interest rate spreads.

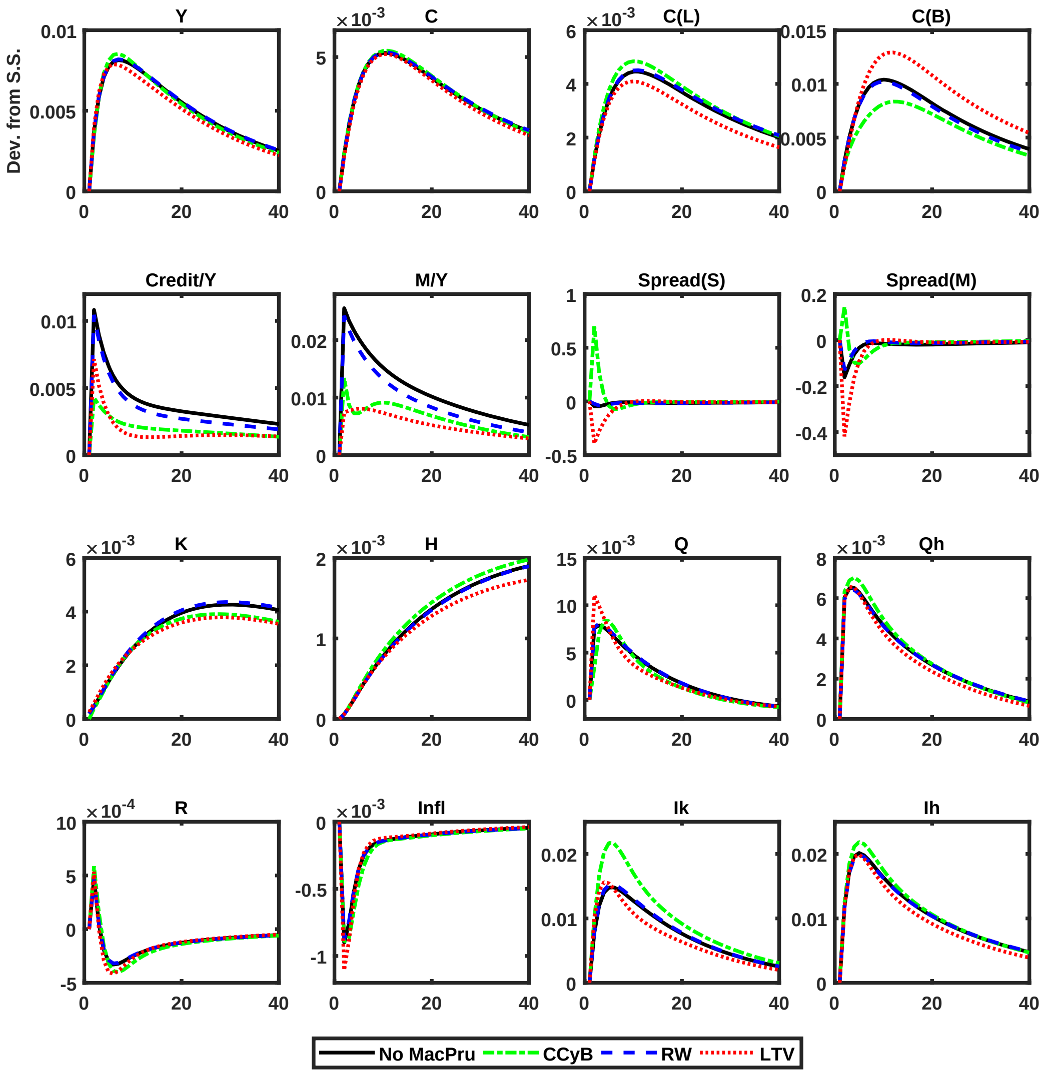

Figure 4: IRF after an expansionary technology shock. Comparison of no macroprudential policies, Countercyclical Capital Buffer (CCyB), Macroprudential Risk Weights (RW) and LTV rule (LTV).

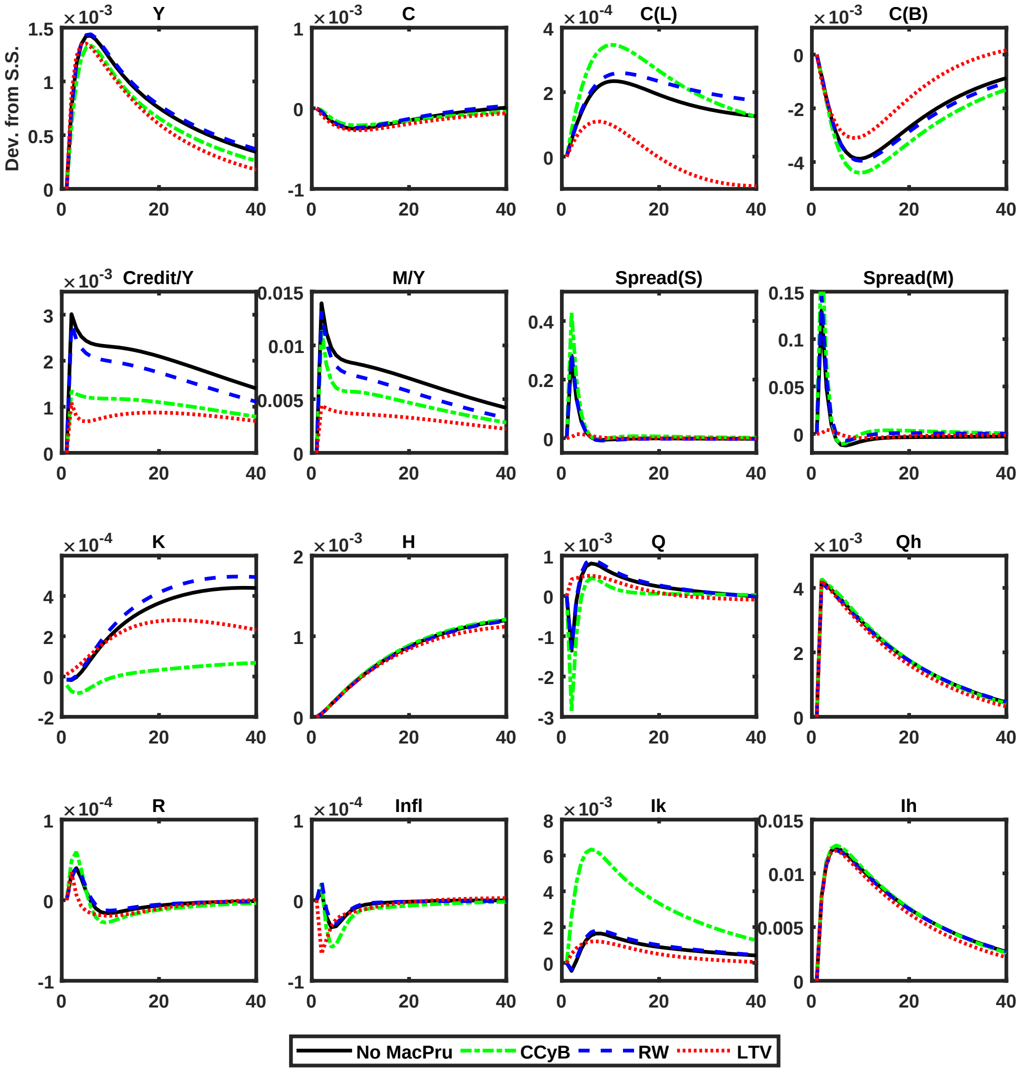

Figure 5: IRF after a housing preference shock (housing demand shock). Comparison of no macroprudential policies, Countercyclical Capital Buffer (CCyB), Macroprudential Risk Weights (RW) and LTV rule (LTV).

Meanwhile, the LTV has the strongest effects, yielding a significant decrease in mortgages and – due to demand effects – also on the lending rate. While housing preference has increased, the LTV also channels some funds into the corporate sector. Overall, however, consumption and investment are lower as fewer funds are used by households to buy more houses rather than spend the income on consumption. While consumption of borrowing households is slightly higher compared to the baseline, this does not cover up the stronger decrease in lender consumption and capital investment.

4.3 Discussion

Overall, the model confirms investment dynamics, the price of credit, and borrower consumption as key transmission channels of credit to the real economy. Confining mortgages or increasing their relative price restricts the ability of households to borrow, which might result in *ceteris paribus* both overall lower consumption and a reduced demand for housing collateral. Confining banking leverage via the CCyB, meanwhile, reduces overall bank credit availability, which might slow down production, investment and consumption and thus overall output in the economy. The price of credit in the model economy has two effects: while higher credit is more costly for borrowers, there might also be advantages for lenders that have higher returns and income. Thus, an open-economy version should show different results. The model supports the argumentation of Claessens et al. (2014) that macroprudential policy might affect output by confining borrowing. These distributional issues are also implied by a welfare analysis.[43]

From a financial stability perspective, the results of the different shocks show that macroprudential instruments are capable of dampening mortgage credit growth. Target variables are credit and mortgages relative to GDP, i.e. the mortgage and credit gap. The different instruments, however, have their own strengths and weaknesses. The LTV as a quantity-restricting instrument is the most effective in curbing mortgage credit increases, followed by the CCyB and the sectoral risk weights. The LTV thus allows policymakers to specifically target mortgage credit. The CCyB as a general instrument is most suitable to curb overall credit increases, with restrictions to mortgage credit being a "beneficial" side effect. Sectoral risk weights, meanwhile, also allow policymakers to target mortgage credit, yet the impact appears to be much more muted compared to both the quantity restricting LTV and the broad CCyB.

The effectiveness of the instruments also comes at the cost of potentially unintended consequences. With regard to market efficiency or volatility, prices of housing and corporate securities are important indicators. Again, there appears to be a trade-off: the

[43] See section D in the appendix. While overall welfare cannot be properly derived due to the heterogeneous agents, the results show that while lenders are willing to pay for price-based instruments that drive up their interest income and overall consumption path, borrowers are less willing to do so. Most interestingly, borrowers profit from quantity restrictions, at least in the current calibration.

LTV might be effective, but also less efficient due to strong substitution effects and increases in both asset and house price volatility. The CCyB, meanwhile, is less prone to substitution effects, but also has distributional issues. Confining overall credit might, on the one hand, drive up the cost of borrowing while decreasing interest income. On the other hand, it might also curb otherwise beneficial activity. The sectoral risk weights are less effective, but also very efficient: there are potential substitution effects accompanying sectoral regulation, yet less pronounced compared to the LTV. However, compared to the CCyB a targeted focus on housing credit, is feasible.

Thus, the overall effectiveness and efficiency of an instrument across all key indicators should critically depend on the nature of the shock to be addressed.

- The CCyB seems to be more effective with regard to general shocks than sectoral risk weights or the LTV, but might also curb beneficial credit activities. It is also the only instrument that is able to confine overall procyclicality. Using the CCyB against sectoral shocks appears to be less efficient. The surge in a single sector of the economy comes at the cost of curbing overall credit.

- The LTV is very effective in addressing strong and rapid movements in sectoral credit. The accuracy of sectoral instruments, however, comes at the cost of substitution or "waterbed" effects. In the model economy, the stricter regulation of mortgage credit results in a portfolio shift in favor of corporate securities and higher volatility in both asset and house prices. Moreover, the LTV appears to have a stronger impact on output when responding to demand-driven shocks, and investment dynamics appear to be more procyclical subject to LTV regulation compared to the other instruments. The LTV is thus targeted and very effective, yet its lower efficiency warrants caution in its application. Substitution effects appear to be smaller in response to sectoral shocks such as housing demand. However, compared to price-based instruments the LTV also has some impact on the behavior of monetary policy variables.

- Sectoral risk weights appear to be less effective overall. Yet their relatively high efficiency compared to the LTV makes risk weights an interesting instrument as a first backstop against potential future adverse movements. Similar to the LTV, there are substitution effects, yet to a much lesser extent.

In conclusion, general shocks where housing credit is increasing as a side effect of larger movements might warrant the use of the CCyB or also sectoral risk weights to correct for sector-specific credit movements. Simple sectoral shocks can be dealt with or responded to first with sectoral risk weights. The LTV is much more effective than sectoral risk weights in confining credit growth, but shows less efficiency due to strong substitution effects.

One note on the positive impact of tightening housing credit on output: This effect is founded on the model assumptions, as corporate financing increases the capital stock and boosts overall production, while housing affects GDP in the short term via housing investment only. Yet corporate financing as a whole might also comprise very risky segments such as high yield bonds, leveraged or even covenant lite loans which are not mirrored in this model economy. Thus, substitution effects triggering a redirection of capital flows to relatively riskier sectors might even destabilize the financial systems. Moreover, higher volatility in specific market segments might also alter the risk aversion of investors and have an impact on financial stability in general.

What is also of interest for policymakers: concerning house price booms or the interaction of monetary policy, the macroprudential instruments can only marginally slow down the increase in house prices due to a housing demand shock. This suggests that these macroprudential instruments are not suitable to counteract strong fluctuations in house price movements that do not relate to credit booms, but are demand-driven. While the additional procyclical impact due to housing finance and the volatility paradox can be counteracted, the remaining effect has to be attributed to demand surpassing supply: this real economic effect should be addressed with fiscal policy rather financial regulation. The interaction of macroprudential and monetary policy appears to be less a problem in the model economy, at least with price-based instruments. In general, the impact of the CCyB and the risk weights on inflation and the policy rate is negligible in the model economy. Also, overall output as a potential target variable for monetary policy is less affected with price-based instruments compared to quantity restrictions. This can be considered a sign of complementarity between standard monetary policy and macroprudential regulation, in particular under the assumption, the central bank pursues an inflation objective only. As the risk weights are effective, yet most efficient compared to the other instruments, they might represent an ideal companion for a potentially first-moving monetary policy. However, these results certainly require further analysis. They might depend on the state of the financial sector, i.e. if the sector well capitalized or capital depleted, the nature of the shock, but also the calibration of the policy intensity of macroprudential regulation.

5 Sensitivity

The calibration of macroprudential policy is an important question for regulators. In order to gain more understanding about the calibration used as well as changes in the intensity of applying macroprudential policy, this section applies some sensitivity analysis to the intensity of macroprudential instruments. Regulatory intensity χ is calculated as the multiple elasticity of changes in the target variables relative to the baseline specifications. That said, χ equalling unity means we use the baseline specification of κ_{ltv}, κ_{rw} and κ_{ccb}, respectively. Meanwhile, 2χ equals twice the absolute elasticity for each instrument. Thus, a value of χ close to zero implies almost no responsiveness of the instrument to changes in the target variables, while twice the elasticity implies strong reactions. For example, assuming a 10% increase of the respective target variable, twice the intensity of the LTV would equal a reduction of the LTV from 80% to nearly 70% (baseline: 75%), for the CCyB a surcharge of almost 5.5 percentage points (2.5%) or for the sectoral monitoring costs/risk weights an increase from 35% to 71% (50%). We investigate the impact of changes in regulatory intensity again on the volatility, procyclicality and persistence of key variables. Figures 7 and 6 show the sensitivity of quantity and price variables, respectively. The relative volatility is calculated as in the previous section. To normalize also for differences in the target variables and a better readability of results, there is a further normalization where the volatility in the baseline specification is used as denominator. That said, in the baseline scenario, i.e. $\chi = 1$, the relative volatility equals one. For correlation and persistence, no further normalization is required.

Relative Volatility: Concerning quantity variables, for all instruments more regulation tends to reduce the relative volatility of mortgage credit granted relative to output volatility as well as the volatility of overall credit. The quantity-restricting LTV is more effective compared to both the general CCyB and the sectoral risk weights in reducing the relative volatility of quantities, as can be seen in the higher steepness of the curves up to the baseline case. Concerning the corporate asset, more sectoral regulation drives up the relative volatility. This is again in line with substitution effects. With regard to the price variables, the CCyB has some impact in reducing asset price volatility by around 50 percentage points relative to the baseline volatility, while there is only a small increase in house price volatility when the intensity is increased. Risk weights and LTV, however, tend to increase asset price volatility, while decreasing house price volatility. The price-based instruments hardly have an effect on inflation and the policy rate, while the LTV shows some effect. In general, the relative horizontal development for $\chi > 1$ points to a sensible calibration, but also indicates that higher intensity might up to some point only yield a small impact.

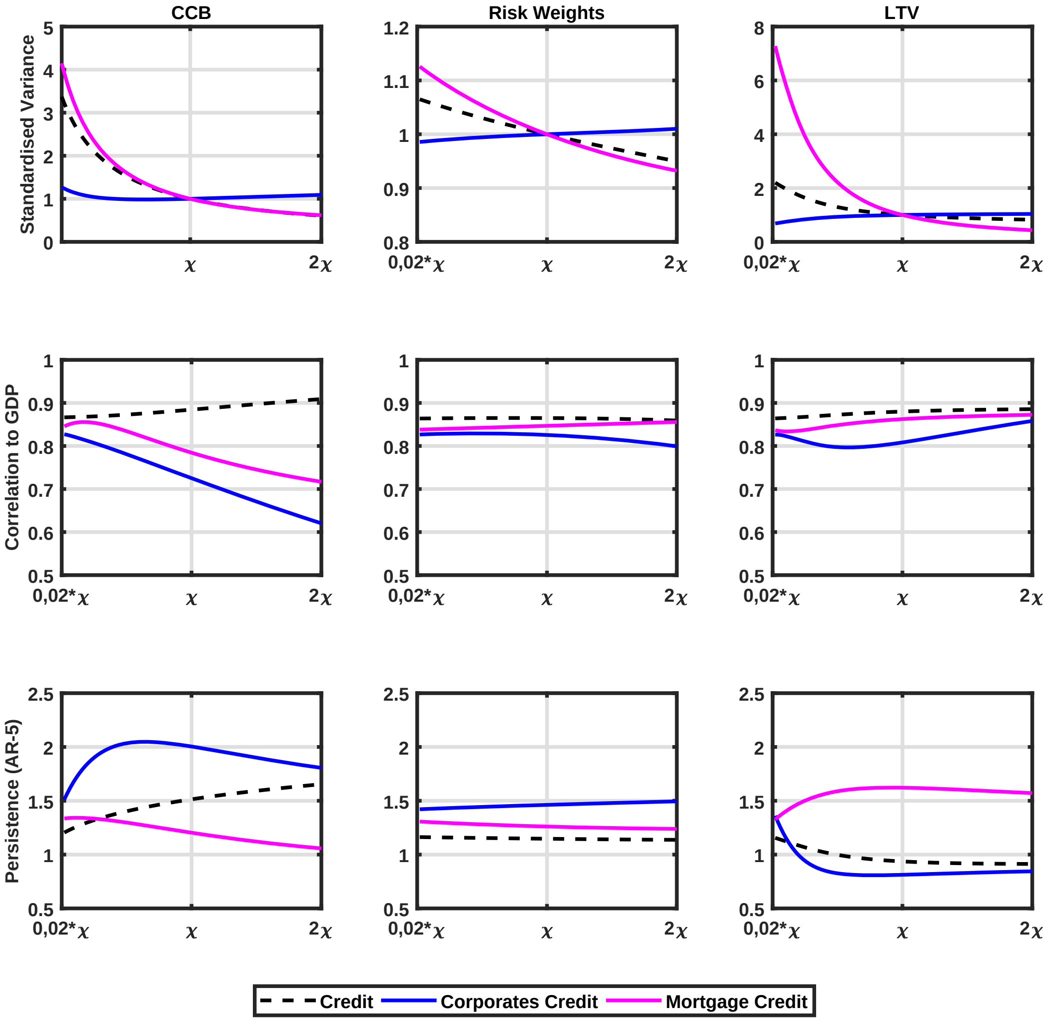

Figure 6: Comparative statics by key quantity variable and instrument relative to the intensity of regulation.

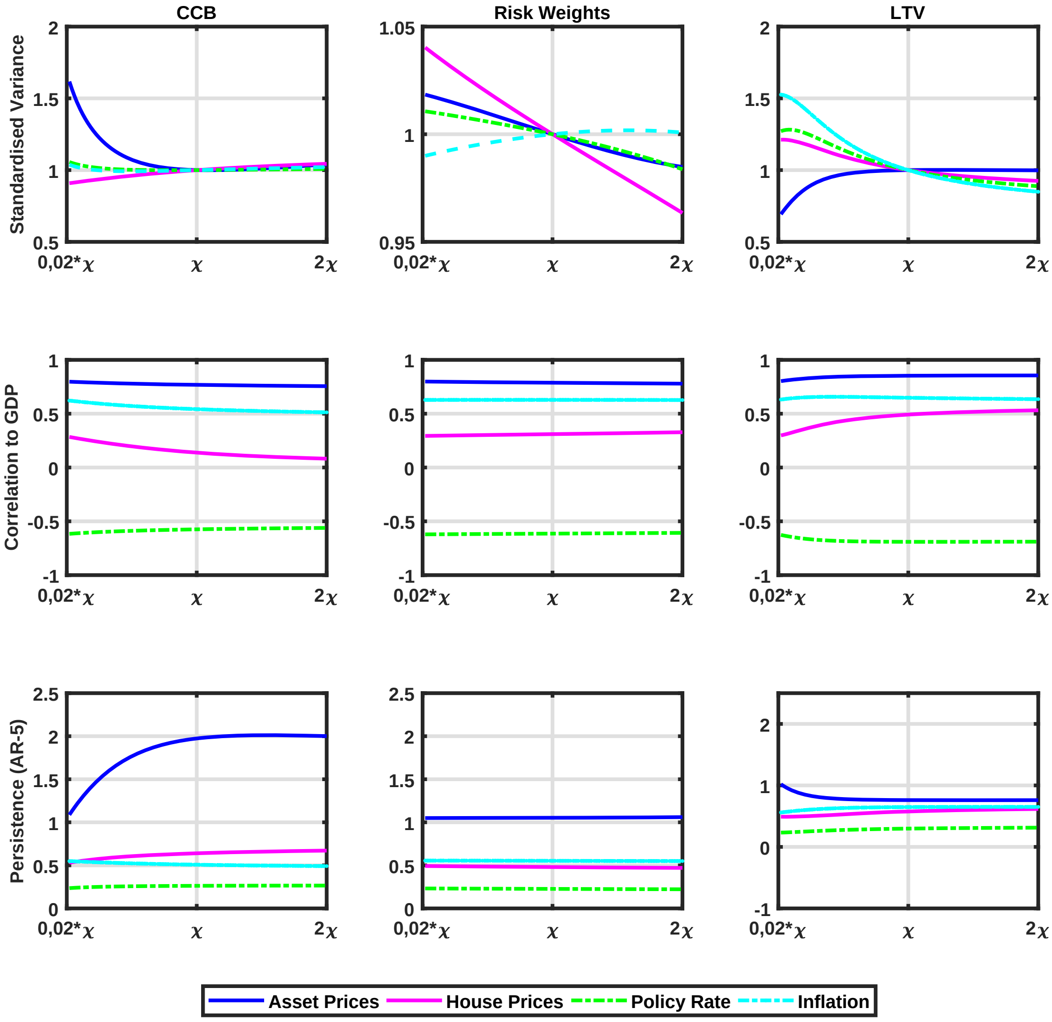

Figure 7: Comparative statics by key price variable and instrument relative to the intensity of regulation.

Procyclicality: Procyclicality of overall credit is very stable for all three instruments. Increasing CCyB intensity reduces procyclicality of mortgage and corporate credit, while the sectoral instruments have only a small impact on procyclicality. There are also some non-linearities, with CCyB increasing procyclicality of mortgage credit for low levels, and the LTV decreasing corporate asset volatility for levels of up to 0.5χ. Concerning price variables, there is hardly any impact. Only the LTV slightly drives up house price volatility with increasing intensity. The non-linearities imply that there is no corner solution in all instances, with tighter regulation implying lower procyclicality.

Persistence: Persistence is measured as the sum of the coefficients of the AR(5) process estimated for the endogenous variables. Higher values indicate that the shocks affect variables relatively for a longer time. Sensitivity analysis shows that the CCyB drives up persistence of shocks for mortgage and corporate credit, while the risk weights have hardly any effect. For the LTV there is a trade-off when intensifying regulation: the persistence of mortgages increases, while corporate assets decrease. For price variables, only asset prices are affected. Increases in the intensity of the CCyB increase persistence of asset prices up to $\chi = 1$. For very low intensity of LTV usage, the persistence of asset prices is slightly higher compared to the baseline case. Meanwhile, for other variables and the risk weights in general, there is no impact.

To sum up, concerning the quantity variables, higher intensity has some effect and can indeed reduce volatility of mortgage credit. In general, more regulation tends to be more effective with regard to mortgage credit. However, some results also show some trade-offs. First, there might be substitution effects when a lower volatility of mortgage credit comes at the cost of higher corporate asset volatility. Also, price variables might be affected. In particular, the LTV as quantity restriction might have some side effects. The sensitivity analysis also indicates some border solutions. However, for each variable there might be some point where increasing intensity only yields marginal changes in the comparative statics. Non-linearities for certain variables also imply that "the more, the better" does not necessarily apply in all cases. Finally, the sensitivity analysis also implies a sensible calibration. Beyond $\chi = 1$ there are hardly changes in the outcome.

6 Conclusion

Regulators aiming to activate and calibrate macroprudential policy face a "counterfactual" dilemma. There is hardly any data as to what extent macroprudential regulation might work as intended and which potential unintended side effects there could be. Thus, as a potential evaluation tool for the analysis of macroprudential regulation of housing credit, this paper builds a model with a financial sector funding both households and entrepreneurs via mortgage credit and corporate securities. Financial intermediaries face dynamic balance sheet constraints via investors, but also face time varying monitoring costs similar to the Basel II IRB approach. Three macroprudential instruments are tested; a CCyB targeting the financial sector balance sheet. Risk weights that affect the monitoring intensity of financial intermediaries and a LTV rule that confines the amount of credit households can receive for their housing wealth. The instruments are calibrated using examples from actual regulation and focus on the credit and mortgage gap, respectively. The underlying assumption is that strong deviations from credit relative to GDP could increase vulnerabilities of the financial system to shocks (Drehmann et al., 2011; Drehmann and Gambacorta, 2012).

The results from comparative statics and IRF analysis show that instruments work largely as intended and are to different extents suitable to dampen credit movements. The main transmission mechanisms are consumption of households as well as investment and asset price dynamics. The model confirms that macroprudential regulation can indeed also affect the real economy. By affecting the price of credit there is an indication of distributive issues. A decrease in mortgage cost is beneficial for borrowers, but at the same time decreases the income of lending households.[44]

The effectiveness and efficiency of the three instruments depends on the nature of the shock. The CCyB is most effective against general shocks where housing credit increases in line with overall credit. For sectoral shocks, LTV and risk weights might allow regulators a more targeted approach. While the CCyB is effective in curbing mortgage credit, it could affect other asset classes and curb beneficial lending activities and, implicitly, growth. Sectoral instruments appear to be more precise in reducing risks in the mortgage sector, but there could be strong spillovers to other sectors and markets. For example, tight regulation might curb credit activity and imply increases in asset price and house price volatilities: in particular, the LTV has strong side effects. Risk weights as price-based instruments are less distortive compared to quantitative restrictions such as the LTV ratio. However, the LTV is also far more effective in terms of confining mortgage credit growth compared to the risk weights. Results are also consistent with the view that macroprudential regulation is useful in containing house price booms caused by an expansion of credit. It is less efficient in dampening house price increases driven by real demand.

[44] See the welfare analysis in annex D.

The results on efficiency might also give insights into the alignment of macroprudential and monetary policy. Price-based instruments have less impact on monetary policy instruments or their target variables such as inflation or GDP. Thus, they appear to be more in line with a potential first-mover monetary policy compared to the more effective quantity restrictions.

Sensitivity analysis shows that the model is properly calibrated, but also confirms substitution and distribution effects of macroprudential regulation. Moreover, there is a non-linear relationship between the intensity of regulation and some price variables. For each variable there might be some point where increasing intensity only yields marginal changes in the comparative statics.

In a nut-shell, macroprudential regulation should not be applied as a one-size-fits-all policy, but be taken into consideration in the context of the prevailing policy mix and nature of potential disturbances to financial stability. The model is intended as a first step for further work concerning the evaluation of financial regulatory reform measures. Further model refinements or modifications should allow to address other relevant questions such as quantitative easing of model behavior at the zero lower bound (using occasionally binding constraints or a penalty function approach). In the appendix it is shown that the model might also be applied beyond macroprudential regulation, i.e. evidence that the dynamic approach of calculating risk weighted capital might have increased the procyclicality of credit extension or distributive aspects of macroprudential regulation.[45] Future work should put the model to the data to estimate a counterfactual scenario for policy evaluation. While the current calibration refers to the US economy, an estimation for different jurisdictions might also shed some insights on differences in policy transmission. Moreover, financial shocks or bubbles have played major roles in past crises. Currently, the model only features shocks emanating from the real economy, asset markets or central banks. A modified model could be used to investigate the effectiveness of macroprudential regulation to stabilize financial stability against non-fundamental price shocks.

[45] A simple comparison of the baseline case of dynamic monitoring efforts mimicking Basel II IRB with static monitoring efforts mimicking Basel I yields higher overall volatility and more pronounced boom-bust cycles in the Basel II world. See appendix for further information.

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A Additional tables and figures

Variance	Basel2	Basel3CCB	Basel3RW	Basel3LTV
Consumption				
Total	1.115	1.250	1.119	1.067
Lender	0.848	1.171	0.850	0.879
Borrower	10.093	4.053	10.007	15.905
Credit				
Total	71.483	19.967	68.038	40.276
Mortgages	318.889	71.541	286.592	52.906
Corporate Assets	16.586	12.588	17.090	31.574
Prices and Rates				
House Prices	10.424	11.373	10.163	10.968
Asset Prices	19.554	11.394	19.484	37.309
Policy Rate	2.115	1.957	2.124	2.132
Inflation	0.740	0.696	0.759	0.617
Output and Target Variables				
Output	3.282	3.312	3.332	4.180
Credit Gap	48.306	8.894	45.326	21.620
Mortgage Gap	268.701	52.525	238.907	33.048

Table 6: Variance of key variables (scaled by $10,000$); Robustness: no standardization relative to output (Second Order Approximation).

Variance	Baseline	CCB	RW	LTV
Consumption relative to Output				
Total	0.342	0.377	0.339	0.258
Lender	0.259	0.353	0.256	0.210
Borrower	3.066	1.206	2.987	3.623
Credit relative to Output				
Total	21.716	5.918	20.413	9.669
Mortgages	93.852	20.742	83.394	12.370
Corporate Assets	4.793	3.680	4.910	7.531
Prices and Rates relative to Output				
House Prices	3.209	3.542	3.080	2.652
Asset Prices	5.690	3.381	5.623	8.903
Policy Rate	0.651	0.614	0.644	0.517
Inflation	0.227	0.218	0.230	0.149
Output and Target Variables (scaled by $10,000$*)*				
Output	3.246	3.182	3.295	4.112
Credit Gap	47.552	8.212	44.706	21.198
Mortgage Gap	255.015	47.609	227.190	30.722

Table 7: Variance of key variables relative to Output (First Order Approximation).

Correlation	Baseline	CCB	RW	LTV
Consumption				
Total	0.80	0.85	0.81	0.68
Lender	0.76	0.81	0.76	0.73
Borrower	0.61	0.75	0.64	0.21
Credit				
Total	0.87	0.89	0.87	0.89
Mortgages	0.84	0.74	0.85	0.84
Corporate Assets	0.85	0.79	0.86	0.86
Prices and Rates				
House Prices	0.80	0.77	0.79	0.86
Asset Prices	0.28	0.13	0.30	0.49
Policy Rate	-0.62	-0.58	-0.62	-0.70
Inflation	0.63	0.55	0.63	0.66

Table 8: Correlation of key variables to output (First Order Approximation).

Persistence	Baseline	CCB	RW	LTV
Consumption				
Total	2.99	2.97	2.98	3.10
Lender	3.13	3.10	3.13	3.12
Borrower	2.81	2.49	2.78	3.22
Credit				
Total	1.16	1.47	1.14	0.93
Mortgages	1.28	1.12	1.24	1.61
Corporate Assets	1.49	2.06	1.52	0.81
Prices and Rates				
House Prices	0.49	0.60	0.48	0.56
Asset Prices	1.09	2.10	1.09	0.75
Policy Rate	0.23	0.26	0.23	0.30
Inflation	0.56	0.52	0.55	0.65
Output and Target Variables				
Output	1.68	1.93	1.69	1.46
Credit Gap	1.12	1.30	1.09	0.82
Mortgage Gap	1.30	1.06	1.24	1.87

Table 9: Persistence of AR(5) Process (First Order Approximation).

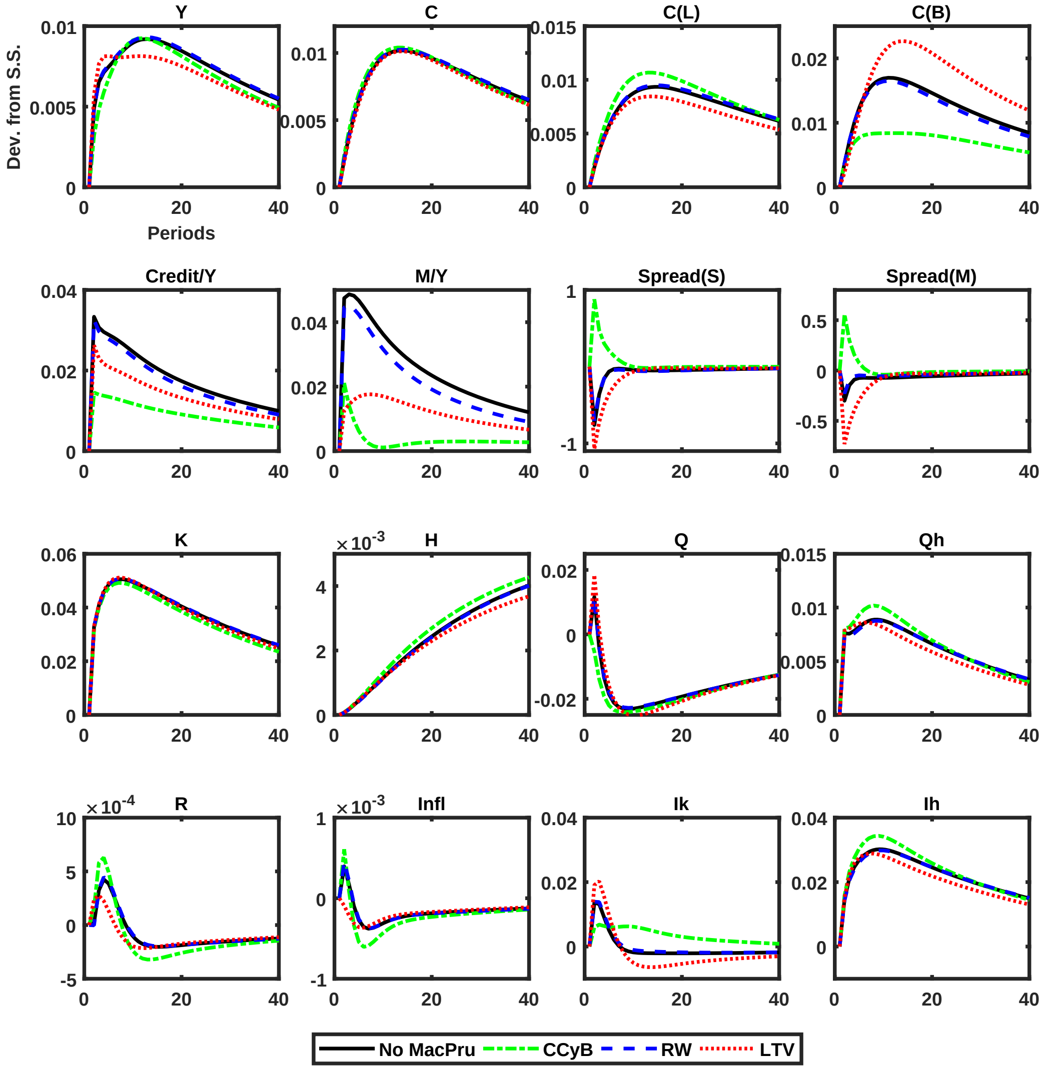

Figure 8: IRF after an increase in capital quality. Comparison of no macroprudential policies, Countercyclical Capital Buffer (CCyB), Macroprudential Risk Weights (RW) and LTV rule (LTV).

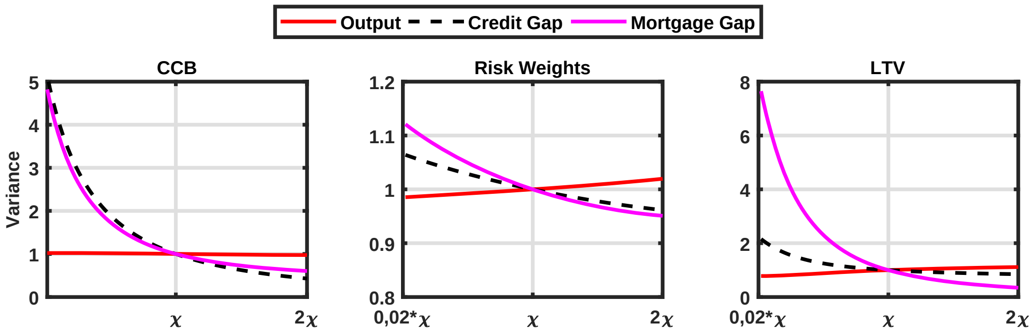

Figure 9: Sensitivity Analysis of the variance of output and the two target variables. Standardized to the variance for the benchmark calibration.

B Comparing a Basel I and Basel II scenario

The first framework, similar to Basel I monitoring efforts for mortgages and corporate stakes, can be assumed to be constants, i.e. $\psi_{m,t} = \psi_m$ and $\psi_{s,t} = \psi_s$. Optimality of the banker's problem then yields the following known relationship between the mortgage rate and the return of the corporate stakes:

$$\frac{R_{k,t} - R_t}{R_{m,t} - R_t} = \frac{(1 - \psi_s)}{(1 - \psi_m)}. \tag{73}$$

In a setting with static risk weights, interest rate spreads are driven by the productivity of the corporate sector. Arbitrage implies that any deviations by both the mortgage rate and the return on corporate stakes from the steady state are symmetric, i.e. changes in the corporate rate are identical to changes in the mortgage rate times the ratio of the relative monitoring efforts.

The following two graphs show impulse responses for two common shocks in the DSGE literature, a monetary policy easing, and a temporary increase of total factor productivity. As regulation is targeted at preventing booms, both shocks are expansionary.

Technology Shock: The transmission of the shock to total factor productivity evolves as usual in the literature (figure 10). The same input allows to produce more output, and inflation falls as there are under-capacities in production. The central bank lowers the policy rate in order to counteract deflationary developments. The interest rate pass-through to lending rates further fuels the amount of credit. A comparison of the two specifications shows that increases in borrower income ($\tilde{w}\tilde{l} \uparrow$) and house prices imply lower mortgages rates in the setting with dynamic risk weights due to a lower relative riskiness of mortgage loans. As a result, mortgage credit rises and housing investment boosts GDP temporarily. Yet the relatively higher capital stock in the static risk weight economy implies a shrinkage of GDP due to dynamic balance sheet constraints as more funds flow to the less productive housing sector.

Monetary Policy Shock: A policy rate decrease boosts output and investment while raising inflation (figure 11). Rising house prices allow borrowers to obtain more mortgage financing. The dynamic balance sheet constraints alter the setup again in a similar fashion as above, yet in a less pronounced way, as there are only modest changes in borrower income.[46] Nevertheless, the mortgage rate with dynamic constraints is slightly

[46] As the wage is the marginal product of labor intensity, the increase in labor of borrowers if offset by lower wages. Thus, this result might be an artefact of the assumption of fully flexible wages.

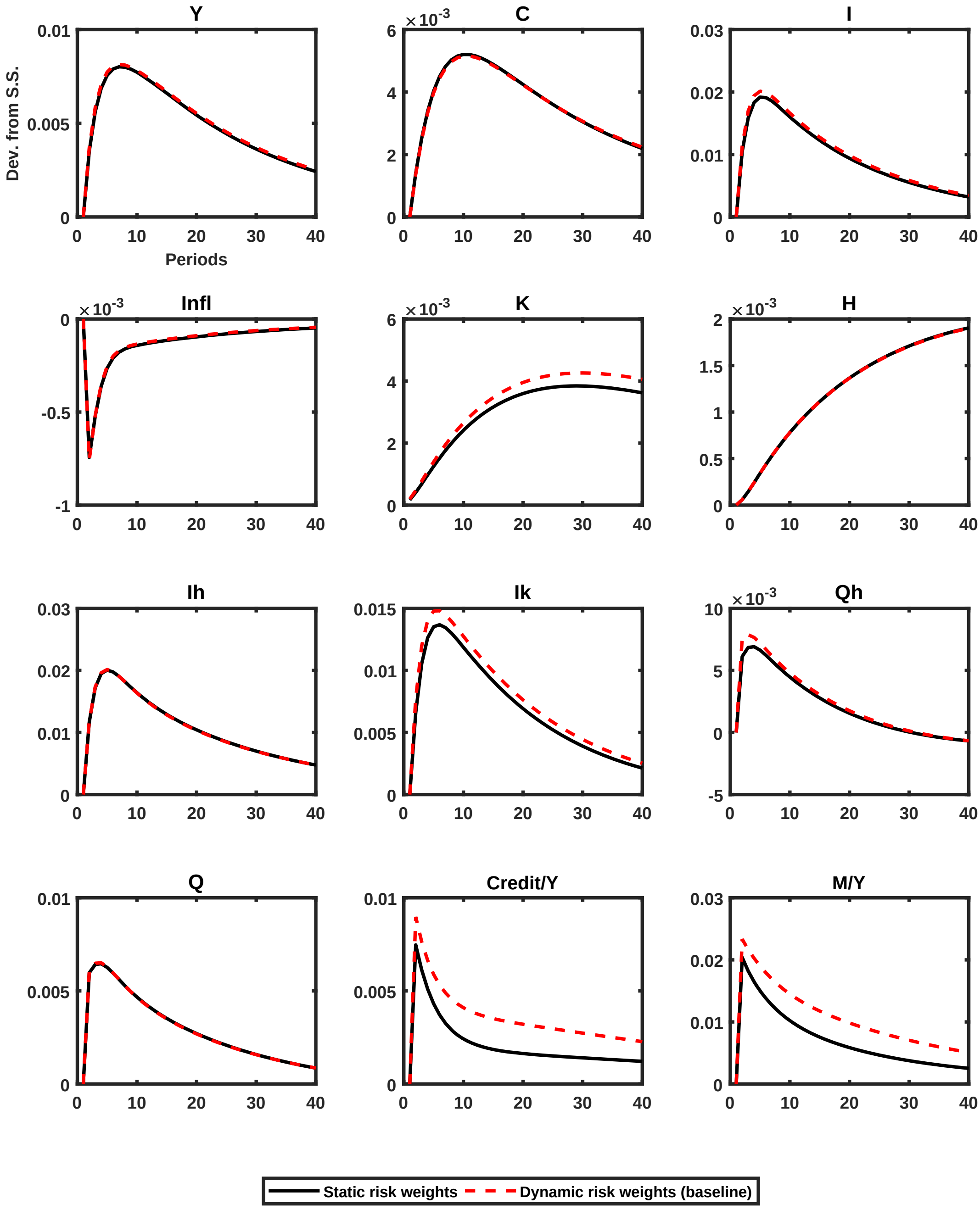

Figure 10: IRF differential between fixed and time-varying monitoring costs/risk weights - Technology Shock.

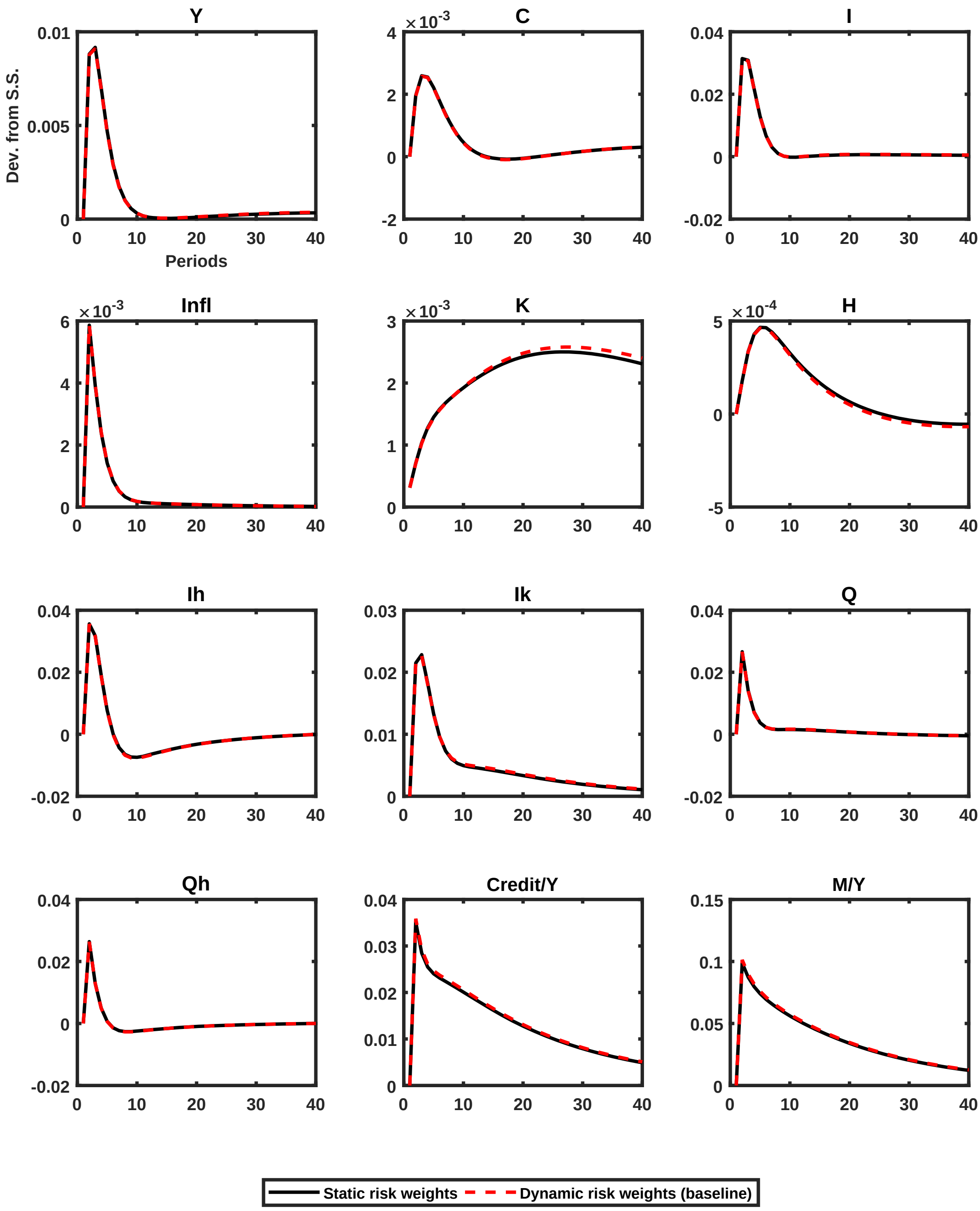

Figure 11: IRF differential between fixed and time-varying monitoring costs/risk weights - Monetary Policy Shock Shock.

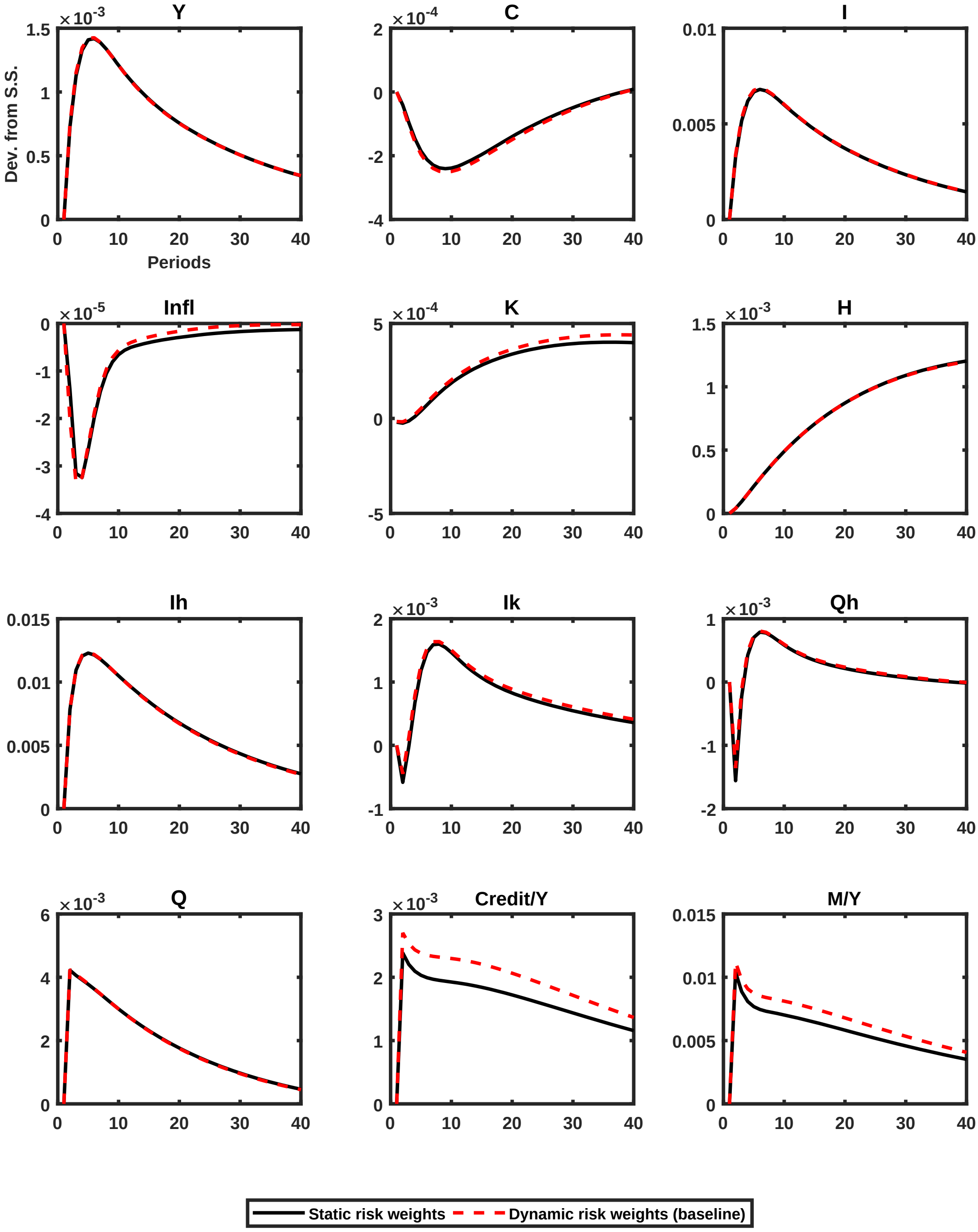

Figure 12: IRF differential between fixed and time-varying monitoring costs/risk weights - Housing Demand Shock.

	C	C(L)	C(B)	Credit	M	S	Qh	Q	R	ϕ	Y	Credit/Y	M/Y
Variance													
Basel1 Vol Basel1	0.36	0.28	3.03	20.61	89.31	4.68	3.27	5.66	0.66	0.23	3.17	43.85	236.84
Basel2	0.34	0.26	3.07	21.72	93.85	4.79	3.21	5.69	0.65	0.23	3.25	47.55	255.01
Correlation to Output													
Basel1	0.80	0.76	0.62	0.86	0.83	0.84	0.81	0.27	-0.63	0.64	-	-	-
Basel2	0.80	0.76	0.61	0.87	0.84	0.85	0.80	0.28	-0.62	0.63	-	-	-
Persistence													
Basel1	2.99	3.13	2.79	1.13	1.25	1.48	0.49	1.16	0.23	0.55	1.68	1.09	1.27
Basel2	2.99	3.13	2.81	1.16	1.28	1.49	0.49	1.09	0.23	0.56	1.68	1.12	1.30

Table 10: Comparison of Basel1 and Basel2 scenario (Linear Approximation).

lower compared to static risk weights, implying again higher mortgages and lower capital/output in relative terms. Yet the effects on aggregate real variables are modest. However, subject to dynamic constraints, mortgages increase by additional 1.4 percentage point from their steady state value compared to the case with static risk weights.

These results are consistent with the lesson from the financial crisis that a mere microprudential approach of financial regulation might not be sufficient (Borio, 2009). Low volatility in boom periods might contribute to a slow increase of risk at the single institutions due to low default rates. Shocks might then trigger a credit contraction that is exacerbated by rising capital requirements and loss provisions due to the rise in default rates and volatility (Adrian and Shin, 2013; Brunnermeier and Sannikov, 2014).

Descriptive statistics for this economy likewise show that Basel II IRB makes the overall economy more procyclical and volatile. Only the volatility of lending households' consumption is lower compared to the Basel II IRB case.

C Role of Investment Adjustment Costs

In order to increase transparency about the role of investment adjustment costs, we show IRFs for three different specifications. The model as used in the model with both short-term (ST) and long-term (LT) investment adjustment costs, as well as a specification with only ST and LT adjustment costs, respectively. The qualitative behavior does not alter for the different models. The LT costs appear to drive the main character of the IRFs in the full model, which are characterized by long and persistent investment shocks for both housing and corporates. ST only results in less persistent, yet more dynamic IRFs.

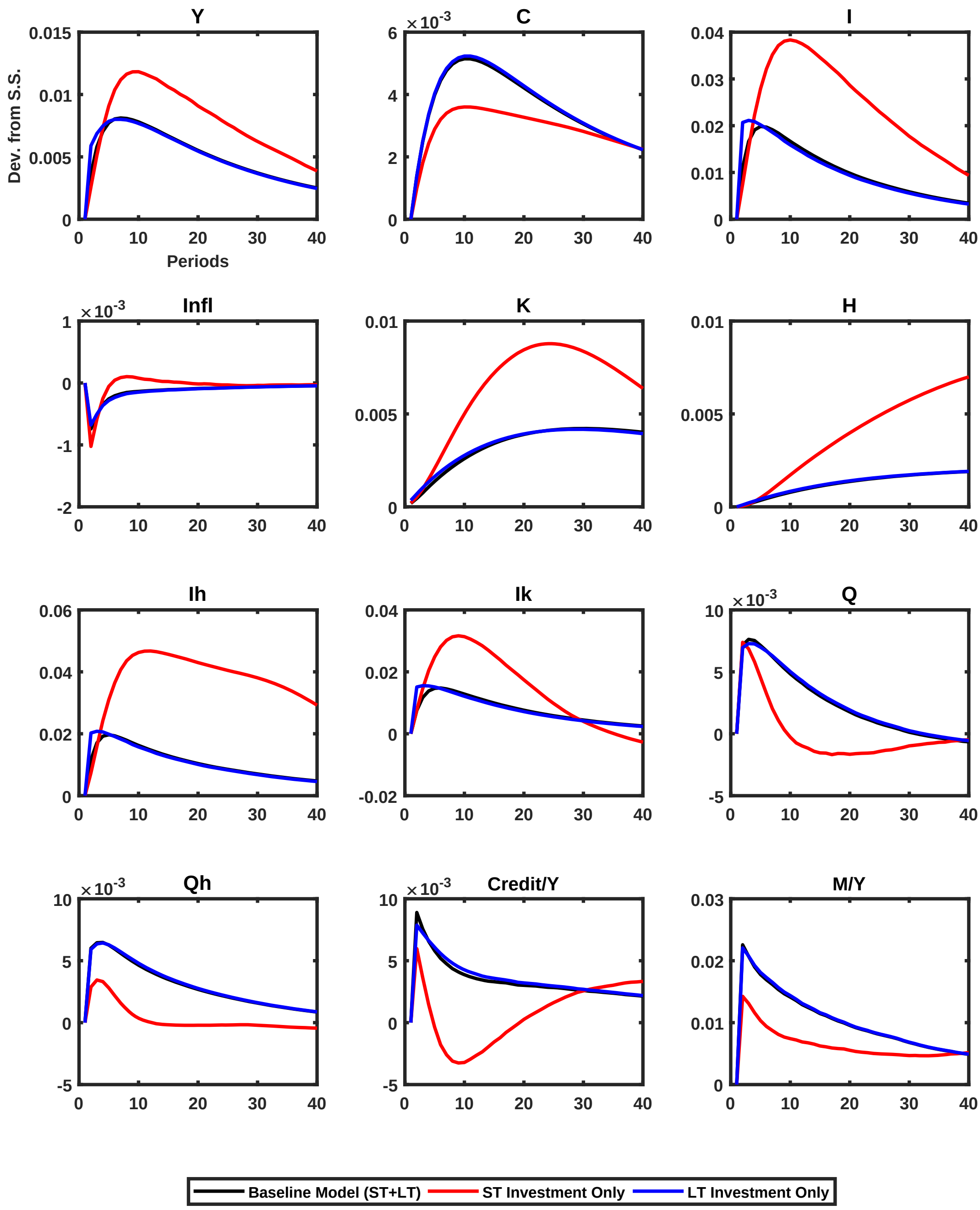

Figure 13: IRF after a positive shock to technology. Comparison of baseline scenario with short-term and long-term investment adjustment costs to scenarios with ST and LT investment adjustment costs only.

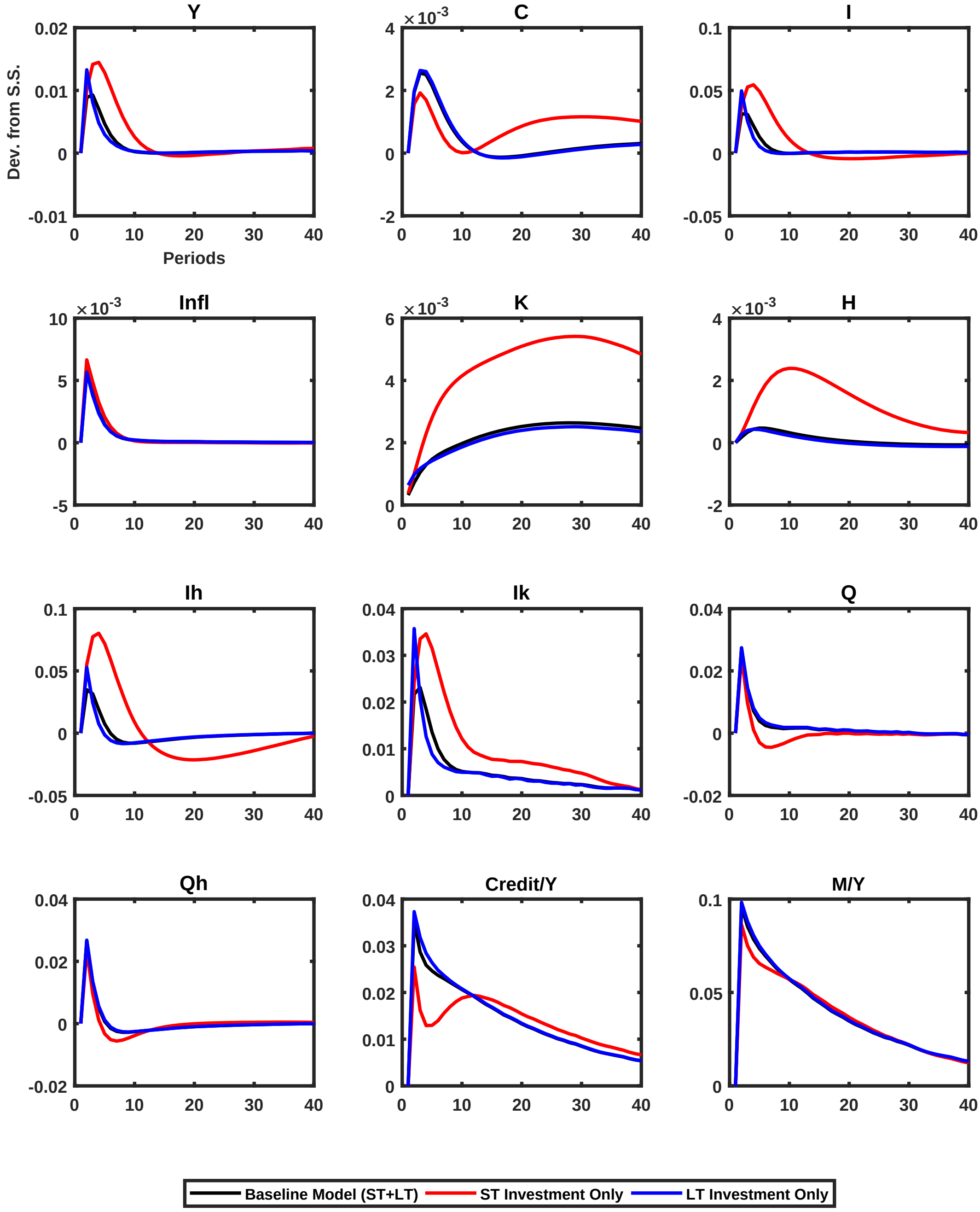

Figure 14: IRF after an increase in policy rate. Comparison of baseline scenario with short-term and long-term investment adjustment costs to scenarios with ST and LT investment adjustment costs only.

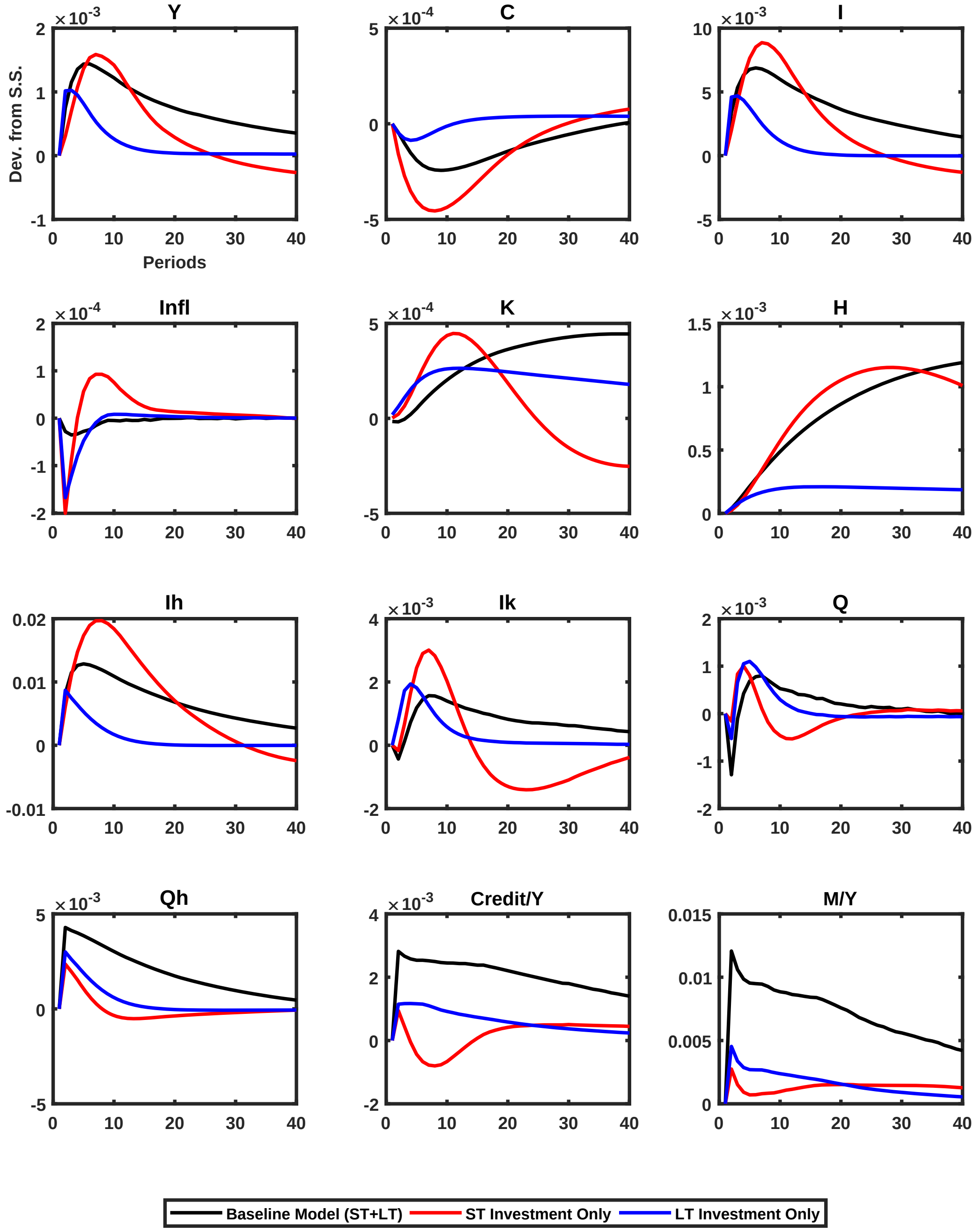

Figure 15: IRF after an increase in housing demand preference rate. Comparison of baseline scenario with short-term and long-term investment adjustment costs to scenarios with ST and LT investment adjustment costs only.

D Normative and distributive aspects

The model also has normative aspects concerning potential distributive issues. Analysis of welfare changes is an alternative route to gauge the impact of different regulatory regimes. Welfare and consumption equivalents are calculated analogous to Rubio and Carrasco-Gallego (2014) by a second order approximation of the steady state.[47]. The calculus follows Rubio and Carrasco-Gallego (2014). Welfare $\mathcal{W}$ of borrowers b and savers s are calculated using a second order approximation of the respective utility function around the steady state.

$$\mathcal{W}_{s,t} = E_t \sum_{n=0}^{\infty} \beta^n \left[u(c_{t+n}, h_{t+n}, l_{t+n})\right] \tag{74}$$

$$\mathcal{W}_{b,t} = E_t \sum_{n=0}^{\infty} \tilde{\beta}^n \left[u(\tilde{c}_{t+n}, \tilde{h}_{t+n}, \tilde{l}_{t+n}\right]. \tag{75}$$

Consumption equivalents are defined as the difference of the welfare function $\mathcal{W}$ in a state with macroprudential policy (MP) and without any policy denoted with an asterisk $*$.

$$CE_s = exp\left[(1-\beta)(\mathcal{W}_s^M P - \mathcal{W}_s^*)\right] - 1, \tag{76}$$

$$CE_b = exp\left[(1-\tilde{\beta})(\mathcal{W}_b^M P - \mathcal{W}_b^*)\right] - 1. \tag{77}$$

As there are heterogeneous agents, overall welfare effects of regulation are hard to derive. Yet welfare analysis shows that there are obvious distributional aspects of the policy. A direct comparison of welfare of each household class in table 11 shows that CCyB and risk weights as price instruments favor borrowers, while the LTV via confining mortgage credit available reduces their welfare. A grid search with various policy weights shows only corner solutions that also diverge for the two household classes. That said, while an increase in the responsiveness of the CCyB instrument favors more and more savers, the welfare of borrowers is decreasing. However, the welfare analysis focusses on households only and does not consider any potential effects (positive or negative) on the long-term financial soundness of financial intermediaries or the probability of crisis episodes that are both not incorporated in the model.

The overall effect and optimal policy cannot be derived within this model scope, as this depends on the share of borrowers and lenders in the economy and how to weigh the welfare of the different sectors. However, the model neglects potential social benefits from macroprudential regulation from a lower probability of systemic stress and

[47] Consumption equivalents represent the amount of consumption that an economic agent is willing to give up for a change in policy. Negative values represent a compensation a household asks for, if a policy causes a decrease in his personal welfare.

Welfare	NoMacroPru	NoMacroPru	CCyB	RW	LTV
Analysis	**(static)**	**(dynamic)**			
Welfare					
Lenders	-583.87	-584.23	-585.28	-584.62	-580.71
Borrowers	-222.79	-224.24	-217.91	-222.80	-225.70
Consumption Equivalent relative to Static Economy					
Lenders		-0.002	-0.007	-0.004	0.016
Borrowers		-0.036	0.130	-0.000	-0.070
Consumption Equivalent relative to Dynamic Economy					
Lenders			-0.005	-0.002	0.018
Borrowers			0.171	0.037	-0.036

Table 11: Welfare Analysis.

financial distress.

E Further model derivations

[label=appequ]

Return on Capital

The derivation of the return on capital makes use of the zero profit assumptions and the optimality conditions. In the main equation

$$\max_{U_t,L_t} P_{w,t}Y_{w,t} - w_t l_t - \tilde{w}_t \tilde{l}_t - R_{k,t}Q_{k,t-1}K_t + (Q_{k,t} - \delta_t)\zeta_t K_t \tag{78}$$

we replace the optimal labor choices with the respective optimality conditions 38 and 39 and assume there are zero profits:

$$\begin{aligned}
0 &= P_{w,t}Y_{w,t} - \frac{(1-\alpha)\iota P_{w,t}Y_{w,t}}{l_t} l_t - \frac{(1-\alpha)(1-\iota)P_{w,t}Y_{w,t}}{\tilde{l}_t}\tilde{l}_t - R_{k,t}Q_{k,t-1}K_t + (Q_{k,t} - \delta_t)\zeta_t K_t \\
0 &= P_{w,t}Y_{w,t}(1-(1-\alpha)) - R_{k,t}Q_{k,t-1}K_t + (Q_{k,t} - \delta_t)\zeta_t K_t \\
R_{k,t}Q_{k,t-1}K_t &= \alpha P_{w,t}Y_{w,t} + (Q_{k,t} - \delta_t)\zeta_t K_t \\
R_{k,t} &= \frac{\frac{\alpha P_{w,t}Y_{w,t}}{K_t} + (Q_{k,t} - \delta_t)\zeta_t}{Q_{k,t-1}}
\end{aligned}$$

Alternative route to asset optimality condition

As an alternative to monitoring costs, bankers are to choose their portfolio subject to an equity constraint similar to Bluhm, Faia, and Krahnen (2014). Thus, equity over risk weighted assets must exceed a regulatory threshold C.

$$\frac{N_t}{rw_{m,t}M_t + rw_{s,t}S_t} \geq C. \tag{79}$$

Risk weights for mortgages $rw_{m,t}$ and corporate stakes $rw_{s,t}$ determine the sum of risk-weighted assets.

$$\mathcal{E}_t = \frac{N_t}{r_{m,t}M_t + rw_{s,t}S_t} - C. \tag{80}$$

In liaison with equation 21, this implies the following optimality conditions:

$$R_{k_t} - R_t - \lambda_{C,t}\frac{N_t r_{s,t}}{(rw_{m,t}M_t + rw_{s,t}S_t)^2} = 0, \tag{81}$$

$$R_{m,t} - R_t - \lambda_{C,t}\frac{N_t r_{m,t}}{(rw_{m,t}M_t + rw_{s,t}S_t)^2} = 0, \tag{82}$$

$$\tag{83}$$

where $\lambda_{C,t}$ denotes the Lagrangean of the equity constraint.

Assuming this would yield the following equation:

$$\frac{R_{k,t} - R_t}{R_{m,t} - R_t} = \frac{rw_{s,t}}{rw_{m,t}}. \tag{84}$$

This is equivalent to monitoring efforts if

$$\frac{(1 - \psi_{m,t})}{(1 - \psi_{s,t})} = \frac{rw_{s,t}}{rw_{m,t}}, \tag{85}$$

i.e. if the ratio of risk weights is equivalent to the inverse ratio of monitoring costs surplus.

A problem with this approach in this model framework is that the constraint might be non-binding, as – in line with empirical evidence – it is assumed that banks hold surplus capital $\mathcal{E}_t$ due to the agency problem. The constraint would only be binding if both the regulatory constraint were to coincide with the investor constraint from the agency problem. This derivation, however, shows that from an economic perspective the two approaches yield the same result.