Economic Modelling 116 (2022) 105966

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.journals.elsevier.com/economic-modelling

An analysis of monetary and macroprudential policies in a DSGE model with reserve requirements and mortgage lending☆

Michael Ben-Gad, Joseph Pearlman *, Ivy Sabuga

City, University of London, United Kingdom

ARTICLE INFO

JEL classification:
E32
E44
E58

Keywords:
Reserve requirements
Endogenous loan defaults
Welfare

1. Introduction

Innovations to macroeconomic theory often develop in response to crises. The high unemployment and low aggregate output that characterised the Great Depression led Keynes (1936), in his *General Theory*, to emphasise a potential role for government spending in augmenting aggregate demand. Similarly, the concurrence of high inflation and low growth during the 1970's motivated the rebuilding of macroeconomics on micro-founded elements, incorporating both forward-looking utility-maximising households and profit-maximising firms. In these early 'real' models, all markets were assumed to be both perfectly competitive and to clear immediately, obviating any role for monetary policy or indeed the existence of money. By incorporating oligopolistic competition together with staggered pricing, New Keynesian DSGE models developed in the early 2000's by Erceg and Levin (2003), Smets and Wouters (2003) and Christiano et al. (2005) created a potential role for central banks to mitigate the welfare-reducing effects of stochastic shocks by adjusting short-term interest rates.

In those models, there is no financial sector. They cannot explain the existence of credit cycles or the way shocks in the financial sector can directly impact the real economy or amplify other shocks. To remedy this, Bernanke et al. (1999) construct a model where asymmetric information between borrowers and lenders generates credit frictions. Christensen and Dib (2008) and others then incorporate financial accelerators into the full-scale NK DSGE model with monetary policy.

Institutionally, the era of relatively high inflation during the 1970's inspired a shift towards greater central bank independence and the adoption of inflation targeting as the main policy framework (Briault et al. (1996)). Following the general election of 1997 in the UK, the new Labour government opted to grant the Bank of England (BoE) instrument independence in achieving its goal of low and stable inflation. Though formally the Bank of England Act of 1998 also gave it responsibility for ensuring the stability of the UK's financial system, the global financial crisis (GFC) in 2008 demonstrated how few (intellectual and policy) tools central banks, including the BoE, had possessed in the intervening years to prevent financial institutions from engaging in behaviour that might generate systemic risk across the sector and ultimately impact the entire economy.

☆ This work was supported by the EU 7th framework collaborative project *Integrated Macro-Financial Modelling for Robust Policy Design (MACFINROBODS)*, Grant no. 612796. An earlier version of this paper was presented at the Economic Modelling Virtual Conference on June 28–29, 2021, and the authors are thankful to the participants for their comments. The authors are also thankful for the comments received from the journal editor and reviewer. We also benefitted from the comments by Gulcin Ozkan, Margarita Rubio, Aino Silvo, Michał Brzoza-Brzezina, Junior Maih, Stephen Millard, Keith Pilbeam, Roy Zilberman, and the participants of the 2019 Money Macro and Finance Society PhD Conference, 2nd RCEA Warsaw Money-Macro-Finance Conference, and Conference on Identification and Global Sensitivity Analysis for Macro Models at European Commission-Joint Research Centre. We also received help from Dominic Quint by sending us the source code. This paper has undergone some revisions and was preliminary presented under the title "Leverage Ratio and Reserve Ratio: Do These Macroprudential Policies Work?".

* Corresponding author.
E-mail address: Joseph.Pearlman.1@city.ac.uk (J. Pearlman).

https://doi.org/10.1016/j.econmod.2022.105966
Received 7 December 2021; Received in revised form 11 July 2022; Accepted 12 July 2022
Available online 16 August 2022

The GFC inspired governments and international bodies to develop tools for stabilising the economy that extend beyond traditional monetary policy and emphasise the stability of the financial system. These new macroprudential tools generally mean not just tighter capital requirements and lower loan-to-value (LTV) ratios, but developing rules to alter these in response to changes in macroeconomic variables. Studies by Agenor et al. (2018), Angeloni and Faia (2013), Benes and Kumhof (2015), Collard et al. (2017), Christensen et al. (2011), Silvo (2019), and Paries et al. (2018) all analyse the interaction of monetary policy and capital regulations. Rubio and Carrasco-Gallego (2014), Beau et al. (2012), and Lambertini et al. (2013) evaluate the interaction of monetary policy and LTV. Angelini et al. (2014), Brzoza-Brzezina et al. (2015), and Suh (2012) consider the interaction of monetary policy, capital regulations, and LTV ratio. De Paoli and Paustian (2017) investigate how monetary policy and LTV ratios interact with taxes on both borrowing and deposits, and Gelain et al. (2013) with loan-to-income (LTI) ratios. Bailliu et al. (2015), Kannan et al. (2012), Ozkan and Unsal (2013), Quint and Rabanal (2014), Suh (2014), and Unsal (2013) interact monetary policy with a short-cut representation of macroprudential policy. Generally, these studies all find that augmenting monetary policy with macroprudential tools can be sufficient for ensuring both economic and financial stability. At the same time, though the reserve ratio is an important element of macroprudential policy, only a few studies, such as Medina and Roldós (2018), and Tavman (2015), have analysed how it interacts with monetary policy.

Moreover, while some DSGE models do incorporate financial accelerators, in these models loans are extended to entrepreneurs to finance investment rather than mortgage borrowing by households. This is despite the strong empirical evidence for its importance in Leamer (2008), provocatively titled “Housing IS the Business Cycle”, which asserts that the experience of the GFC further confirms that “Housing is the single most critical part of the U.S. business cycle, certainly in a predictive sense and, I believe, also in a causal sense.” We observe similar patterns in the Euro area in Fig. 1. Furthermore, in the US government-sponsored enterprises (GSEs), Fannie Mae and Freddie Mac provided implicit government guarantees before 2008 and have provided explicit ones since, which facilitate the securitisation of mortgages.[1] In Europe and elsewhere, these government entities do not exist and so the securitisation of mortgages is far less extensive, leaving nearly all mortgages on bank balance sheets.

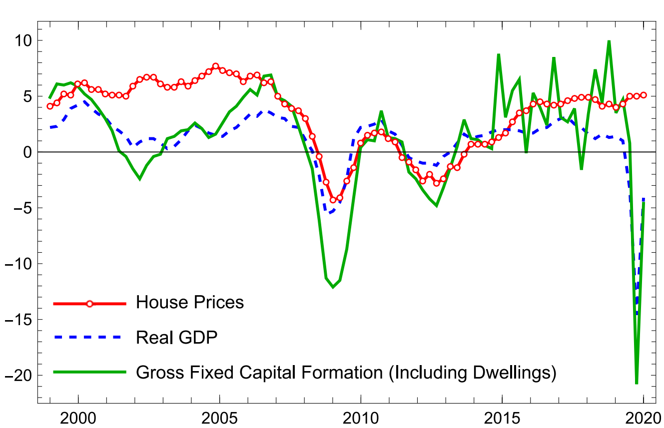

Fig. 1. Residential Investment, House Prices and Real GDP in the Euro Area (% change, y-o-y).
Source: Federal Reserves Economic Data (FRED), St. Louis Fed.

This motivates our development of a general equilibrium framework in which a reserve requirement rule operates alongside conventional monetary policy, in a model with a housing sector in addition to the sector that produces nondurable consumption. We combine a version of the financial accelerator model in Bernanke et al. (1999), used by Quint and Rabanal (2014) to model endogenous loan defaults in the housing sector, with the model of Gertler and Karadi (2011), who introduced a financial intermediation friction via the impact of funds available to banks.[2] The intermediation is explicitly via the deposits of savers that are lent to borrowers. These two types of household are modeled respectively as patient and impatient consumers, as introduced by Gerali et al. (2010), Brzoza-Brzezina and Makarski (2011) and Quint and Rabanal (2014). We then augment the model by introducing a reserve requirement that regulates how much of its deposit funds a bank can allocate to lending. We calibrate our model using euro area data.[3]

The reserve ratio was introduced as early as 1820, when banks in New York and New England agreed to redeem each other’s notes, provided the issuing bank maintained a sufficient deposit of specie (gold or its equivalent) on account with the redeeming bank (Feinman (1993)). The first legal requirements were introduced in the US by the states of Virginia, Georgia, and New York following the Panic of 1837 (Carlson (2015)), implemented nationwide in 1863 with passage of the National Bank Act, and incorporated within the 1913 Federal Reserve Act (Goodfriend and Hargraves (1983)). Given this history, it is notable that alongside the growing emphasis on macroprudential policy in emerging market economies (as shown in Table 1), advanced economies have increasing lowered or eliminated the reserve requirements. In the euro area the required reserve ratio was set at two percent from 1999 until its reduction to one percent in 2012. In the UK, the Bank of England no longer uses required reserve ratios as a policy tool. On March 26, 2020, two centuries after they were introduced, the United States Federal Reserve Board eliminated the reserve requirements for all depository institutions.[4] Our results suggest that these changes may have been ill-advised and that the reintroduction of reserve requirements may ultimately be warranted.

We use our model to examine how the interaction between monetary policy and reserve requirements affect: (i) the credit and business cycle; (ii) the distribution of welfare between savers and borrowers; and (iii) the aggregate welfare when these policies are optimised together or separately. Our inclusion of a reserve ratio as an explicit macroprudential tool, and the addition of a formal banking sector in the model, enable us to compare our results with Quint and Rabanal (2014), which uses a generic macroprudential tool representation.

This analysis produces five main results. First, we consider the model with only monetary policy as the benchmark and show the distributive implications of operating at different levels of static reserve ratio in stochastic and deterministic models. We find that there is a welfare trade-off between borrowers and savers. In both types of models, we find that there is an increase in borrowers’ welfare as the reserve ratio increases. By contrast, savers’ welfare decreases as the level of reserve ratio increases. In aggregate, total household welfare exhibits a minimal gain, as the gains by borrowers offset the losses by savers. These results underscore that a higher reserve ratio increases costs for banks, as only a portion of the available deposits can be used for lending activities. As

[1] Mortgage backed securities by Fannie Mae, Freddie Mac or the U.S. government agency Ginnie Mae accounted for 66.6 percent of total mortgage debt in December 2021. See *Housing Finance at a Glance*, Urban Institute, December 2021.

[2] Quint and Rabanal (2014) capture how changes in the balance sheet of borrowers, due to house price fluctuations caused by idiosyncratic risk shocks, affect the credit market, as well as the spread between lending and deposit rates.

[3] As in Angelini et al. (2014) and Beau et al. (2012), we do not distinguish between different countries within the euro area, but rather treat the euro area as a single economy.

[4] *Reserves Administration Frequently Asked Questions*; https://www.federalreserve.gov/monetarypolicy/reservereq.htm.

Table 1
Required reserve ratio for selected economies.

Country	Central Bank	Ratio (%)
Advanced Economies		
Czech Republic	Czech National Bank	2.0
Denmark	National Bank of Denmark	2.0
Euro Area	European Central Bank	1.0
Iceland	Central Bank of Iceland	0.00
Israel	Bank of Israel	6.0
United States	Federal Reserve	0.0
Switzerland	Swiss National Bank	2.50
Emerging Market, Middle- and Low-Income Economies		
Albania	Bank of Albania	10.0
Angola	National Bank of Angola	22.0
Argentina	Central Bank of Argentina	44.0
Brazil	Central Bank of Brazil	17.0
Bulgaria	Bulgarian National Bank	10.0
Cape Verde	Bank of Cape Verde	10.0
China	People's Bank of China	10.0
Costa Rica	Central Bank of Costa Rica	12.0
Croatia	Croatian National Bank	12.0
Curacao and St. Maarten	Central Bank of Curacao and St. Maarten	19.0
Egypt	Central Bank of Egypt	14.0
Ethiopia	National Bank of Ethiopia	10.0
Fiji	Reserve Bank of Fiji	10.0
Gambia	Central Bank of The Gambia	13.0
Guatemala	Bank of Guatemala	14.6
Liberia	Central Bank of Liberia	25.0
Moldova	National Bank of Moldova	28.0
Mozambique	Bank of Mozambique	10.5
Nicaragua	Central Bank of Nicaragua	10.0
Nigeria	Central Bank of Nigeria	27.0
Philippines	Bangko Sentral ng Pilipinas	12.0
Seychelles	Central Bank of Seychelles	10.0
South Sudan	Bank of South Sudan	15.0
Suriname	Centrale Bank van Suriname	35.0
Taiwan, China	Central Bank of the Rep. of China (Taiwan)	10.75
Tonga	Reserve Bank of Tonga	10.0
Trinidad & Tobago	Central Bank of Trinidad & Tobago	14.0
Uruguay	Central Bank of Uruguay	25.0
Venezuela	Central Bank of Venezuela	19.0
Zimbabwe	Reserve Bank of Zimbabwe	10.0

Source: Individual central banks as compiled by Central Bank News as of January 20, 2022.

banks have fewer funds to lend, they also reduce excessive risk-taking. By doing so, they are able to eliminate extending loans to subprime borrowers and thereby reduce the probability of default. However, banks accumulate less profits in the process which are then remitted to savers as owners of banks. Meanwhile, worthy borrowers enjoy a stable flow of credit as the probability of default decreases with the higher reserve ratio. This narrative reflects why savers experience welfare losses, and borrowers experience welfare gains, when the reserve ratio increases.

Second, we compute the parameters associated with both the monetary and macroprudential policy rules that optimise total welfare. We use consumer welfare as a goal rather than the stabilisation objectives of the monetary authority and macroprudential regulator. Since both agencies are maximising consumer welfare, what emerges is a team solution, so that there is no difference between cooperation and noncooperation for the two policy makers.[5] This contrasts with Angelini et al. (2014), where the optimal parameters in the cooperative and noncooperative cases differ, because the objective functions of the two policy makers are different.

[5] If there is a high probability of violating the ZLB (which is not the case in this model), one can introduce a cost in the central bank's objective function to penalise deviations from steady state interest rate, and likewise for macroprudential - penalising deviations from steady state reserve ratio. Then the two policymakers' objective functions would be distinct, and cooperative and noncooperative solutions will differ.

Third, we use the optimised parameters to generate the impulse response functions (IRFs) to two of the shocks associated with the housing sector, which together account for 43% of the variance in real GDP and nearly all the variance in loans. We demonstrate that macroprudential policy, even if it operates completely on its own, stabilises the economy when a negative risk shock hits, by dampening the financial accelerator mechanism. Macroprudential policy, either on its own, or when combined with monetary policy, also more generally generates a small welfare benefit to borrowers at the expense of savers. This differential impact increases as the reserve ratio shifts higher. Meanwhile, the response of the economy to a negative shock to the housing preference parameter is similar to the impact from the risk shock, but GDP continues to decline for another quarter. Neither macroprudential policy nor monetary policy, when operating in the absence of the other, are able to do much to mitigate the impact of the demand shock. Only when they operate in tandem is there a discernible impact on the economy—particularly in reducing the drop in total loans. Turning to the nondurable goods sector, we find that neither macroprudential policy nor monetary policy, when operating in the absence of the other, are able to do much to mitigate the impact of a nondurable technology shock. We also consider the impact of a negative demand shock in the nondurable sector. The negative impact on consumption for savers and borrowers is roughly similar, though the latter do recover more quickly. Unlike the case for the technology shock, the demand shock on nondurable inflation generates countercyclical declines in both the policy rate and the reserve ratio.

Fourth, we also analyse the welfare effects of the different regimes compared to a baseline model with no policy. We find that monetary policy, when analysed in New Keynesian models, is generally found to mitigate, but only to a small degree, the negative impacts on agents' welfare generated by stochastic shocks to the economy. We also find that at the baseline steady state reserve requirement of 10%, the total impact on welfare of macroprudential policy, either on its own, or in conjunction with monetary policy, reaches consumption equivalents of 0.003% or 0.006% respectively. If the steady state reserve requirement is set as high as 30%, the consumption equivalents are 0.014% and 0.017%, well over an order of magnitude higher than the impact of monetary policy alone. These are still small numbers, but they demonstrate that once we incorporate housing and banks into our model, macroprudential policy is more effective than monetary policy in mitigating the welfare effects of shocks.

Lastly, we demonstrate how much these different regimes can reduce the volatility of key macroeconomic and financial variables. We find that the reduction in the loss function is largest when monetary and macroprudential policy operate together and the reserve ratio is highest. Monetary policy, combined with macroprudential policy, implemented with the low steady state reserve requirement we observe in the Eurozone, achieves a reduction in the loss function nearly as large as macroprudential policy when it operates on its own with the much higher reserve requirement.

We proceed as follows. In Section 2 we provide a brief description of the model, and in Section 3 we discuss the calibration of its structural and stochastic parameters. In Section 4 we analyse the behaviour of the model and consider the welfare implications of different policy choices. Section 5 concludes.

2. The model

Consider a closed economy dynamic stochastic general equilibrium (DSGE) model that combines a balance sheet constraint from Quint and Rabanal (2014) with financial frictions modeled by Gertler and Karadi (2011). Fig. 2 provides a description of the feedback mechanism of the model by showing the flow of transactions among the agents. The model has two sectors, nondurable consumption and housing, and heterogeneous households, the savers and borrowers in equilibrium with discount factor of β and β^B, respectively, where $\beta > \beta^B$. Merging the two

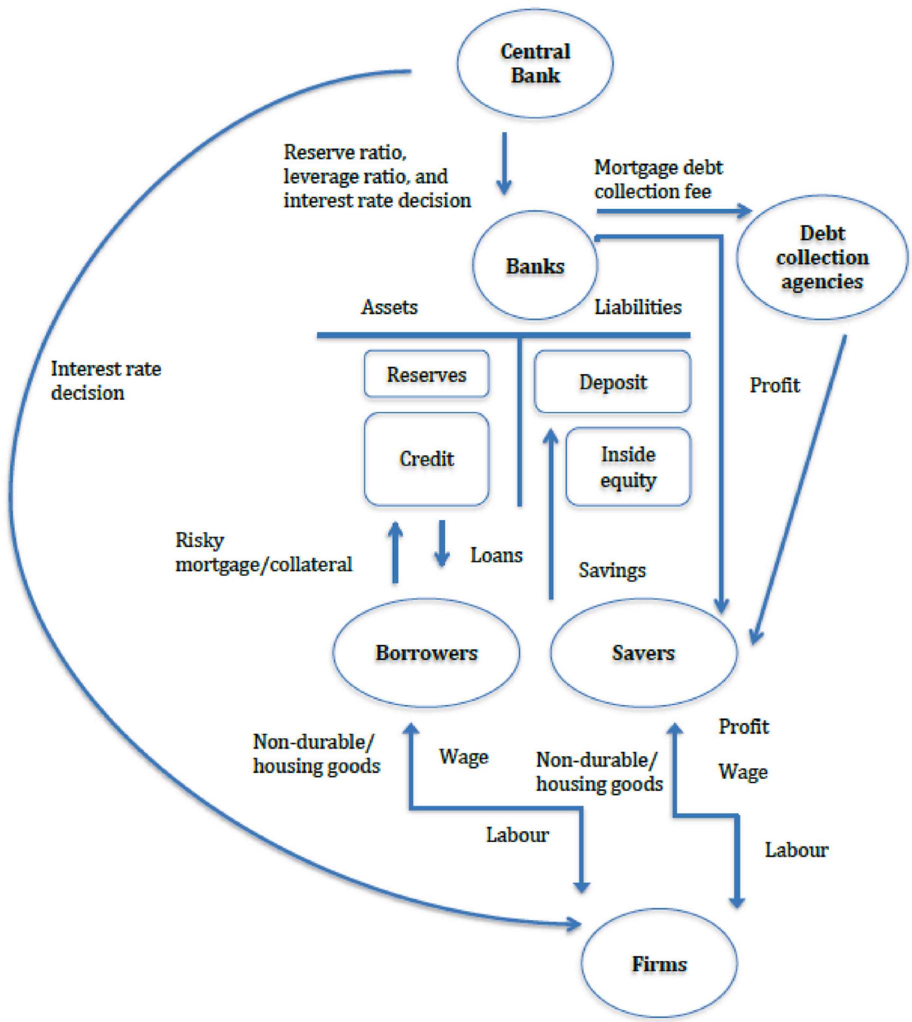

Fig. 2. Model interactions.
Source: Authors' own construction.

models allows us to understand the role of banks that intermediate funds from savers to borrowers (with a reserve ratio that regulates the supply of credit) and face balance sheet constraints. These constraints originate with the endogenous loan defaults of borrowers caused by idiosyncratic shocks to their housing collateral. The two final goods in this economy, nondurables and housing, are produced in perfectly competitive markets, by combining together different sets of intermediate goods. The intermediate goods are produced by two different sets of monopolistically competitive firms associated with each sector. Private banks, too, are monopolistically competitive, and there are also collection agencies that banks engage for a fee to recover a portion of any loans in default. The central bank conducts monetary policy according to a Taylor rule and sets the reserve ratio for banks. We abstract from fiscal policy.

2.1. Savers

Savers indexed by $j \in [0, \lambda]$ maximize expected utility by choosing nondurable consumption, housing, and labour hours:

$$\max_{C_t^j, D_t^j, L_t^j} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\gamma \xi_t^C log(C_t^j - \epsilon C_{t-1}) + (1-\gamma) \xi_t^D log(D_t^j) - \frac{(L_t^j)^{1+\varphi}}{1+\varphi} \right] \right\}, \tag{1}$$

where the parameter ϵ measures the external habit on past total nondurable goods consumption while β, γ, and φ stand for the discount factor, the share of nondurable goods in the utility function, and the inverse elasticity of labour, respectively. There is also a preference shock ξ_t^k, where $k = C, D$ *and* where C and D refer to consumption and housing, respectively, which follow an AR(1) process with zero mean.

The labour disutility index consists of hours worked:

$$L_t^j = \left[\alpha^{-\iota_L} \left(L_t^{C,j}\right)^{1+\iota_L} + (1-\alpha)^{-\iota_L} \left(L_t^{D,j}\right)^{1+\iota_L} \right]^{\frac{1}{1+\iota_L}}, \tag{2}$$

where $L_t^{C,j}$ denotes the nondurable sector and $L_t^{D,j}$ the housing sector, with α as share of employment in the nondurable sector. Reallocating labour across sectors is costly and is governed by parameters ι_L.

Saver households face a budget constraint which we express in real terms:

$$C_t^j + S_t^j + Q_t I_t^j = W_t^C L_t^{C,j} + W_t^D L_t^{D,j} + \frac{R_{t-1} S_{t-1}^j}{\Pi_t^C} + \Psi_t^j, \tag{3}$$

where $Q_t = \frac{P_t^D}{P_t^C}$ is the price of housing relative to the nondurable final consumption good. Real wages paid in the two sectors are denoted by W_t^C and W_t^D. Savers allocate their expenditures between real nondurable consumption C_t^j and housing investment I_t^j. They can save by holding deposits in the financial system S_t^j, which pay a gross nominal deposit interest rate R_t, converted to a real rate by dividing by nondurable consumption inflation Π_t^C. In addition, savers also receive profits Ψ_t^j from intermediate goods producers in the housing and non-durable sectors, from the banks they manage, and from debt-collection agencies that collect fees from banks to recover defaulting loans.

The housing stock, D_t^j, accumulates through housing investment I_t^j by savers:

$$D_t^j = (1-\delta)D_{t-1}^j + \left[1 - f\left(\frac{I_{t-1}^j}{I_{t-2}^j}\right)\right]I_{t-1}^j, \tag{4}$$

where δ denotes the rate of depreciation for the housing stock and $f(\cdot)$ is an adjustment cost function. Following Christiano et al. (2005), $f(\cdot)$ is a convex function, which in steady state satisfies: $\bar{f} = \bar{f}' = 0$ and $\bar{f}'' > 0$.[6]

Defining the stochastic discount factor as $\mathrm{P}_{t,t+1} \equiv \beta\frac{\mathrm{P}_{t+1}}{\mathrm{P}_t}$, the first order conditions (FOCs) for the savers' optimisation problem are as follows: Euler consumption

$$1 = \beta R_t E_t\left[\frac{C_t - \epsilon C_{t-1}}{C_{t+1} - \epsilon C_t}\frac{\xi_{t+1}^C}{\xi_t^C}\Pi_{t+1}^C\right], \tag{5}$$

Stochastic discount factor

$$\mathrm{P}_{t,t+1} \equiv \beta\frac{\mathrm{P}_{t+1}}{\mathrm{P}_t} = \beta\frac{\gamma\xi_{t+1}^C C_t - \epsilon C_{t-1}}{\gamma\xi_t^C C_{t+1} - \epsilon C_t}, \tag{6}$$

Labour supply

$$\alpha^{-\iota_L} L_{t+s}^{\varphi-\iota_L}(L_{t+s}^C)^{\iota_L} = \frac{\xi_t^C W_t^C}{C_t - \epsilon C_{t-1}}, \tag{7}$$

$$(1-\alpha)^{-\iota_L} L_{t+s}^{\varphi-\iota_L}(L_{t+s}^D)^{\iota_L} = \frac{\xi_t^C W_t^D}{C_t - \epsilon C_{t-1}}, \tag{8}$$

Investment

$$\frac{\gamma\xi_t^C Q_t}{C_t - \epsilon C_{t-1}} = \beta E_t \varrho_{t+1}\left[1 - f\left(\frac{I_t}{I_{t-1}}\right) - f'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] + \beta^2 E_t\left[\varrho_{t+2} f'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right]. \tag{9}$$

2.2. Borrowers

The borrowers in this economy, indexed by $j \in [\lambda, 1]$, also maximize their expected utility with respect to nondurable consumption, housing and labour hours:

$$\max_{C_t^{B,j}, D_t^{B,j}, L_t^{B,j}} E_0\left\{\sum_{t=0}^{\infty}\beta^{B,t}\left[\gamma\xi_t^C log(C_t^{B,j} - \epsilon^B C_{t-1}^B) + (1-\gamma)\xi_t^D log(D_t^{B,j}) - \frac{(L_t^{B,j})^{1+\varphi}}{1+\varphi}\right]\right\}. \tag{10}$$

We define $F(\overline{\varpi}, \overline{\sigma}_\omega)$ as the cumulative distribution function (CDF) of the idiosyncratic shock to the quality of the housing stock. Hence, the budget constraint, in real terms, aggregated across all borrowers, incorporates both the fraction $F(\overline{\varpi}, \overline{\sigma}_\omega) = \int_0^{\overline{\varpi}} dF(\omega, \sigma_\omega)d\omega$ of households that receive shocks to the quality of their housing below the threshold $\overline{\varpi}$ and default on their loans, and the fraction $1 - F(\overline{\varpi}, \overline{\sigma}_\omega) = \int_{\overline{\varpi}}^{\infty} dF(\omega, \sigma_\omega)d\omega$ that receive shocks above the threshold and pay their loans:

$$C_t^B + Q_t I_t^B + \left[R_t^D + (1 - F(\overline{\varpi}, \sigma_\omega))R_{t-1}^L\right]S_{t-1}^B = S_t^B + W_t^C L_t^{B,C} + W_t^D L_t^{B,D}. \tag{11}$$

where $R_t^D = G(\overline{\varpi}, \overline{\sigma}_\omega)\frac{Q_t D_t^B}{S_{t-1}^B}$ is the rate that is paid to banks after a debt-collection agency intervenes. Borrowers receive no income from profits.

Defining the stochastic discount factor as $\mathrm{P}_{t,t+1}^B \equiv \beta\frac{\mathrm{P}_{t+1}^B}{\mathrm{P}_t^B}$, FOCs for this optimisation problem are as follows: Euler consumption

$$1 = \beta^B E_t\left[R_{t+1}^D + (1 - F(\overline{\varpi}, \overline{\sigma}_\omega))R_t^L\right]\left[\frac{C_t^B - \epsilon C_{t-1}^B}{C_{t+1}^B - \epsilon^B C_t}\frac{\xi_{t+1}^C}{\xi_t^C}\Pi_{t+1}^C\right], \tag{12}$$

Stochastic discount factor

$$\mathrm{P}_{t,t+1}^B \equiv \beta^B\frac{\mathrm{P}_{t+1}^B}{\mathrm{P}_t^B} = \beta^B\frac{\gamma\xi_{t+1}^C C_t^B - \epsilon^B C_{t-1}^B}{\gamma\xi_t^C C_{t+1}^B - \epsilon^B C_t^B}, \tag{13}$$

Labour supply

$$\alpha^{-\iota_L} L_{t+s}^{\varphi-\iota_L}(L_{t+s}^{B,D})^{\iota_L} = \frac{\xi_t^C W_t^C}{C_t^B - \epsilon^B C_{t-1}^B}, \tag{14}$$

$$(1-\alpha)^{-\iota_L} L_{t+s}^{\varphi-\iota_L}(L_{t+s}^{B,D})^{\iota_L} = \frac{\xi_t^C W_t^D}{C_t^B - \epsilon^B C_{t-1}^B}, \tag{15}$$

Investment

$$\frac{\gamma\xi_{t+s}^C Q_t}{C_{t+s}^B - \epsilon^B C_{t+s-1}^B} = \beta E_t \varrho_{t+1}^B\left[1 - f\left(\frac{I_t^B}{I_{t-1}^B}\right) - f'\left(\frac{I_t^B}{I_{t-1}^B}\right)\frac{I_t^B}{I_{t-1}^B}\right] + \beta^2 E_t\left[\varrho_{t+2}^B f'\left(\frac{I_{t+1}^B}{I_t^B}\right)\left(\frac{I_{t+1}^B}{I_t^B}\right)^2\right]. \tag{16}$$

An endogenous default risk is introduced into the model similar to that of Quint and Rabanal (2014), which was originally introduced by Bernanke et al. (1999). The risk is introduced in the credit and housing market by assuming an idiosyncratic quality shock to the value of the housing stock of each borrower household, which is used as collateral for their loans. However, as with the former, we do not model asymmetric information or agency problems. Borrowers will only default if they are hit by a shock that would make the value of their housing stock lower than their outstanding debts.

This idiosyncratic shock is log-normally distributed: $\log(\omega_t^j) \sim N(\mu_\omega, \sigma_{\omega,t}^2)$ where setting $\mu_\omega = -\frac{1}{2}\sigma_{\omega,t}^2$ ensures that $E(\omega_t^j) = 1$. That means the cumulative distribution of the shocks is $F(\omega, \sigma_\omega) = \Phi(\frac{ln\omega + \frac{1}{2}\sigma_\omega^2}{\sigma_\omega})$ where $\Phi(x) = \int_{-\infty}^{x}\frac{1}{\sqrt{2\pi}}e^{\frac{-t^2}{2}}dt.$

The standard deviation of the housing quality shock $\sigma_{\omega,t}$ that follows is an AR(1) process in logs:

$$log(\sigma_{\omega,t}) = (1 - \rho_{\sigma_\omega})log(\overline{\sigma}_\omega) + \rho_{\sigma_\omega}log(\sigma_{\omega,t-1}) + u_{\omega,t}, \tag{17}$$

where $u_{\omega,t} \sim (0, \sigma_{u_\omega})$ follows the log normal distribution on the support (0,∞), so ω_t^j is always positive. Any rise in $\sigma_{\omega,t}$ is mean-preserving and only increases the skewness of the distribution, resulting in more of the mass of the distribution concentrated on the left and lower values for ω_t^j. As a result, the probability of mortgage default increases, requiring banks to set higher spreads.

The shock ω_t^j equals the ex-ante threshold default value $\overline{\varpi}_t^a$ if the expected value of the housing stock exactly matches the gross interest payment on the loan. We define D_t^B as the real value of the housing stock held by borrowers, and writing S_t^B as the real value of the loan, it follows that:

$$\overline{\varpi}_t^a E_t[Q_{t+1}\Pi_{t+1}^C D_{t+1}^B] = R_t^L S_t^B. \tag{18}$$

For borrowers, the ex-post threshold value $\overline{\varpi}_{t-1}^p$ where a borrower still

[6] The cost function is included so that the model can replicate the hump-shaped responses of residential investment to shock and reduce the residential investment volatility.

repays its loan is:

$$\overline{\omega}^p_{t-1} Q_t \Pi^C_t D^B_t = R^L_{t-1} S^B_{t-1}. \tag{19}$$

As in Quint and Rabanal (2014), the one-period lending rate R^L_{t-1} is predetermined and not a function of the state of the economy, and since investment increases the housing stock with a lag, D^B_t is also a predetermined variable. Therefore the housing risk, ex-ante $\overline{\omega}^a_t$ and ex-post $\overline{\omega}^p_t$, can differ even though when the loan contract is signed, $\overline{\omega}^a_t = E_t \overline{\omega}^p_t$. Ex-post, borrowers hit by shocks above and below the threshold $\overline{\omega}^p_{t-1}$ face different budget constraints. A high realisation of ω^j_t leads to borrowers paying in full:

$$\overline{\omega}^p_{t-1} Q_t D^B_t \geq \frac{R^L_{t-1} S^B_{t-1}}{\Pi^C_t}. \tag{20}$$

However, low realisation of ω^j_t leads to borrowers defaulting:

$$\overline{\omega}^p_{t-1} Q_t D^B_t < \frac{R^L_{t-1} S^B_{t-1}}{\Pi^C_t}. \tag{21}$$

The fraction of loans that banks expect to default in period $t+1$ equals the CDF of the quality shock:

$$F(\overline{\omega}, \overline{\sigma}_\omega) = \int_0^{\overline{\omega}} dF(\omega) = \int_0^{\overline{\omega}} \frac{1}{\omega \overline{\sigma}_\omega \sqrt{2\pi}} e^{-\frac{\left(ln\omega + \frac{1}{2}\overline{\sigma}^2_\omega\right)^2}{2\overline{\sigma}^2_\omega}} d\omega, \tag{22}$$

where the log-normal distribution of ω_t implies that the steady state of the mean is $\overline{\mu}_\omega = -\frac{1}{2}\overline{\sigma}^2_\omega$.[7] Since the expected value of the quality shock conditional on being less than the threshold $\overline{\omega}^p_{t-1}$ is $G = 1 - \Phi\left(\frac{\frac{1}{2}\overline{\sigma}^2_\omega - ln\overline{\omega}}{\overline{\sigma}_\omega}\right)$, the value of the housing stock recovered by debt collection agencies in each period is:

$$R^D_t S^B_{t-1} = G Q_t D^B_t. \tag{23}$$

2.3. Banks

The banking sector in this model closely follows that of Gertler and Kiyotaki (2010) but embeds the New Keynesian (NK) model of sticky prices similarly to Gertler and Karadi (2011). Specifically, banks in our model face costs associated with enforcing contracts in an environment where financial frictions also limit the funds available to banks from savers. To these two elements, we add an additional friction in the form of a reserve ratio, which rations the funds available for banks to purchase state-contingent securities.

Banks operate in a monopolistically competitive environment where they adjust the deposit and lending rates in response to shocks or the cyclical conditions of the economy. Banks pay depositors a gross interest rate R_t and extend loans to borrowers at a gross rate R^L_t against the future value of their housing collateral. Banks introduce a wedge between the cost of deposits from savers, R_t, and the average interest rate banks receive for the loans they choose to make, $R^D_t + (1-F)R^L_{t-1}$, subject to the required reserve ratio, rr_t. Banks will tend to increase the loanable amount they issue in a credit boom environment while decreasing it when times are uncertain. The reserve ratio limits riskier credit activity during booms.

The activity of banks can be summarised in two phases. First, banks raise deposits, an average of S_t, from each saver at a deposit rate R_{t+1} over the interval $[t, t+1]$. These deposits and the internal equity n_t they raise from households serve as the banks' liabilities. Banks retain a certain proportion of unremunerated reserves rr_t from the deposits they receive from households. In the second phase, banks use these liabilities to make loans averaging S^B_t to each borrower. The housing borrowers purchase serves as collateral.

The total amount of assets against which the loans are obtained is the end-of-period housing stock D_t in (3). The lending rate for those who fully repay is known in advance and is a contractual obligation, while the average return on those loans that default is only known at time t. A bank's balance sheet is summarised by:

$$(1-\lambda) S^B_t \leq n_t + \lambda(1 - rr_t) S_t, \tag{24}$$

while the net worth of the banks accumulates according to:

$$n_{t+1} = (1-\lambda)\left[(1-\mu) R^D_{t+1} + (1-F) R^L_t\right] S^B_t - \lambda(R_{t+1} - rr_t) S_t. \tag{25}$$

The interest rate on the loans that are recovered in full is:

$$R^L_{t-1} = \frac{1}{\beta^B}\left\{\frac{1}{1 - F + G/\overline{\omega}^p_{t-1}}\right\}, \tag{26}$$

and the return on the assets recovered from those who default is:

$$R^D_t = \frac{Q_t G D^B_t}{S^B_{t-1}}. \tag{27}$$

If default occurs, banks call in debt-collection agencies which return the fraction $(1-\mu)$ of the realised value of borrower j's housing stock and retain the fraction μ in fees, which is distributed as profits to savers. Banks each face an exit probability $1-\sigma_B$ each period and therefore exit in the ith period with probability $(1-\sigma_B)\sigma_B^{i-1}$. As banks only pay dividends when they exit, the bankers' objective function maximises expected discounted terminal wealth:

$$V_t = E_t \sum_{i=0}^{\infty} (1-\sigma_B) \sigma_B^{i-1} \mathrm{P}_{t,t+i} n_{t+i}, \tag{28}$$

where $\mathrm{P}_{t,t+i} = \beta^i \frac{\mathrm{P}_{C,t+i}}{\mathrm{P}_{C,t}}$ is the stochastic discount factor, subject to an incentive constraint (below) for savers to be willing to supply funds to the banks.

Assume (24) holds with equality; solving for S_t and substituting into (25) yields:

$$n_{t+1} = E_t\left\{(1-\lambda)\left[\left(1-\mu\right) R^D_{t+1} + (1-F) R^L_t - \frac{R_{t+1} - rr_t}{1 - rrt}\right] S^B_t + \frac{R_{t+1} - rr_t}{1 - rr_t} n_t\right\}. \tag{29}$$

We assume that after a bank obtains funds and complies with the required reserve ratio, the bank's owner may transfer a fraction Θ of the assets not held as reserves to his family, causing the bank to default on its debts and shut down. In recognition of the possibility that as much as $\Theta(1-\lambda)S^B_t$ of the bank's assets could be diverted for personal gain—leaving only $(1-\Theta)(1-\lambda)S^B_t$ to be reclaimed by creditors—households limit the funds they lend to banks. To ensure that banks do not divert funds, a bank's franchise value, V_t, must be at least as large as its gain from diverting funds:

$$V_t \geq \Theta(1-\lambda) S^B_t. \tag{30}$$

The right-hand side of this incentive constraint is what the bank's owner gains by diverting a fraction of assets, and the left-hand side is what is lost from diverting funds. The optimisation problem for the bank is to choose a path for loans $\{S^B_{t+i}\}$ which maximises V_t subject to (24), (25) and (30). Given that the objectives and constraints are all linear, it makes sense to conjecture that the solution is of the linear form:[8]

$$V_t = E_t \Omega_{t+1} \mathrm{P}_{t,t+1} n_{t+1}. \tag{31}$$

The value of the bank at the end of period $t-1$ satisfies the Bellman

[7] See Quint and Rabanal (2014) Appendix for the complete derivation.

[8] Unsurprisingly, the solution is exactly equivalent to theirs, but is obtained without the need for the Lagrangian, as utilised by Gertler and Kiyotaki (2010).

equation:

$$V_{t-1} = E_{t-1}\mathrm{P}_{t-1,t}[(1-\sigma_B)n_t + \sigma_B V_t]. \tag{32}$$

Substituting (29) and (31) into (30) and (32) yields the dynamic programming problem:

$$V_{t-1} = E_{t-1}\mathrm{P}_{t-1,t}\Big[(1-\sigma_B)n_t + \sigma_B E_t\Omega_{t+1}\mathrm{P}_{t,t+1}\Big\{(1-\lambda)\Big[(1-\mu)R^D_{t+1} + (1-F)R^L_t - \frac{R_{t+1}-rr_t}{1-rr_t}\Big]S^B_t + \frac{R_{t+1}-rr_t}{1-rr_t}n_t\Big\}, \tag{33}$$

subject to the constraint:

$$E_t\Omega_{t+1}\mathrm{P}_{t,t+1}\Big\{\Big(1-\lambda\Big)\Big[\Big(1-\mu\Big)R^D_{t+1} + (1-F)R^L_t - \frac{R_{t+1}-rr_t}{1-rrt}\Big]S^B_t + \frac{R_{t+1}-rr_t}{1-rr_t}n_t\Big\} \geq \Theta(1-\lambda)S^B_t. \tag{34}$$

If $E_t\Omega_{t+1}\mathrm{P}_{t+1}\Big[\Big(1-\mu\Big)R^D_{t+1} + (1-F)R^L_t - \frac{R_{t+1}-rr_t}{1-rr_t}\Big] \geq \Theta$,

then the constraint (34) does not bind and the (assets to equity) leverage ratio, defined as $\varphi_t \equiv \frac{(1-\lambda)S^B_t}{n_t}$, is indeterminate. Assuming instead that the constraint does bind, the value function is then:

$$V_{t-1} = E_{t-1}\mathrm{P}_{t-1,t}n_t\Big[\Big(1-\sigma_B\Big) + \sigma_B\Theta\frac{(1-\lambda)S^B_t}{n_t}\Big], \tag{35}$$

and therefore

$\Theta = E_t\Omega_{t+1}\mathrm{P}_{t,t+1}\Big\{\frac{R_{t+1}-rr_t}{(1-rr_t)(1-\lambda)S^B_t}n_t + \Big[\Big(1-\mu\Big)R^D_{t+1} + (1-F)R^L_t - \frac{R_{t+1}-rr_t}{1-rr_t}\Big]\Big\}$.

Aggregating (24), the balance sheet for the banking sector as a whole is:

$$(1-\lambda)S^B_t = N_t + \lambda(1-rr_t)S_t, \tag{36}$$

and its leverage ratio is:

$$\varphi_t = \frac{(1-\lambda)S^B_t}{N_t}. \tag{37}$$

The net worth of all the banks founded before time t which survive to period t is $N_{0,t}$, and it equals the earnings on all the assets S^B_{t-1} of all the banks that operated in the previous period, after subtracting the cost of deposit finance and complying with the reserve ratio requirement, multiplied by the survival probability σ_B:

$$N_{0,t} = \sigma_B\big\{(1-\lambda)\big[(1-\mu)R^D_t + (1-F)R^L_{t-1}\big]S^B_{t-1} - \lambda(R_t - rr_{t-1})S_{t-1}\big\}. \tag{38}$$

As in Gertler and Karadi (2011), new banks, those founded in period t, raise equity from households in an amount equal to the fraction $\xi_B/(1-\sigma_B)$ of the total value of assets held by banks that exited at the end of period $t-1$, which amounts to the fraction ξ_B of the total value of bank assets in $t-1$:

$$N_{n,t} = \xi_B\big\{(1-\lambda)\big[(1-\mu)R^D_t + (1-F)R^L_{t-1}\big]S^B_{t-1}\big\}. \tag{39}$$

Summing (38) and (39) yields the net worth of the banking sector:

$$N_t = (\xi_B + \sigma_B)\big\{(1-\lambda)\big[(1-\mu)R^D_t + (1-F)R^L_{t-1}\big]S^B_{t-1}\big\} - \sigma_B\lambda(R_t - rr_{t-1})S_{t-1}. \tag{40}$$

2.4. Firms

Firms in both the homogeneous nondurable final consumption sector and the housing sector operate in perfectly competitive markets with flexible prices. Producers in each sector purchase sector-specific intermediate goods that exist in a continuum and are imperfect substitutes, and produce them using a Dixit-Stiglitz aggregator:

$$Y^k_t = \Big[\int_0^1 (Y_t(i)^k)^{\frac{\sigma_k-1}{\sigma_k}}di\Big]^{\frac{\sigma_k}{\sigma_k-1}}, k = C, D, \tag{41}$$

where $\sigma_k > 1$ represents the price elasticity of substitution between intermediate goods.

The final goods firm chooses $Y_t(i)$ to minimize its costs, and so the demand function for intermediate good i is:

$$Y_t(i)^k = \left(\frac{P_t(i)^k}{P^k_t}\right)^{-\sigma_k}Y^k_t, \ \ k = C, D, \tag{42}$$

and the price index is:

$$P^k_t = \Big[\int_0^1 (P_t(i)^k)^{1-\sigma_k}di\Big]^{\frac{1}{\sigma_k-1}}, k = C, D. \tag{43}$$

The two markets for intermediate goods are monopolistically competitive and price setting is staggered as in Calvo (1983). In each period only a fraction $1-\theta_C(1-\theta_D)$ of intermediate goods producers in the nondurable (housing) sector receive a signal to re-optimise their price. For the remaining fraction $\theta_C(\theta_D)$, their prices are partially indexed to lagged sector-specific inflation (with a coefficient φ_C, φ_D in each sector). In both sectors, intermediate goods are produced solely with labour and subject to sector-specific stationary technology shocks Z^C_t and Z^D_t, each of which follows a zero-mean $AR(1)$ process in logs:

$$Y^k_t = Z^k_t L^k_t, \ \ k = C, D. \tag{44}$$

Cost minimization implies that real marginal costs in both sectors are:

$$MC^C_t = \frac{W^C_t}{Z^C_t}, \tag{45}$$

$$MC^D_t = \frac{W^D_t}{Q_t Z^D_t}. \tag{46}$$

Each intermediate goods producer solves a standard Calvo model profit-maximization problem with indexation described by a set of three equations:

$$J^C_t - \beta\theta^C E_t\left[\left(\frac{\Pi_{t+1}}{\Pi^{\varphi^C}_t}\right)^{\sigma}J^C_{t+1}\right] = \frac{MC^C_t Y^C_t}{C_t - \epsilon C_{t-1}}, \tag{47}$$

$$H^C_t - \beta\theta^C E_t\left[\left(\frac{\Pi_{t+1}}{\Pi^{\varphi^C}_t}\right)^{\sigma-1}H^C_{t+1}\right] = \left(1-\frac{1}{\sigma}\right)\frac{Y^C_t}{C_t - \epsilon C_{t-1}}, \tag{48}$$

$$J^D_t - \beta\theta^D E_t\left[\left(\frac{\Pi_{t+1}}{\Pi^{\varphi^D}_t}\right)^{\sigma}J^D_{t+1}\right] = \frac{MC^D_t Y^D_t}{D_t}, \tag{49}$$

$$H^D_t - \beta\theta^D E_t\left[\left(\frac{\Pi_{t+1}}{\Pi^{\varphi^D}_t}\right)^{\sigma-1}H^D_{t+1}\right] = \left(1-\frac{1}{\sigma}\right)\frac{Y^D_t}{D_t}, \tag{50}$$

$$1 = (1-\theta^k)\left(\frac{J^k_t}{H^k_t}\right)^{1-\sigma} + \theta^k\left(\frac{\Pi_t}{\Pi^{\varphi^k}_{t-1}}\right)^{\sigma-1}, \ \ k = C, D. \tag{51}$$

Producers of the intermediate good used in the production of the nondurable consumption good solve (47), (48) and (51), and their counterparts in the intermediate goods sector that supplies the housing sector solve (49), (50) and (51).

2.5. Monetary and macroprudential policy

The monetary authority sets the nominal interest rate by operating a Taylor-type rule:

$$log\left(\frac{R_t}{\overline{R}}\right) = \rho_r log\left(\frac{R_{t-1}}{\overline{R}}\right) + (1-\rho_r)\left(\rho_{r\pi} log\left(\frac{\Pi_t}{\overline{\Pi}}\right) + \rho_{ry} log\left(\frac{Y_t}{\overline{Y}}\right)\right) + \varepsilon_{M,t}. \quad (52)$$

Similarly, there is a separate macroprudential authority that imposes a required reserve ratio rr_t to limit the ability of banks to engage in risky lending. Traditionally, required reserve ratios have been imposed as a floor on bank reserves, but in recent years, with the introduction of negative interest rates on excess reserves, they also represent a type of ceiling. Reflecting this, the reserve requirement is a target relative to a steady-state reserve ratio $\overline{rr}$ set to 10%, which according to Gray (2011) is the average required reserve ratio for most countries that use a reserve ratio as a policy instrument. We also follow Rubio and Carrasco-Gallego (2015) in setting the macroprudential policy rule to include credit growth SB_t, relative house prices Q_t, and output Y_t to reduce systemic risk and promote macroeconomic stability:

$$log\left(\frac{rr_t}{\overline{rr}}\right) = \varphi_{rry} log\left(\frac{Y_t}{\overline{Y}}\right) + \varphi_{rrsb} log\left(\frac{SB_t}{\overline{SB}}\right) + \varphi_{rrq} log\left(\frac{Q_t}{\overline{Q}}\right) + \varepsilon_{rr,t}. \quad (53)$$

2.6. Market clearing conditions

In the nondurable sector, production is equal to demand by savers C_t and borrowers C_t^B:

$$Y_t^C = \lambda C_t + (1-\lambda) C_t^B. \quad (54)$$

Production in the housing goods sector is equal to the residential investments of savers and borrowers:

$$Y_t^D = \lambda I_t + (1-\lambda) I_t^B. \quad (55)$$

Total output is:

$$Y_t = Y_t^C + Q_t Y_t^D, \quad (56)$$

and the total hours worked in each sector equals the aggregate supply of labour:

$$\int_0^1 L_t^k dk = \lambda \int_0^1 L_t^{k,j} dj + (1-\lambda) \int_0^n L^{B,k,j} dj, \quad k = C, D. \quad (57)$$

Table 2
Calibrated structural parameters.

Parameters	Value	Definition
Households		
β	0.99	Discount rate for savers
β^B	0.96	Discount rate for borrowers
γ	0.7368	Share of nondurable consumption in utility
ϵ	0.72	External habit formation for savers
ϵ^B	0.46	External habit formation for borrowers
φ	0.37	Inverse elasticity of labour supply
ι_L	0.72	Cost of reallocating labour across sector
δ	0.0125	Depreciation rate
ψ	1.75	Investment adjustment cost
α	0.94	Size of nondurable sector in GDP
λ	0.61	Fraction of savers in total population
Firms		
θ_C	0.62	Calvo lottery nondurable goods
θ_D	0.64	Calvo lottery housing goods
φ_C	0.15	Indexation nondurable goods
φ_D	0.25	Indexation housing goods
σ_C	10	Elasticity of substitution nondurable goods
σ_D	10	Elasticity of substitution housing goods
Banks		
μ	0.2	Share of housing value paid to debt-collection agency
σ_B	0.9688	Proportion of bankers that survive
ξ_B	0.0026	Transfers to new bankers
Θ	0.3841	Proportion of divertable assets
Monetary and Macroprudential		
$\overline{rr}$	0.1	Steady-state reserve ratio
φ	4.0	Steady state leverage ratio
$spread$	0.0025	Interest spread target
ρ_r	0.8	Interest rate smoothing in Taylor rule
φ_π	1.56	Response to inflation in Taylor rule
φ_y	0.2	Response to output growth in Taylor rule

3. Calibration

3.1. Structural parameters

Table 2 lists the calibrated values of the 27 structural parameters in the model. Mostly, the parameter values match the quarterly data estimates in Quint and Rabanal (2014) for the core members of the euro area.[9] Parameters for the banking sector are calibrated using Gertler and Kiyotaki (2010). The probability σ_B is chosen so that the banks survive on average eight years (32 quarters). Parameters for divertable assets and transfers to new banks, Θ and ξ_B, respectively, are computed to match an economy-wide leverage ratio of four, an average credit spread of 100 basis points per year, and as mentioned above, a reserve ratio of ten percent.[10]

3.2. Stochastic parameters

The business cycle movements in this model are driven by seven stochastic shocks: to nondurable and housing preferences, nondurable and housing technology, housing risk,[11] monetary policy, and the reserve ratio. All follow an AR(1) process in logs.[12] The shock processes are calibrated using the estimates in Quint and Rabanal (2014) to match the standard moments of the euro area data and presented in Table 3.

3.3. Variance decomposition

To analyse the behaviour of the model, we start by decomposing the contribution of each of the six stochastic shocks to the variance of the model's most salient variables as presented in Table 4.[13] There are four

Table 3
Calibrated stochastic shocks.

Parameters	Value	Description
ρ_{ZD}	0.86	Productivity shock housing-autocorrelation
ρ_{ZC}	0.79	Productivity shock nondurable autocorrelation
ρ_{ξ^D}	0.98	Preference shock housing-autocorrelation
ρ_{ξ^C}	0.66	Preference shock nondurable-autocorrelation
ρ_ω	0.84	Idiosyncratic housing quality shock-autocorrelation
σ_{ZD}	0.0162	Productivity shock housing-standard deviation
σ_{ZC}	0.0062	Productivity shock nondurable-standard deviation
σ_{ξ^D}	0.0309	Preference shock housing-standard deviation
σ_{ξ^C}	0.0187	Preference shock nondurable-standard deviation
σ_ω	0.1179	Idiosyncratic housing quality shock-standard deviation
σ_M	0.0012	Monetary shock-standard deviation

[9] Except for β^B which is adopted from Pearlman (2015).

[10] The choice of a 10 percent reserve ratio matches the lowest required reserve ratios in emerging, middle- and low-income economies as shown in Table 1. We also consider a 30 percent reserve ratio to represent the required reserve ratios from 20 to 44 percent that prevail in Angola, Argentina, Liberia, Moldova, Nigeria, Suriname and Uruguay (also in Table 1).

[11] Housing quality shock is used to highlight the properties of house prices and returns which could be connected to asset price movements. Housing thus played an implicit role as part of payoffs and risk adjustment. As an example, the study of Andre et al. (2022) presents the possible connection between housing and asset price movements.

[12] The monetary policy shock is assumed to be white noise.

[13] Historically, central banks do not change reserve ratios frequently. Hence, when calculating the variance decomposition, we set it to a constant steady state value of 10% and exclude the macroprudentential rule (53).

Table 4
Variance decomposition.

	Contribution of each shock (in percent)					
	Nondurable goods productivity	Housing productivity	Nondurable goods preference	Housing preference	Housing risk	Monetary policy
Real GDP	18.76	1.81	35.94	30.99	11.55	0.96
Total loans	0.04	0.09	0.05	79.93	19.88	0.01
House prices	1.52	4.05	0.52	93.82	0.07	0.02
Total consumption	25.15	0.04	55.04	2.53	16.00	1.24
Total investment	0.02	18.61	0.05	80.83	0.44	0.04
House price inflation	5.99	27.29	2.93	55.82	6.61	1.36
Nondurable goods inflation	37.56	0.37	2.78	8.97	39.62	10.69
Lending rate	0.89	0.34	0.27	4.81	93.57	0.12
Policy rate	10.92	0.29	12.18	13.94	36.94	25.73
Reserve ratio	0.80	0.38	0.03	88.49	10.25	0.04
Banks net worth	0.40	0.57	0.11	16.43	82.44	0.06
Savers consumption	29.49	0.02	64.90	2.78	2.40	0.41
Borrowers consumption	5.69	0.07	12.96	9.36	70.47	1.44
Savers investment	0.08	29.99	0.18	67.48	2.22	0.04
Borrowers investment	0.05	5.47	0.04	88.11	6.13	0.20

shocks out of the six that generate nearly all the variance in real GDP, with 67% resulting from the two demand shocks (nondurable goods and housing preferences). In terms of the shocks associated with the housing sector, the demand shock for housing is the second most important, accounting for 30.99% of the variance. The shock to housing quality is 11.55%, while productivity in that sector accounts for only 1.59%. Taken together, the three shocks associated with housing account for nearly half (44.35%) the variance associated with the business cycle, matching the observations made in Leamer (2008) and Leamer (2015).

Shocks to the demand for housing generate 79.93% of the variance in credit, and together with the shock to housing quality drive nearly 100% of the credit cycle. Housing investment as a whole is largely driven by shocks to the demand for housing (81.60%) and then sector supply shocks (18.68%), but not by quality shocks. These results are also consistent with estimates by Musso et al. (2011) and Brzoza-Brzezina et al. (2015), which find that changes in monetary policy have little effect on housing investment, whereas shocks to housing quality generate more than half the variance in the policy interest rate. Indeed, outside of their direct impact on the policy rate, monetary shocks have little effect on the economy beyond their impact on the inflation rate for nondurable consumption. At the same time, the quality shocks account for nearly all the variance in the net worth of banks (82.44%) and the interest rate they charge borrowers (93.57%).

3.4. Static reserve requirements

Fig. 3 shows the distributive implications of operating the different levels of static reserve ratio in the stochastic model. A similar result for the steady state of the model is shown analytically in Appendix D, for a plausible range of parameters (for the case of no banking constraints, for simplicity). We now consider the model with a benchmark of monetary policy alone. We show that there is a welfare trade-off between borrowers and savers. In both cases, borrowers tend to enjoy welfare gains as the reserve ratio increases. By contrast, savers tend to experience lower welfare as the reserve ratio increases. In aggregate, total household welfare exhibits a minimal gain given that the gains by borrowers offset the losses by savers. These results underscore that a higher reserve ratio increases costs for banks, as only a portion of the available deposits can be used for lending activities. As banks have fewer funds to lend, they also reduce excessive risk-taking. By doing so, banks are able to eliminate extending loans to the worst of the subprime borrowers and reduce the probability of default, as shown in Fig. 4. However, banks accumulate less profits in the process, which are then remitted to savers as owners of banks. Savers also earn lower returns on deposits as fewer funds are intermediated. Meanwhile, worthy borrowers enjoy a stable flow of credit as the probability of default decreases with a higher reserve ratio. This reflects why savers experience welfare losses and borrowers increase welfare gains when the reserve ratio increases.

4. Model analysis

4.1. Optimal policy

What criterion should policy makers use to determine the parameter values in both (52) and (53)? One option is to follow Angelini et al. (2014) and make stabilisation of the economy the goal of monetary and macroprudential policy. Instead we opt for a policy that maximises a population-weighted aggregate measure of welfare across the two types

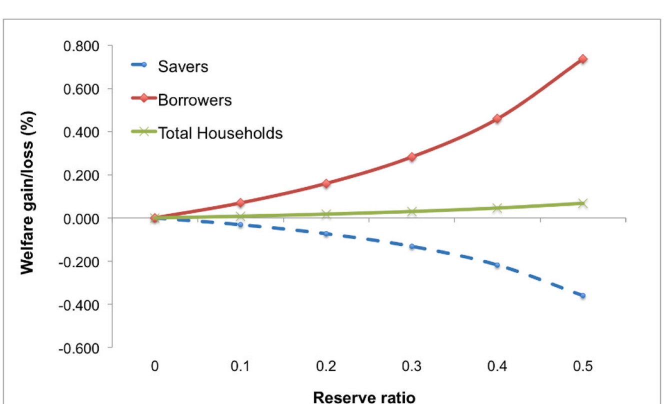

Fig. 3. Welfare in consumption equivalent in stochastic model.

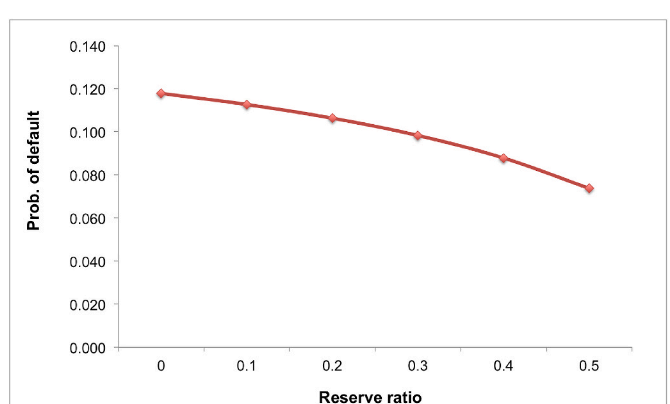

Fig. 4. Probability of default at different levels of reserve ratio.

of agents, and then consider the distributive welfare impact these policies generate.

First, we solve the benchmark version of the model—where neither monetary policy (other than the minimum necessary to eliminate indeterminacy) or macroprudential policy is employed—using second-order approximations, and then calculate individual utility measures for savers and borrowers:

$$\Omega_t^S \equiv \quad E_t\left\{\sum_{\tau=0}^{\infty}\beta^\tau\left[\gamma\xi_{t+\tau}^C log(C_{t+\tau}^j - \epsilon C_{t-1+\tau}) + (1-\gamma)\xi_t^D log(D_{t+\tau}^j) - \frac{(L_{t+\tau}^j)^{1+\varphi}}{1+\varphi}\right]\right\}, \tag{58}$$

$$\Omega_t^B \equiv \quad E_t\left\{\sum_{\tau=0}^{\infty}\beta^{B,\tau}\left[\gamma\xi_{t+\tau}^C log(C_{t+\tau}^{B,j} - \epsilon^B C_{t-1+\tau}^B) + (1-\gamma)\xi_{t+\tau}^D log(D_{t+\tau}^{B,j}) - \frac{(L_{t+\tau}^{B,j})^{1+\varphi}}{1+\varphi}\right]\right\}. \tag{59}$$

This process is then repeated, with the macroprudential policy using the reserve ratio activated, to generate the utility measures $\Omega^{i,RR}$, $i = B, S$. To calculate the welfare impact of implementing monetary (MP) or macroprudential policy (RR), or both (MPRR), in terms of consumption equivalents, we follow Ascari and Ropele (2012) and Rubio and Carrasco-Gallego (2014) to derive consumption equivalents—the constant fraction of consumption each type of agent would sacrifice in order to obtain the benefits of the policy:

$$CE^B = exp\left[(1-\beta^B)(\Omega^{B,j} - \Omega^B)\right] - 1, \; j \in \{MP, RR, MPRR\}, \tag{60}$$

$$CE^S = exp\left[(1-\beta)(\Omega^{S,j} - \Omega^S)\right] - 1, \; j \in \{MP, RR, MPRR\}, \tag{61}$$

and the total welfare effect, which is the population-weighted sum of the two:

$$CE = (1-\lambda)CE^B + \lambda CE^S. \tag{62}$$

Historically, central banks set both policy interest rates and required reserve ratios. However, in the wake of the 2008 financial crisis, governments have looked for tools beyond traditional monetary policy to help stabilise the economy, with special emphasis on the financial system. In the UK, these macroprudential tools are situated within the monetary authority—both the Financial Policy Committee and the Prudential Regulation Authority operate under the aegis of the Bank of England. By contrast, the Financial Stability Oversight Council in the US is chaired by the Secretary of the Treasury, and of the ten voting members only the Chairman of the Federal Reserve represents the central bank. The European Systemic Risk Board occupies a middle ground. It is independent of the European Central Bank but is chaired by its President. The vice president of the ECB is a voting member of the board, as are the governors of the Eurozone national central banks alongside a representative of the EU and several other European institutions. Given that the objective in this paper is for both policy makers to maximize average consumer welfare, this effectively leads to cooperation. However, we later examine what the effects of the various optimised policies are on plausible differing welfare loss functions for the two policy makers.

We compute the parameters associated with both the monetary (52) and macroprudential policy rules (53) that optimise total welfare (62) as in Quint and Rabanal (2014). Under the team solution, i.e. *cooperation*:

$$(\rho_r^{C*}, \varphi_\pi^{C*}, \varphi_y^{C*}, \varphi_{rry}^{C*}, \varphi_{rrsb}^{C*}, \varphi_{rrq}^{C*}) = argmaxCE(\rho_r, \varphi_\pi, \varphi_y, \varphi_{rry}, \varphi_{rrsb}, \varphi_{rrq}), \tag{63}$$

the two sets of parameters are optimised jointly.

It is no surprise that when macroprudential policy operates on its own (RR(10%) and RR(30%)), in the absence of active monetary policy, the parameters associated with this policy, φ_{rry}, φ_{rrsb} and φ_{rrq}, in (53) are larger than when macroprudential policy accompanies monetary policy (MPRR(10%) and MPRR(30%)). This is particularly the case for φ_{rrq}, which determines the response of the reserve ratio to deviations from steady-state house prices. By contrast, the parameters associated with the Taylor rule (52), ρ_r, φ_π and φ_y, appear larger when monetary policy operates alone (MP) rather than together with macroprudential policy.[14] The response of the central bank to inflation is nearly identical across the three regimes (MP, RR(10%) and RR(30%)) once we consider the impact of the higher rate of interest rate smoothing in the presence of macroprudential policy. However, the central bank should behave more aggressively when setting policy in response to deviations in output when it can do so in tandem with macroprudential policy.

4.2. Impulse response functions

We use the parameters in Table 5 to generate impulse response functions (IRFs) to the two of three shocks associated with the housing sector that together account for 43% of the variance in real GDP and nearly all the variance in loans in Table 4. We view these two variables (housing risk shock in Figs. 5 and 6 and housing demand shock in Figs. 7 and 8) as the main proxies for credit cycles. We also generate IRFs for shocks to technology and demand in the nondurable goods sector in Figs. 9–12, as they together account for 54.7% of the variance in GDP. In each case we consider how output, consumption, prices, loan activity, investment, interest rates and banks' net worth vary, differentiating between the impact of policy on the behaviour of borrowers and savers when monetary policy operates alone (MP), macroprudential policy operates on its own with steady-state reserve requirements of 10% (RR (10%)) and 30% (RR(30%)), and where monetary and macroprudential policy operate in tandem with steady-state reserve requirements of 10% (MPRR(10%)) and 30% (MPRR(30%)). All are juxtaposed against a baseline case of no policy (NP), where there is no macroprudential policy or required reserve ratio and the policy rate is fixed at a constant real value.[15]

Figs. 5 and 6 show what happens when the standard deviation of

Table 5
Optimising parameters.

	Policy rule coefficients					
	ρ_r	φ_π	φ_y	φ_{rry}	φ_{rrsb}	φ_{rrq}
NP baseline	0	1.0001	0	0	0	0
MP	0.466	1.054	0.069	0	0	0
MP(10%)	0.466	1.054	0.069	0	0	0
MP(30%)	0.466	1.054	0.069	0	0	0
RR(10%)	0	1.0001	0	0.634	0.496	1.092
RR(30%)	0	1.0001	0	0.634	0.496	1.092
MPRR(10%)	0.653	1.736	0.171	0.370	0.257	0.326
MPRR(30%)	0.646	1.742	0.181	0.359	0.246	0.318

NP means no policy (policy rate is fixed at an almost constant real value using a MP rule that just eliminates indeterminacy). MP means monetary policy only. RR means only reserve ratio rule operates. MPRR means monetary policy plus reserve ratio rule.

[14] The response of policy to output and inflation shocks is larger given that the relevant coefficients are multiplied by 1-ρ_r.

[15] For the case of no policy (NP) and macroprudential policy alone (RR(10%) and (RR(30%), we set the coefficients in (52): $\rho_r = 0$, $\rho_{ry} = 0$ and $\rho_{r\pi} = 1.0001$, keeping the real policy rate nearly fixed while ensuring saddle path stability of the economy. The IRFs in Figs. 5–12 are calculated for 20 quarters. The IRFs for 100 quarters, Figs. 13, 14 and 17–20, and 200 quarters, Figs. 15 and 16 can be found in the Appendix, Section E.

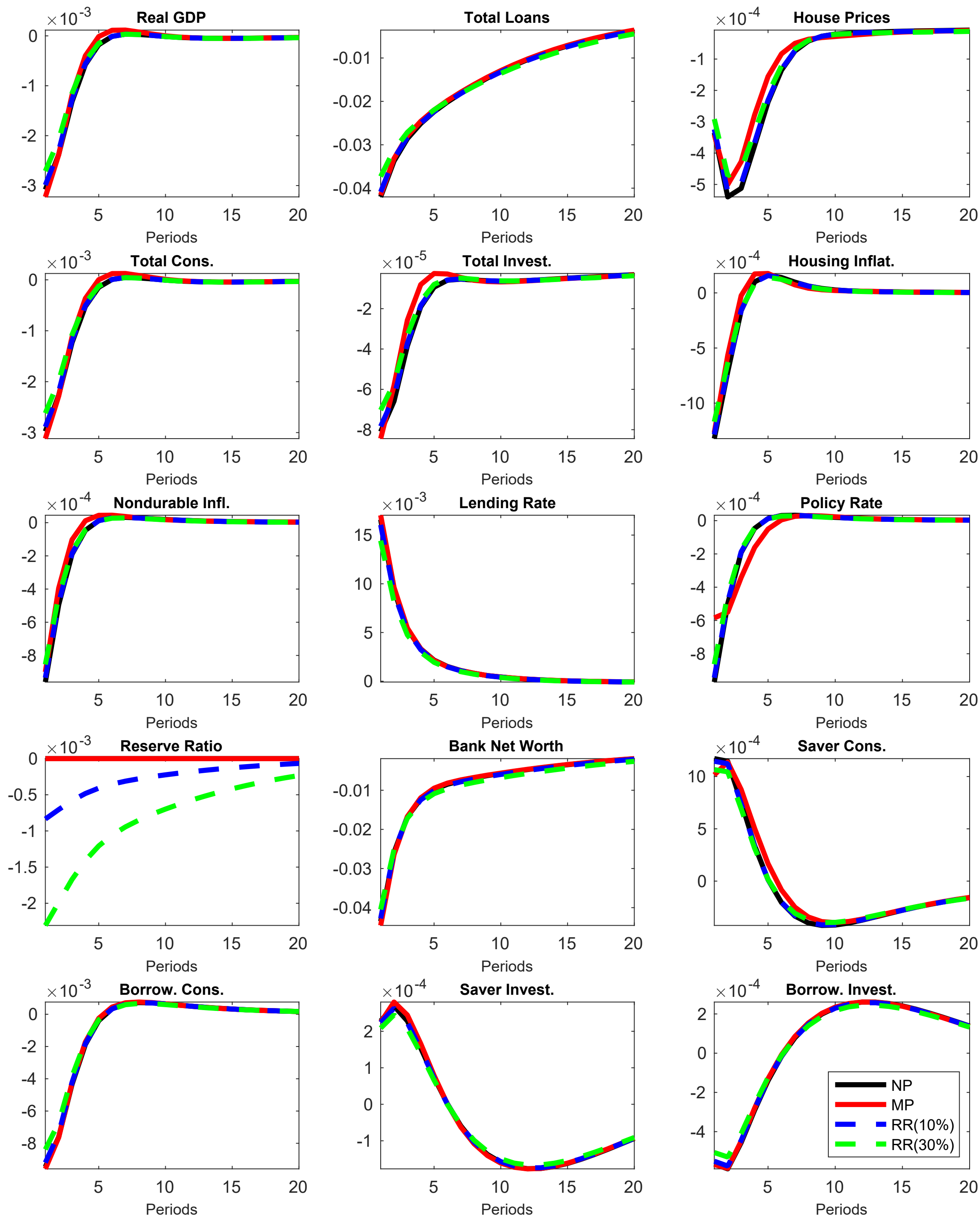

Fig. 5. IRFs with housing risk shock (deviations from steady state).

housing quality in (17) temporarily increases due to a shock equivalent to 11.79% (one standard deviation in the shock process). The distribution of housing quality becomes more skewed to the left, prompting more borrowers to default on their loans. Banks' net worth declines, and their balance sheets deteriorate. As their leverage ratios increase, banks offer fewer new loans and charge higher interest rates. Though savers take advantage of the decline in house prices and invest in more housing, this is not enough to compensate for the decline in borrowers' investment and, overall, fewer houses are built.[16] Output drops and so does inflation, prompting a decline in the policy rate and further increasing

[16] Figs. 13 and 14 show that over the course of the first decade, investment by borrowers and particularly savers, oscillate around their steady state values in response to the risk shock.

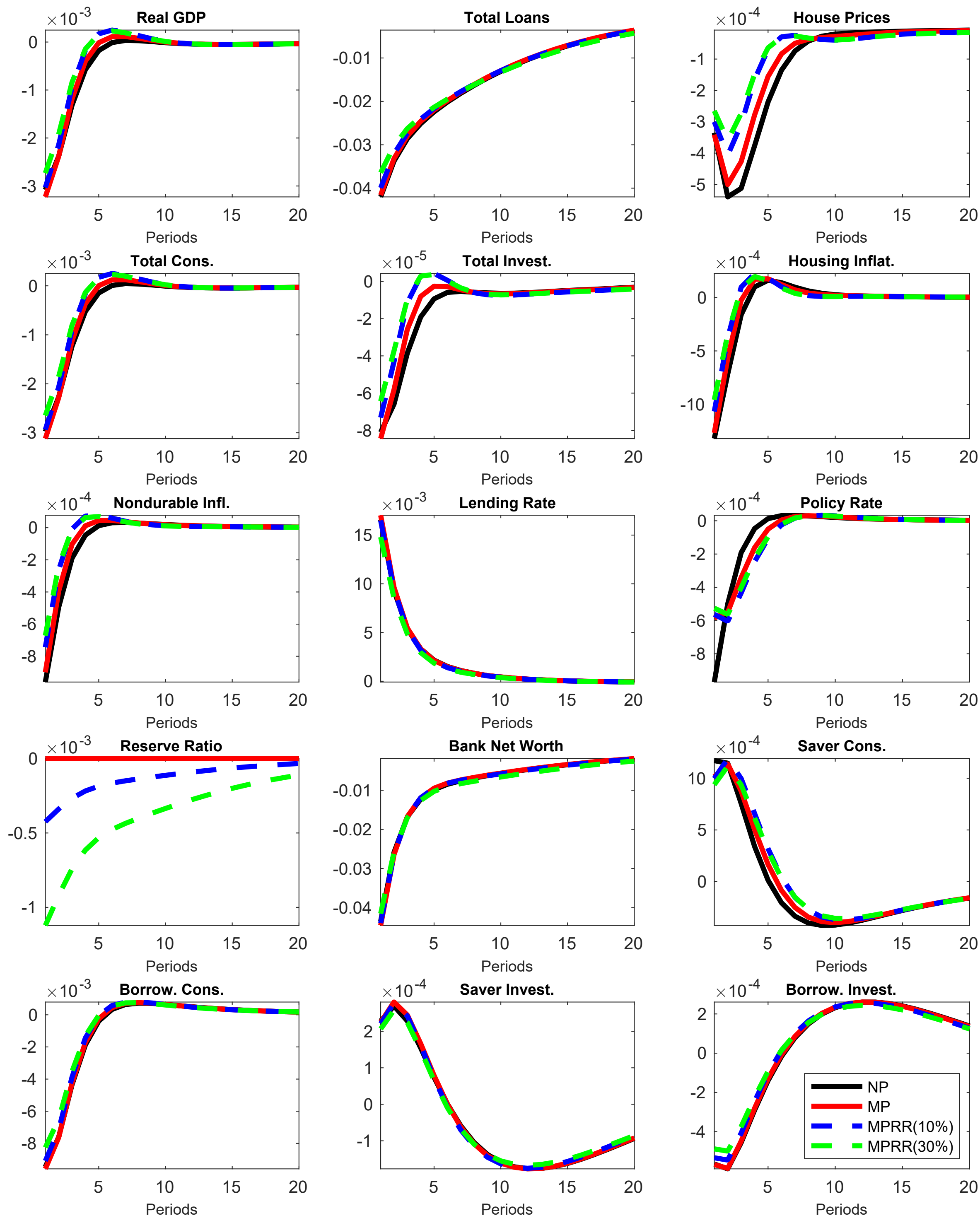

Fig. 6. IRFs with housing risk shock (deviations from steady state).

the interest spread.

When monetary policy operates alone, the high coefficient on inflation and low coefficient on output in the optimised rule in Table 5 means that the central bank immediately lowers the policy rate by 5.4 basis points and keeps it there for an additional period in the second period in response to the 0.08% drop in nondurable goods inflation. By contrast, if the policy rate is kept fixed at its steady state real value, the drop in inflation is greater and so is the initial response. However, the policy rate recovers more quickly, whereas when the Taylor rule operates, the policy rate remains low for longer.

Fig. 5 also demonstrates that macroprudential policy, even if it operates completely on its own, stabilises the economy by dampening the financial accelerator mechanism, thus performing a role similar to monetary policy. However, the negative risk shock has a differential impact on savers and borrowers; despite the decline in output, consumption of the former increases on impact and remains high for six quarters while borrowers' consumption bears the full impact of the downturn. A policy that relies on macroprudential policy only to stabilise the economy slightly ameliorates this effect. Macroprudential policy, either on its own, where the reserve requirement drops on impact

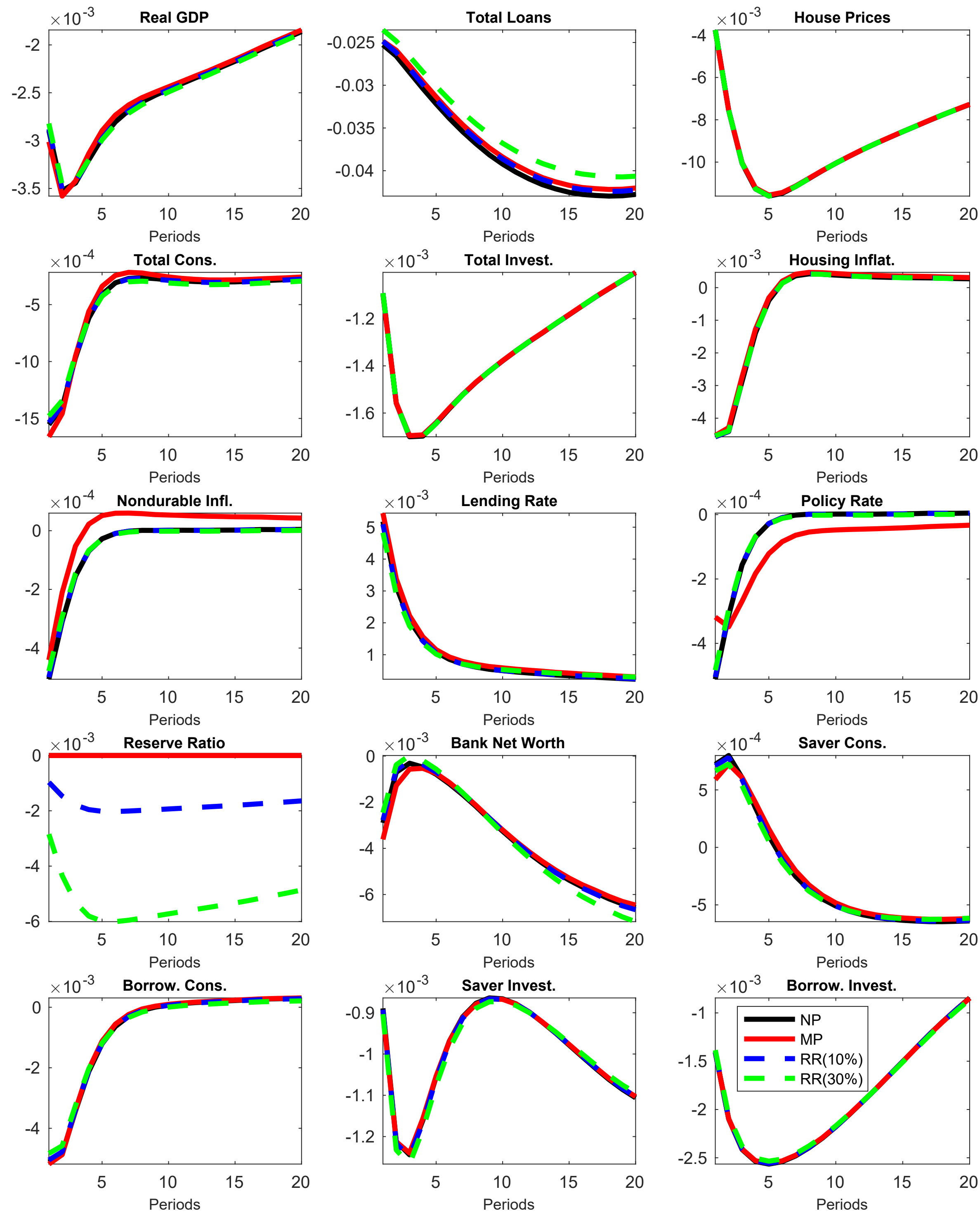

Fig. 7. IRFs with housing demand shock (deviations from steady state).

from 10% to 9.92% or from 30% to 29.78%, or when combined with monetary policy (MPRR(10%) and MPRR(30%)) in Fig. 6, where the reserve requirement drops on impact from 10% to 9.96% or from 30% to 29.89%, stabilises the economy and more generally, as we shall see in Section 4.3, also generates a small overall welfare benefit to borrowers at the expense of savers. This differential impact accelerates as the ratio shifts higher from 10% to 30%, as it does when reserve ratios are static in Fig. 3.

Figs. 7 and 8 show the response of the economy to a negative one standard deviation shock to the housing preference parameter. The initial impact on GDP is similar to the impact from the risk shock, but GDP carries on declining for another quarter. Overall, the impact of the demand shock lasts for a very long time, far longer than the impact from the risk shock, and so the recovery is much slower (see Figs. 15 and 16). Total investment drops on impact by 0.1% and then continues to decline for another three quarters before slowly recovering. Total loans decline on impact and then carry on declining for 21 quarters before they begin to recover, but even after 100 quarters they are still 1.06% below their steady- state level, and banks' net worth is still only three-quarters of the way recovered from its lowest point in quarter 30.

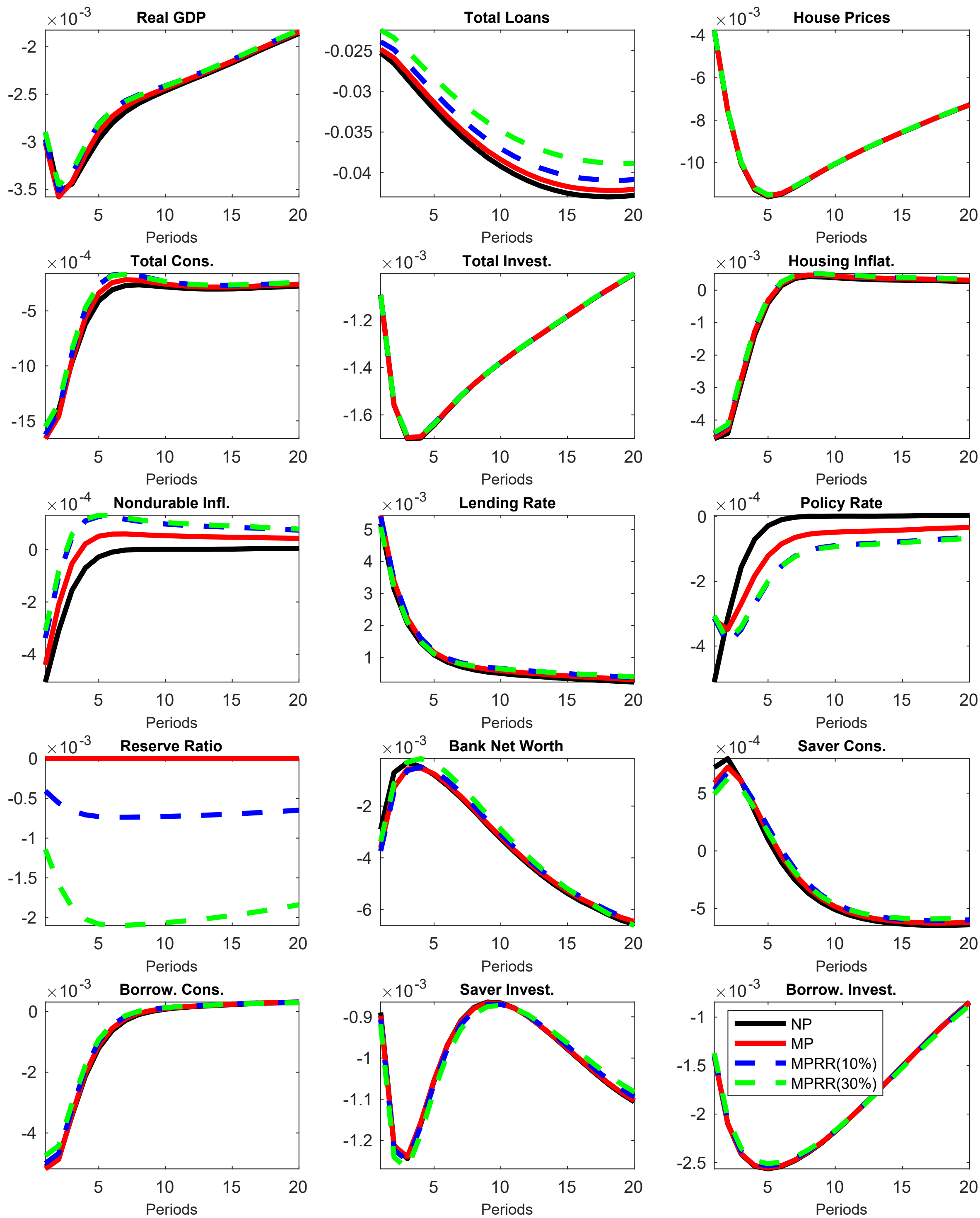

Fig. 8. IRFs with housing demand shock (deviations from steady state).

House prices drop, causing the value of collateral to decline. This triggers a higher default probability, immediately decreasing banks' net worth. However, the countervailing impact of the sharp 50 basis points increase in the lending rate means that initially, net worth recovers during the first four quarters, before declining once again for another 23 quarters before beginning to recover. As is the case for the risk shock, the demand shock on investment causes investment in housing, disaggregated between savers and borrowers, to oscillate for years to come. On impact, investment by savers declines by 0.1%, then declines still further for two more periods, reaching 0.13% below its steady-state value. It then recovers so that by the tenth quarter it is 0.86% below steady state. It then declines once again for a further 19 quarters (Figs. 15 and 16) before finally converging back to steady state.

The long-lasting impact of the demand shock on the housing and banking sectors means that whereas the monetary authority will respond with a sharp but short-lived drop in the policy rate, the response of macroprudential policy will leave reserve requirements below their steady-state values for decades. When macroprudential policy operates alone, the reserve ratio requirement drops on impact from 10% to 9.9% or from 30% to 29.7% and then declines further for another three

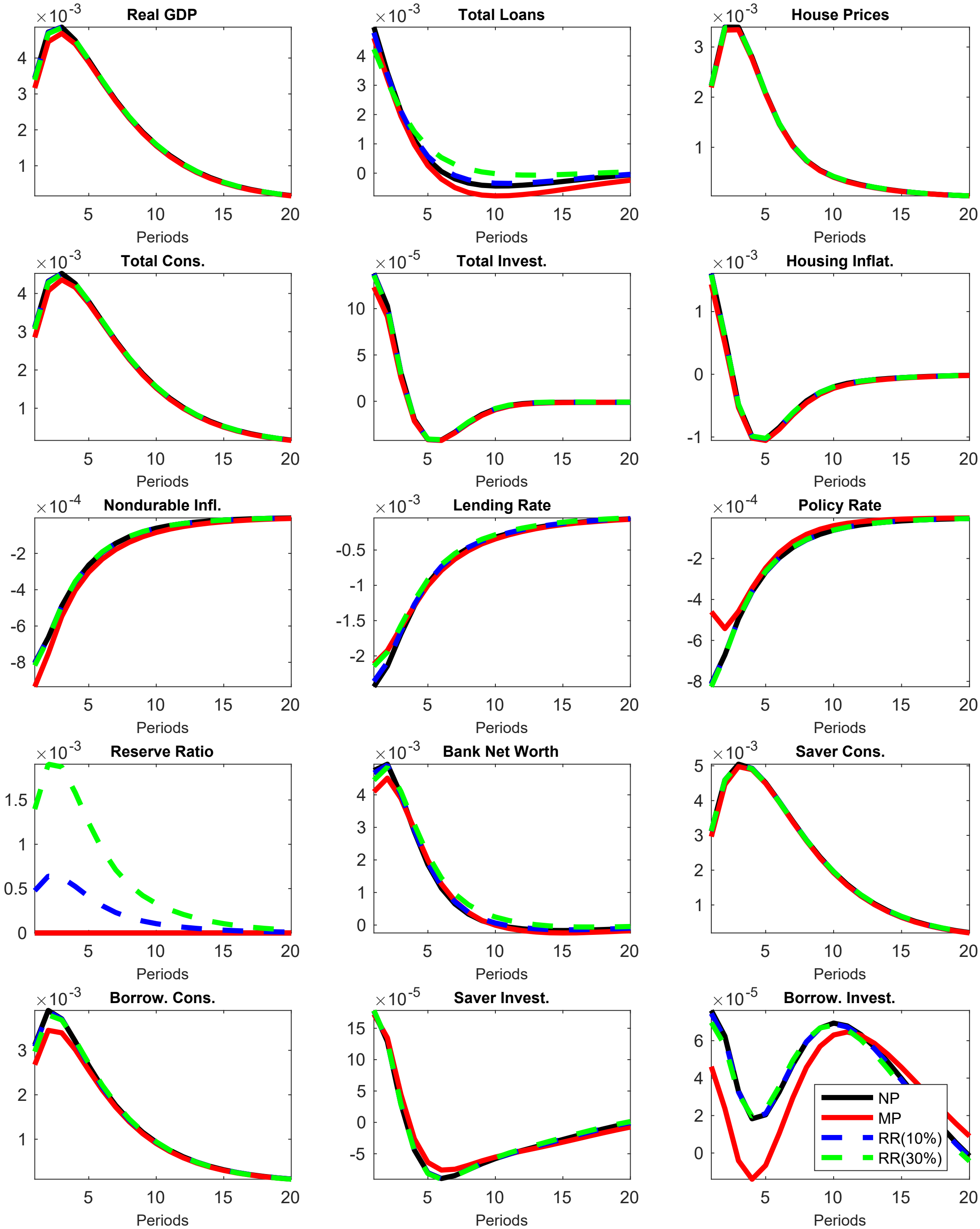

Fig. 9. IRFs with nondurable technology shock (deviations from steady state).

quarters till it reaches 9.8% (RR(10%)) or 29.4% (RR(30%)). Even after 40 quarters the reserve requirements are still 9.9% and 29.7%, respectively.

Neither macroprudential policy nor monetary policy when operating in the absence of the other are able to do much to mitigate the impact of the demand shock. Only when they operate in tandem, in Fig. 8, is there a discernible impact on the economy—particularly in reducing the drop in total loans. This happens because though the reserve requirements drop less than when macroprudential policy operates without monetary policy, the presence of macroprudential policy prompts the central bank to lower its policy rate more aggressively and for longer than it would choose to do if it were operating alone. While the impact of the demand shock on house prices is an order of magnitude larger than the impact generated by a risk shock, macroprudential policy is only effective in mitigating the latter.

Turning to the nondurable goods sector, Figs. 9 and 10 show the response of the economy to a positive one standard deviation shock to nondurable technology. As is the case for other models with habit persistence in consumption (Christiano et al. (2005), Smets and Wouters (2007) and Leith et al. (2012)), the shock produces the hump-shaped

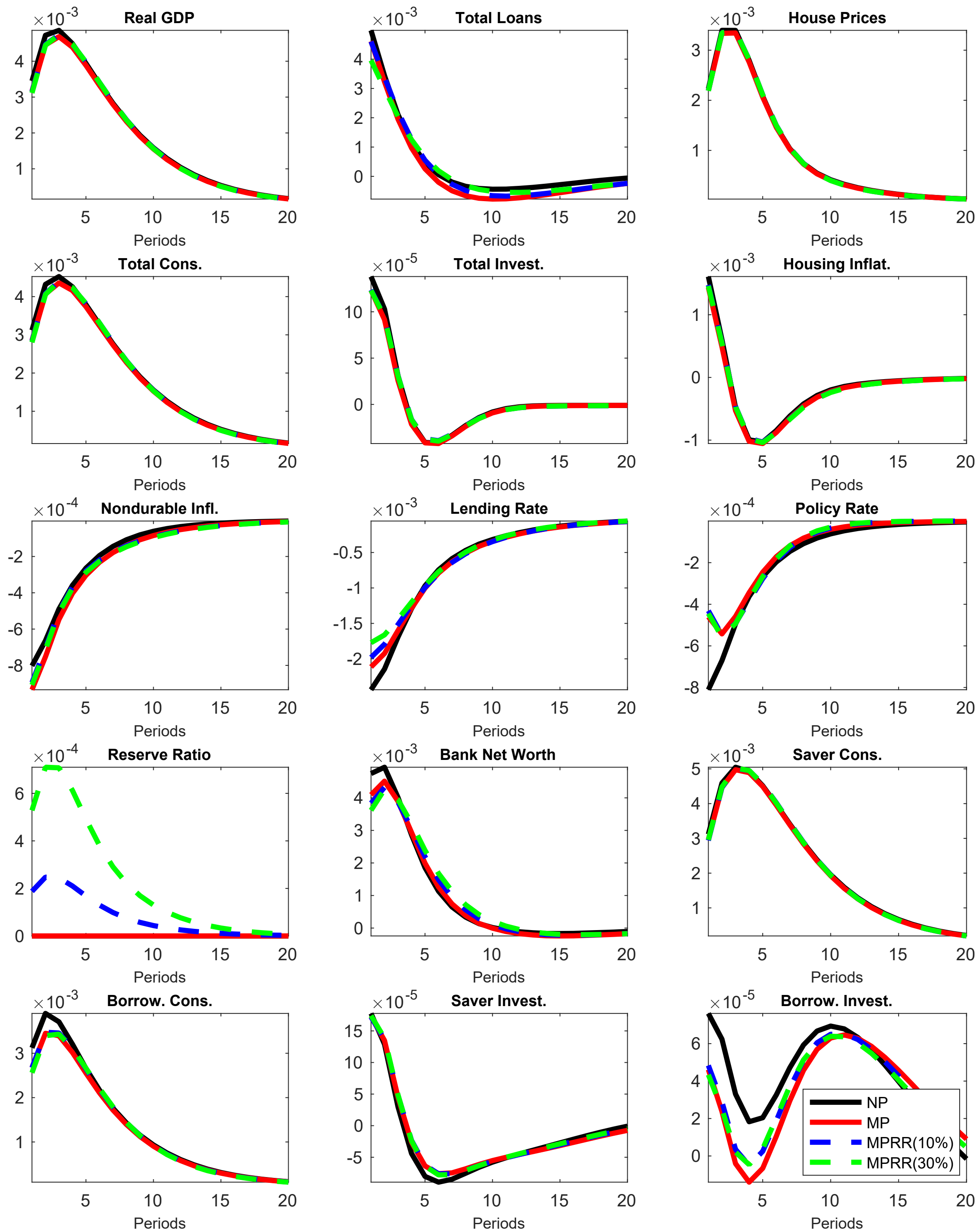

Fig. 10. IRFs with nondurable technology shock (deviations from steady state).

rise in output that resembles that generated by VAR models.

Nondurable inflation falls on impact due to the decline in real marginal costs, while the relative price of houses increases. The distribution of housing quality becomes less skewed to the left, prompting fewer borrowers to default on their loans. Banks' net worth increases, and their balance sheets improve. As their leverage ratios decrease, banks offer more loans and charge lower interest rates. Both savers and borrowers increase consumption and investment. In the case of the latter, the shock generates particularly long-lasting oscillations in investment, as seen in Figs. 17 and 18.

As with demand shocks, neither macroprudential policy nor monetary policy, when operating in the absence of the other, are able to do much to mitigate the impact of a nondurable technology shock in Fig. 9. Note in particular that the response of monetary policy to the positive shock is expansionary—though output increases, the central bank responds more aggressively to the drop in inflation and lowers the policy rate by 4.5 basis points. As house prices, credit and output all increase, the macroprudential authority does implement countercyclical policy,

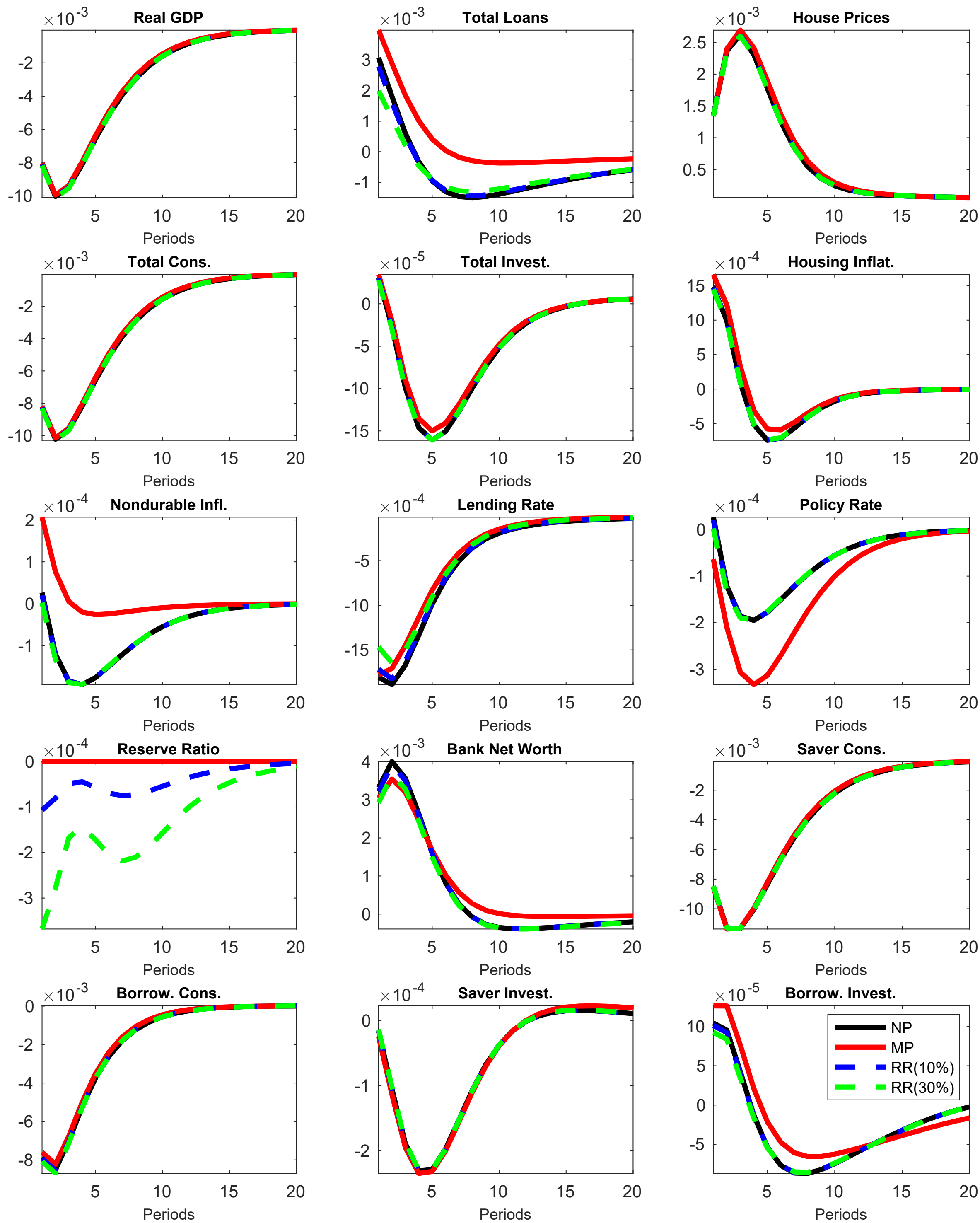

Fig. 11. IRFs with nondurable demand shock (deviations from steady state).

by raising the reserve ratio to 10.05% (RR(10%)) or 30.14% (RR(30%)) in the absence of monetary policy and 10.02% (MPRR(10%)) or 30.05% (MPRR(30%)), moderating somewhat the impact of the shock on banks' net worth, the lending rate and the total amount of lending.

Finally, in Figs. 11 and 12 we consider the impact of a negative demand shock in the nondurable sector. The negative impact on consumption for savers and borrowers is roughly similar, though the latter do recover more quickly. House prices increase on impact by 0.13% and increase further till the fourth quarter, when they reach 0.24% above their steady state value. Rather than substitute from nondurable consumption to housing in response to the shock, the higher prices are enough to deter savers from investing in housing—they choose more leisure instead. At the same time the lending rate declines by 18 basis points—enough to induce borrowers to invest in what are temporarily more expensive homes.

Unlike the case for the technology shock, here the demand shock on nondurable inflation generates countercyclical declines in both the policy rate and the reserve ratio in Fig. 11. Furthermore, particularly in the case of monetary policy, the two appear to reinforce each other. Hence, by the fourth quarter the policy interest rate drops by 3 basis

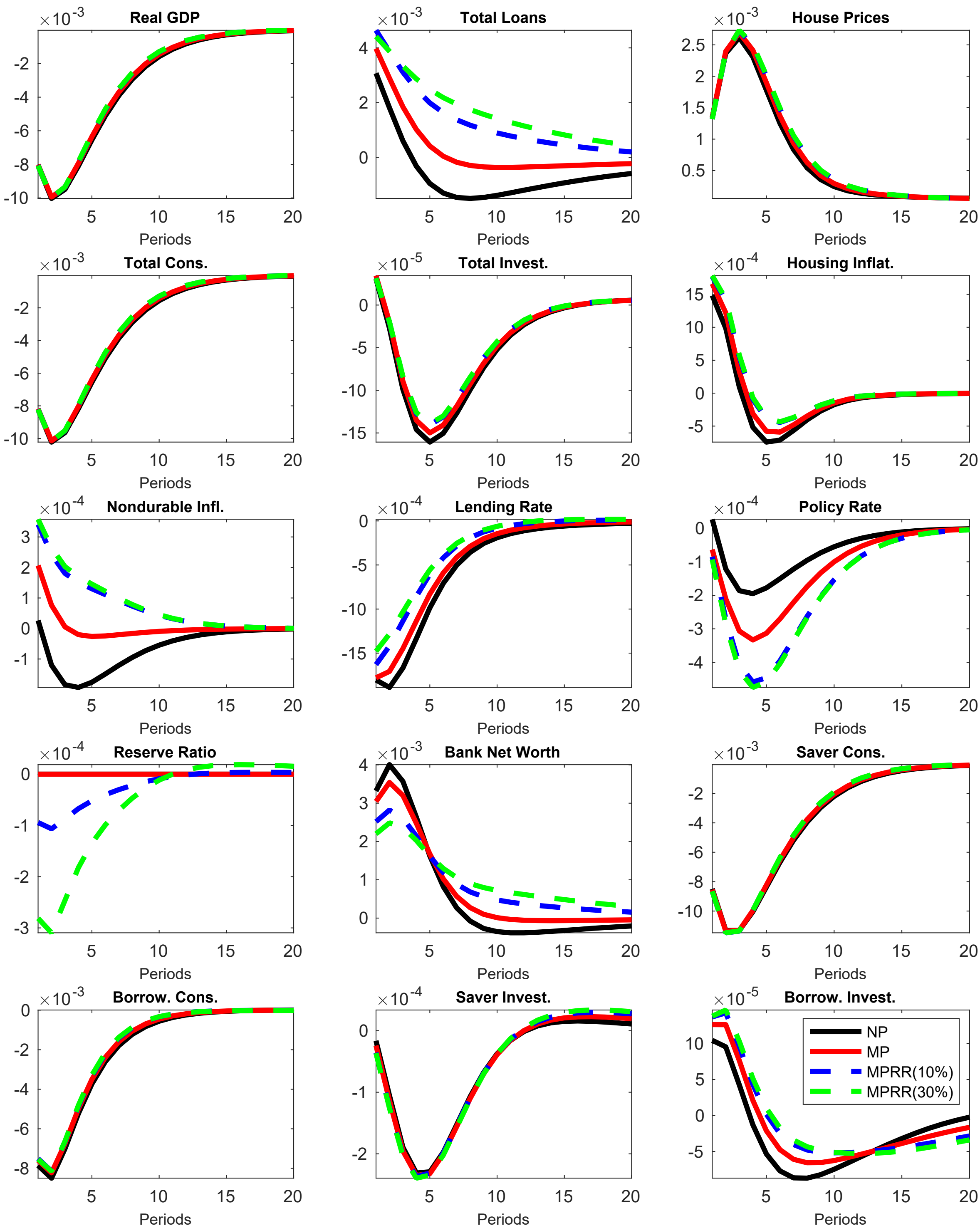

Fig. 12. IRFs with nondurable demand shock (deviations from steady state).

points if monetary policy operates in isolation and 5 basis points if macroprudential policy is activated as well. This effect compounds the increase in total loans and nondurable inflation but smooths the impact of the shock on banks' net worth and borrowers' investment.

4.3. Welfare

Monetary policy, when analysed in New Keynesian models, is generally found to mitigate, but only to a small degree, the negative impacts on agents' welfare generated by stochastic shocks to the economy (Rubio and Carrasco-Gallego (2015); Gertler et al. (2012); Cantore et al. (2019); Tayler and Zilberman (2016); Levine et al. (2012)). Here, the limited efficacy of monetary policy is even more acute—in Table 6 implementation of the optimised Taylor rule (52) yields an overall welfare benefit equivalent to only a 0.001% permanent increase in consumption for both types of agents. Why so small? In steady state, savers spend 47% and borrowers 52% of their incomes on nondurable goods, and the rest is invested in housing. Nonetheless, we assume the central bank's optimal Taylor rule only responds to the rate of nondurable goods inflation, as this is the closest analog to rates of

Table 6
Interaction of monetary policy and macroprudential regulation.

Model	Consumption equivalent welfare(%)		
	Savers	Borrowers	Total
MP	0.001	0.001	0.001
MP(10%)	−0.040	0.075	0.005
MP(30%)	−0.167	0.301	0.015
RR(10%)	−0.041	0.073	0.003
RR(30%)	−0.170	0.301	0.014
MPRR(10%)	−0.040	0.078	0.006
MPRR(30%)	−0.168	0.307	0.017

change in the traditional consumer price index. Under these circumstances, introducing a housing sector lessens the scope for traditional monetary policy tools to improve welfare.

Adding a fixed reserve requirement alongside monetary policy generates a larger effect on total welfare and a significant differential impact on borrowers and savers. The consumption equivalent welfare gain to borrowers is 0.075% at the expense of a 0.04% loss to savers if the reserve requirement is fixed at 10% (MP(10%)) and a 0.301% gain for borrowers at the expense of a 0.167% loss if fixed at 30% (MP(30%)). At the baseline steady state reserve requirement of 10%, the total impact on welfare of macroprudential policy, either on its own (RR(10%)) or in conjunction with monetary policy (MPRR(10%)), reaches consumption equivalents of 0.003% or 0.006% respectively. If the steady state reserve requirement is set as high as 30%, the consumption equivalents are 0.014% and 0.017%, well over an order of magnitude higher than the impact of monetary policy alone. Moreover, these are the net effects from aggregating across our two types of agents and obscures the policy's differential impact. The small total welfare effects are the residual gains that accrue to the economy's borrowers from macroprudential policy, after the losses suffered by the economy's savers are accounted for. Macroprudential policy alone generates a benefit to borrowers equivalent to 0.073% (0.301%) of permanent consumption at the expense of savers, who suffer a loss equivalent to 0.041% (0.170%) for RR(10%) (RR(30%)). The addition of monetary policy improves these welfare effects to only a marginal degree. These are still small numbers, but they demonstrate that once we incorporate housing and banks into our model, macroprudential policy alone is more effective than monetary policy in mitigating the welfare effects of shocks. Combining monetary policy with either a fixed reserve ratio, or better still, macroprudential policy is the best way to raise total welfare.

4.4. The loss functions of policy authorities

Beyond welfare, how much can these different regimes reduce the volatility of key macroeconomic and financial variables? In Table 7, total loans volatility falls from 28.3% in the no-policy case to 27.7% when monetary policy is introduced. Meanwhile, introducing a fixed reserve requirement in addition to monetary policy with no macroprudential policy being activated reduces total loan volatility to 27.5% and 26.6% in MP(10%) and MP(30%), respectively. Macroprudential policy applied on its own reduces this to 28.0% (26.8%) in RR (10%) (RR(30%)). When the two policies are combined the volatility of total loans declines to 26.9% (25.8%) in MPRR(10%) (MPRR(30%)). Monetary policy alone also reduces volatility of output and house prices, and reduces it further if combined with macroprudential policy. However these policies also exacerbate the volatility of inflation.

To better understand these trade-offs we compute the loss functions for monetary and macroprudential policy as in Angelini et al. (2014). The macroprudential policy maker minimises the volatility of credit growth, output, and —to maintain consistency with (53)—house prices as well:

$$L^{MaP} = \sigma^2_{SB} + \sigma^2_Q + \kappa_{Y,MaP}\sigma^2_Y + \kappa_{rr}\sigma^2_{\Delta_{rr}}, \tag{64}$$

where σ^2_i represents the asymptotic variance of the target variables, while parameters $\kappa_{Y,MaP} \geq 0$ characterize the policy maker's preferences over output. As in Angelini et al. (2014), we set $\kappa_{rr} = 0.1$— they demonstrate it must be strictly positive to ensure that the policy instrument is not too volatile. The monetary policy loss function is:

$$L^{MP} = \sigma^2_\pi + \kappa_{Y,MP}\sigma^2_Y + \kappa_R\sigma^2_{\Delta R}, \tag{65}$$

and as in Angelini et al. (2014), we set $\kappa_{Y,MP} = 0.5$ and $\kappa_R = 0.1$.

In Table 7 we see how the reduction in the loss function is largest when monetary and macroprudential policy operate together and the reserve ratio is highest. Whether it is feasible to impose a reserve requirement as high as 30% is beyond the scope of our analysis. Yet it is encouraging to note that when combined with monetary policy, macroprudential policy with a low steady state reserve requirement MPRR (10%)—similar to the observed reserve ratio in the Eurozone—achieves a reduction in the loss function nearly as large as macroprudential policy when it operates on its own with the much higher reserve requirement RR(30%).

5. Conclusion

The GFC demonstrated the role financial markets can play as both sources and propagators of shocks to the aggregate economy. It also demonstrated how vulnerable the financial sector can be to downturns in one particular sector—housing. Researchers have responded by building models that explicitly incorporate the unique role of banks as financial intermediaries and distinguishing between nondurable consumption and investment in housing, which must be financed by mortgage borrowing. For policy makers, particularly central bankers, the GFC demonstrated that standard monetary policy tools may be inadequate to stabilise an economy if they cannot keep the banking system solvent. A variety of new macroprudential policy tools have been developed to overcome this problem. Required reserve ratios were designed for the narrow purpose of preventing bank runs, but as we

Table 7
Loss functions.

Model	Volatility (%)						Loss Functions		
	π	Y	ΔR	SB	Q	Δrr	MP	MaP	MaP
								$\kappa_{Y,MaP} = 0$	$\kappa_{Y,MaP} = 0.25$
NP	0.179	3.053	0.203	28.295	5.461	0.000	4.696	830.409	832.739
MP	0.190	3.000	0.186	27.739	5.454	0.000	4.539	799.198	801.448
MP(10%)	0.189	3.000	0.186	27.476	5.453	0.000	4.538	784.683	786.933
MP(30%)	0.185	3.000	0.183	26.625	5.452	0.000	4.537	738.640	740.889
RR(10%)	0.178	3.054	0.201	27.976	5.461	1.118	4.698	812.592	814.923
RR(30%)	0.173	3.056	0.197	26.849	5.460	3.311	4.702	751.761	754.095
MPRR(10%)	0.191	2.982	0.213	26.937	5.448	0.440	4.487	755.311	757.534
MPRR(30%)	0.192	2.974	0.213	25.795	5.447	1.252	4.462	695.193	697.403

Note: The volatility of the select variables are computed from a 1000-period simulation having all shocks active.

demonstrate, can also be deployed as a macroprudential tool.

Our DSGE framework combines housing default with reserve requirements. We use this model to examine how the interaction between monetary policy and reserve requirements affect: (i) the credit and business cycle; (ii) the distribution of welfare between savers and borrowers; and (iii) aggregate welfare when these policies are optimised together or separately.

Our results show there are potential distributive implications surrounding the imposition of different levels of required reserve ratios—borrowers gain at the expense of savers. These results suggest that a higher reserve ratio increases costs for banks, inducing them to restrict loans to subprime borrowers to reduce their losses from defaults. Less financial intermediation means that savers earn lower returns on deposits, while eligible borrowers enjoy a stable flow of credit—the probability of default is inversely related to the reserve ratio. Furthermore, we demonstrate that macroprudential policy, even if it operates completely on its own, stabilises the economy in response to a negative risk shock, by dampening the financial accelerator mechanism. At the same time, neither macroprudential policy nor monetary policy, when operating in isolation, can ameliorate the impact of a demand shock in the nondurable sector. Only when the two operate in tandem do we observe a discernible effect on the economy—particularly in mitigating the drop in lending. While the welfare effects of introducing macroprudential policy, either on its own or in conjunction with monetary policy, are generally small, it is still more effective than monetary policy alone in mitigating welfare losses from shocks. The highest welfare gains are achieved by combining monetary policy with a macroprudential policy that sets a high required reserve ratio.

While the results show that the reserve ratio can influence credit and real economic activity, the magnitude of that impact will depend on the specific characteristics of the economy. Future work should incorporate occasionally binding constraints to model the implications of an effective lower bound on nominal interest rates. At the same time, this work suggests that policy makers might want to rethink eliminating required reserve requirements and instead retain them as a macroprudential policy tool.

Declaration of competing interest

There are no conflicts of interest - neither direct nor indirect.

Appendices

A. Saver's optimisation problem

To solve the savers problem we have

$$L = E_0\left\{\sum_{s=0}^{\infty}\beta^s\left[\gamma\xi^C_{t+s}log(C_{t+s}-\epsilon C_{t+s-1})+(1-\gamma)\xi^D_{t+s}log(D_{t+s})-\frac{(L_{t+s})^{1+\varphi}}{1+\varphi}\right]+\varrho_{t+s}\left\{\frac{R_{t+s-1}S_{t+s-1}}{\Pi^C_{t+s}}+W^C_{t+s}L^C_{t+s}+W^D_{t+s}L^D_{t+s}+\Pi_{t+s}-C_{t+s}-Q_{t+s}I_{t+s}-S_{t+s}\right.\right.$$
$$\left.\left.+\left[\left(1-\delta\right)D_{t+s-1}+\left[1-F\left(\frac{I_{t+s}}{I_{t+s-1}}\right)\right]I_{t+s}-D_{t+s}\right]\right\}\right. \tag{A.1}$$

The FOCs with respect to C_{t+s}, S_{t+s-1}, D_{t+s}, I_{t+s} and L_{t+s} are the following:

$$C_{t+s}: E_t\left[\frac{\gamma\xi^C_{t+s}}{C_{t+s}-\epsilon C_{t+s-1}}-\beta^s\varrho_{t+s}\right]=0; s\geq 0 \tag{A.2}$$

$$S_{t+s-1}: E_t\left[\beta^s\varrho_{t+s}\frac{R_{t+s-1}}{\Pi^C_{t+s}}-\beta^{s-1}\varrho_{t+s-1}\right]=0; s>0; (S_{t-1}given) \tag{A.3}$$

$$D_{t+s}: E_t\left[\frac{(1-\gamma)\xi^D_{t+s}}{D_{t+s}}-\beta^s\varrho_{t+s}+\beta^{s+1}\varrho_{t+s+1}(1-\delta)\right]=0; s\geq 0 \tag{A.4}$$

$$I_{t+s}: E_t\left[-\beta^s\varrho_{t+s}Q_{t+s}+\beta^{s+1}\varrho_{t+s+1}\left[1-F\left(\frac{I_{t+s}}{I_{t+s-1}}\right)-F'\left(\frac{I_{t+s}}{I_{t+s-1}}\right)\frac{I_{t+s}}{I_{t+s-1}}\right]\right.$$
$$\left.+\beta^{s+2}\varrho_{t+s+2}F'\left(\frac{I_{t+s+1}}{I_{t+s}}\right)\left(\frac{I_{t+s+1}}{I_{t+s}}\right)^2\right]=0; s\geq 0 \tag{A.5}$$

$$L^C_{t+s}: E_t[\alpha^{-\iota_L}L^{\varphi-\iota_L}_{t+s}(L^C_{t+s})^{\iota_L}-\varrho_{t+s}W^C_{t+s}]=0; s\geq 0 \tag{A.6}$$

$$L^D_{t+s}: E_t[(1-\alpha)^{-\iota_L}L^{\varphi-\iota_L}_{t+s}(L^D_{t+s})^{\iota_L}-\varrho_{t+s}W^D_{t+s}]=0; s\geq 0 \tag{A.7}$$

Putting $s=0$ in (A.2), (A.4), (A.5), (A.6), and (A.7) and $s=1$ in (A.3) and defining the stochastic discount factor as $P_{t,t+1}\equiv\beta\frac{P_{t+1}}{P_t}$, we now have:

Euler consumption

$$1=\beta R_t E_t\left[\frac{C_t-\epsilon C_{t-1}}{C_{t+1}-\epsilon C_t}\frac{\xi^C_{t+1}}{\xi^C_t}\Pi^C_{t+1}\right] \tag{A.8}$$

Stochastic discount factor

$$P_{t,t+1}\equiv\beta\frac{P_{t+1}}{P_t}=\beta\frac{\gamma\xi^C_{t+1}C_t-\epsilon C_{t-1}}{\gamma\xi^C_t C_{t+1}-\epsilon C_t} \tag{A.9}$$

Labour supply

$$\alpha^{-\iota_L} L_{t+s}^{\varphi-\iota_L} (L_{t+s}^C)^{\iota_L} = \frac{\xi_t^C W_t^C}{C_t - \epsilon C_{t-1}} \tag{A.10}$$

$$(1-\alpha)^{-\iota_L} L_{t+s}^{\varphi-\iota_L} (L_{t+s}^D)^{\iota_L} = \frac{\xi_t^C W_t^D}{C_t - \epsilon C_{t-1}} \tag{A.11}$$

Investment

$$\frac{\gamma \xi_t^C Q_t}{C_t - \epsilon C_{t-1}} = \beta E_t \varrho_{t+1} \left[1 - f\left(\frac{I_t}{I_{t-1}}\right) - f'\left(\frac{I_t}{I_{t-1}}\right) \frac{I_t}{I_{t-1}}\right] + \beta^2 E_t \left[\varrho_{t+2} f'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right] \tag{A.12}$$

B. Borrower's optimisation problem

To solve the borrowers problem we have:

$$L = E_0 \left\{ \sum_{s=0}^{\infty} \beta^{B,s} \left[\gamma \xi_{t+s}^C log(C_{t+s}^B - \epsilon^B C_{t+s-1}^B) + (1-\gamma)\xi_{t+s}^D log(D_{t+s}^B) - \frac{(L_{t+s}^B)^{1+\varphi}}{1+\varphi} \right] + \varrho_{t+s}^B \left[S_t^B + W_t^C L_t^{B,C} + W_t^D L_t^{B,D} - C_{t+s}^B - Q_{t+s} I_{t+s}^B \right.\right.$$
$$\left.\left. - \left\{ R_{t+s}^D + \Phi\left(\frac{-log\overline{\omega}_{t-1}^p}{\sigma_{\omega,t-1}} - \frac{\sigma_{\omega,t-1}}{2}\right) R_{t+s-1}^L \right\} S_{t+s-1}^B + \left[\left(1-\delta\right) D_{t+s-1}^B + \left[1 - f\left(\frac{I_{t+s}}{I_{t+s-1}}\right)\right] I_{t+s} - D_{t+s}^B \right] \right. \tag{B.1}$$

The FOCs with respect to C_{t+s}^B, S_{t+s-1}^B, D_{t+s-1}^B, I_{t+s}^B and L_{t+s}^B are the following

$$C_{t+s}^B : E_t\left[\frac{\gamma \xi_{t+s}^C}{C_{t+s}^B - \epsilon^B C_{t+s-1}^B} - \beta^{B,s} \varrho_{t+s}^B\right] = 0; s \geq 0 \tag{B.2}$$

$$S_{t+s-1}^B : E_t\left[\beta^{B,s} \varrho_{t+s}^B - \beta^{B,s-1} \varrho_{t+s-1}^B \left[R_{t+1}^D + \Phi\left(\frac{-log\overline{\omega}_{t-1}^p}{\sigma_{\omega,t-1}} - \frac{\sigma_{\omega,t-1}}{2}\right) R_{t+s-1}^L\right]\right] = 0;\ s > 0;\ (where\ S_{t-1}\ is\ given) \tag{B.3}$$

$$D_{t+s}^B : E_t\left[\frac{(1-\gamma)\xi_{t+s}^D}{D_{t+s}} - \beta^s \varrho_{t+s}^B + \beta^{B,s+1} \varrho_{t+s+1}^B (1-\delta)\right] = 0; s \geq 0 \tag{B.4}$$

$$I_{t+s}^B : E_t\left[-\beta^s \varrho_{t+s+1}^B Q_{t+s} + \beta^{B,s+1} \varrho_{t+s}^B \left[1 - f\left(\frac{I_{t+s}^B}{I_{t+s-1}^B}\right) - f'\left(\frac{I_{t+s}^B}{I_{t+s-1}^B}\right)\frac{I_{t+s}^B}{I_{t+s-1}^B}\right] + \beta^{s+2} \varrho_{t+s+2}^B f'\left(\frac{I_{t+s+1}^B}{I_{t+s}^B}\right)\left(\frac{I_{t+s+1}^B}{I_{t+s}^B}\right)^2\right] = 0; s \geq 0 \tag{B.5}$$

$$L_{t+s}^{B,C} : E_t[\alpha^{-\iota_L} L_{t+s}^{\varphi-\iota_L} (L_{t+s}^{B,C})^{\iota_L} - \varrho_{t+s}^B W_{t+s}^C] = 0; s \geq 0 \tag{B.6}$$

$$L_{t+s}^{B,D} : E_t[(1-\alpha)^{-\iota_L} L_{t+s}^{\varphi-\iota_L} (L_{t+s}^{B,D})^{\iota_L} - \varrho_{t+s}^B W_{t+s}^D] = 0; s \geq 0 \tag{B.7}$$

Putting $s = 0$ in (B.2), (B.4), (B.5), (B.6), and (B.7) and $s = 1$ in (B.3) and defining the stochastic discount factor as $\mathrm{P}_{t,t+1}^B \equiv \beta \frac{\mathrm{P}_{t+1}^B}{\mathrm{P}_t^B}$ we now have:

Euler consumption

$$1 = \beta^B E_t\left[R_{t+1}^D + (1-F)R_t^L\right]\left[\frac{C_t^B - \epsilon C_{t-1}^B}{C_{t+1}^B - \epsilon^B C_t} \frac{\xi_{t+1}^C}{\xi_t^C} \Pi_{t+1}^C\right] \tag{B.8}$$

where $R_t^D = Q_t G \frac{D^B \Pi_t^C}{S_{t-1}^B}$ and $\omega_t^p Q_t D_t^B = \frac{R_{t-1}^L S_{t-1}^B}{\Pi_t^C}$

Stochastic discount factor

$$\mathrm{P}^{B}_{t,t+1} \equiv \beta^{B}\frac{\mathrm{P}^{B}_{t+1}}{\mathrm{P}^{B}_{t}} = \beta^{B}\frac{\gamma\xi^{C}_{t+1}C^{B}_{t} - \epsilon^{B}C^{B}_{t-1}}{\gamma\xi^{C}_{t}C^{B}_{t+1} - \epsilon^{B}C^{B}_{t}} \tag{B.9}$$

Labour supply

$$\alpha^{-\iota_L}L^{\varphi-\iota_L}_{t+s}\left(L^{B,D}_{t+s}\right)^{\iota_L} = \frac{\xi^{C}_{t}W^{C}_{t}}{C^{B}_{t} - \epsilon^{B}C^{B}_{t-1}} \tag{B.10}$$

$$(1-\alpha)^{-\iota_L}L^{\varphi-\iota_L}_{t+s}\left(L^{B,D}_{t+s}\right)^{\iota_L} = \frac{\xi^{C}_{t}W^{D}_{t}}{C^{B}_{t} - \epsilon^{B}C^{B}_{t-1}} \tag{B.11}$$

Investment

$$\frac{\gamma\xi^{C}_{t+s}Q_t}{C^{B}_{t+s} - \epsilon^{B}C^{B}_{t+s-1}} = \beta E_t\varrho^{B}_{t+1}\left[1 - f\left(\frac{I^{B}_{t}}{I^{B}_{t-1}}\right) - f'\left(\frac{I^{B}_{t}}{I^{B}_{t-1}}\right)\frac{I^{B}_{t}}{I^{B}_{t-1}}\right] + \beta^{2}E_t\left[\varrho^{B}_{t+2}f'\left(\frac{I^{B}_{t+1}}{I^{B}_{t}}\right)\left(\frac{I^{B}_{t+1}}{I^{B}_{t}}\right)^{2}\right] \tag{B.12}$$

C. *Steady state*

$$R = \frac{1}{\beta} \tag{C.1}$$

$$R^{D} = G\frac{R^{L}}{\overline{\omega}} \tag{C.2}$$

$$R^{L} = \frac{1}{\beta^{B}\left(\frac{G}{\overline{\omega}} + 1 - F\right)} \tag{C.3}$$

$$\Gamma^{B} = \frac{\gamma(1-\beta^{B}(1-\delta))}{\beta^{B}(1-\gamma)(1-\epsilon^{B})} \tag{C.4}$$

$$\Gamma = \frac{\gamma(1-\beta(1-\delta))}{\beta(1-\gamma)(1-\epsilon)} \tag{C.5}$$

$$L^{B} = \left\{\frac{\gamma}{1-\epsilon^{B}}\left(1 + \frac{\delta + G + \left(1 - F - \frac{1}{R^{L}}\right)\overline{\omega}}{\Gamma^{B}}\right)\right\}^{\frac{1}{1+\varphi}} \tag{C.6}$$

$$\gamma\left(1-\frac{1}{\sigma}\right)\left(\frac{\lambda}{1-\varepsilon} + \frac{1-\lambda}{1-\varepsilon^{b}}\frac{L}{L^{B}}\right)\left(\alpha + (1-\alpha)Q^{1+\frac{1}{\iota_L}}\right) = \alpha L^{\varphi}((1-\lambda)L^{B} + \lambda L) \tag{C.7}$$

$$\left(1 - \alpha + \alpha Q^{-1-\frac{1}{\iota_L}}\right)\gamma^{\delta}\left(1-\frac{1}{\sigma}\right)\left(\frac{\lambda}{(1-\varepsilon)\Gamma} + \frac{\lambda}{(1-\varepsilon^{b})\Gamma}\left(\frac{L}{L^{B}}\right)\varphi\right) = (1-\alpha)L^{\varphi}((1-\lambda)L^{B} + \lambda L) \tag{C.8}$$

$$W^{D} = W^{C}Q$$

$$C^{B} = \frac{W^{C}\gamma}{1-\epsilon^{B}}(L^{B})^{-\varphi}\left(\alpha + (1-\alpha)Q^{1+\frac{1}{\iota_L}}\right)^{\frac{\iota_L}{1+\iota_L}} \tag{C.9}$$

$$C = \frac{W^{C}\gamma}{1-\epsilon}L^{-\varphi}\left(\alpha + (1-\alpha)Q^{1+\frac{1}{\iota_L}}\right)^{\frac{\iota_L}{1+\iota_L}} \tag{C.10}$$

$$D^{B} = \frac{C^{B}Q}{\Gamma^{B}} \tag{C.11}$$

$$D = \frac{CQ}{\Gamma^B} \tag{C.12}$$

$$I^B = \delta D^B \tag{C.13}$$

$$I = \delta D \tag{C.14}$$

$$S^B = QG\frac{D^B}{R^D} \tag{C.15}$$

$$\varrho = \frac{Q\gamma}{\beta}\frac{C}{(1-\epsilon)} \tag{C.16}$$

$$\varrho^B = \frac{Q\gamma}{\beta^B}\frac{C^B}{(1-\epsilon^B)} \tag{C.17}$$

$$L^D = \alpha L\left(\alpha + (1-\alpha)Q^{1+\frac{1}{\iota_L}}\right)^{\frac{-1}{1+\iota_L}} \tag{C.18}$$

$$L^C = \alpha L\left(\alpha + (1-\alpha)Q^{1+\frac{1}{\iota_L}}\right)^{\frac{-1}{1+\iota_L}} \tag{C.19}$$

$$L^{B,C} = (1-\alpha)L^B Q^{\frac{1}{\iota_L}}\left(\alpha + (1-\alpha)Q^{1+\frac{1}{\iota_L}}\right)^{\frac{-1}{1+\iota_L}} \tag{C.20}$$

$$L^{B,D} = (1-\alpha)L^B Q^{\frac{1}{\iota_L}}\left(\alpha + (1-\alpha)Q^{1+\frac{1}{\iota_L}}\right)^{\frac{-1}{1+\iota_L}} \tag{C.21}$$

$$\omega^a = \omega^p \tag{C.22}$$

$$C^{TOTAL} = \lambda C + (1-\lambda)C^B \tag{C.23}$$

$$L^{C,TOTAL} = \lambda L^C + (1-\lambda)L^{B,C} \tag{C.24}$$

$$L^{D,TOTAL} = \lambda L^D + (1-\lambda)L^{B,D} \tag{C.25}$$

$$Y^C = L^{C,TOTAL} \tag{C.26}$$

$$Y^D = L^{D,TOTAL} \tag{C.27}$$

$$Y = Y^C + QY^D \tag{C.28}$$

$$MC^C = W^C \tag{C.29}$$

$$MC^D = W^C \tag{C.30}$$

$$J^D = \frac{1}{(1-\beta\theta^D)}\frac{Y^D MC^D}{C(1-\epsilon)} \tag{C.31}$$

$$H^D = \frac{1}{(1-\beta\theta^D)}\frac{Y^C W^D}{C(1-\epsilon)} \tag{C.32}$$

$$J^C = \frac{1}{(1-\beta\theta^C)}\frac{Y^C MC^C}{C(1-\epsilon)} \tag{C.33}$$

$$H^C = \frac{1}{(1-\beta\theta^C)}\frac{Y^C W^C}{C(1-\epsilon)} \tag{C.34}$$

$$rr = \overline{rr} \tag{C.35}$$

$$\mathrm{P} = \beta \tag{C.36}$$

$$N = \frac{(\xi_B + \sigma_B)\left\{(1-\lambda)\left[(1-\mu)R^D + (1-F)R^L\right]S^B\right\} - (1-\lambda)\sigma\frac{R-rr}{1-rr}S^B}{1-\sigma\lambda\frac{R-rr}{1-rr}} \tag{C.37}$$

$$\varphi = \frac{(1-\lambda)S^B}{N} \tag{C.38}$$

$$\Omega = 1 - \sigma_B + \sigma_B\Theta\varphi \tag{C.39}$$

D. Steady state effects on welfare of rr changes

For simplicity we focus on the case when there are no banking frictions.

D.1. Effect on $\overline{\omega}$

The relationship between rr and $\overline{\omega}$ is given by

$$Z = \frac{\frac{rr\beta^b}{\beta} - 1 + \mu}{\overline{\omega}}\Phi\left(\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right) + \left(\frac{rr\beta^b}{\beta} - 1\right)\Phi\left(-\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right) = 0 \tag{D.1}$$

For later convenience, we define $F = \Phi\left(-\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right)$, $G = \Phi\left(\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right)$, where Φ is the cumulative normal distribution.

It follows that $\frac{\partial Z}{\partial rr} = (G/\overline{\omega} + F)\frac{\beta^b}{\beta}$. In addition

$$\frac{\partial Z}{\partial \overline{\omega}} = \frac{\mu}{\sigma_\omega\overline{\omega}^2}\left[\varphi\left(\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right) - \sigma_\omega\Phi\left(\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right)\right] + \frac{1}{\overline{\omega}^2}\left(1 - \frac{rr\beta^b}{\beta}\right)\Phi\left(\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right) \tag{D.2}$$

(where φ is the normal probability density function, and we have used the result that $\varphi(\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}) = \overline{\omega}\varphi(-\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2})$).

A reasonable assumption is that the threshold value $\overline{\omega} < 1$; from (D.1) it is clear that $\overline{\omega} = 1$ when $\mu = 2(1 - \frac{rr\beta^b}{\beta})$, so it follows that a sufficient condition for $\overline{\omega} < 1$ is that $\mu > 2(1 - \frac{rr\beta^b}{\beta})$. Most calibrations of the agency parameter μ are of the order of 0.1, with $\frac{\beta^b}{\beta} = 0.97$, so that this sufficiency condition holds over the range of rr we investigate. Noting that the term in square brackets is 0 when $\overline{\omega} = 0$ and that its derivative is increasing provided that $(-\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}) > 0$, it follows that it must be positive provided that $\overline{\omega} > e^{-\frac{\sigma_\omega^2}{2}}$. Note also that this term is positive at $\overline{\omega} = 1$ provided that $\sigma_\omega < 1.22$. Thus provided that $\mu > 0.08$ and $\sigma_\omega < 1.22$, this term is positive, and therefore $\frac{\partial Z}{\partial \overline{\omega}} > 0$.

It immediately follows that $\frac{d\overline{\omega}}{drr} < 0$.

We can next write $\frac{R}{R^L} = \frac{1}{rr}((1-\mu)\frac{G}{\overline{\omega}} + F) = \frac{\beta^b}{\beta}(\frac{G}{\overline{\omega}} + F)$, where $\beta R = 1$, from which it follows that

$$-\frac{R}{(R^L)^2}\frac{\partial R^L}{\partial \overline{\omega}} = -\frac{\beta^b}{\beta}\frac{G}{\overline{\omega}^2} \tag{D.3}$$

and hence $\frac{dR^L}{drr} < 0$.

D.2. Effect on other variables

$$R^D = \frac{GR^L}{\overline{\omega}} = \frac{1}{\beta^b}\frac{G/\overline{\omega}}{G/\overline{\omega} + F} \tag{D.4}$$

Hence

$$\beta^b\frac{\partial R^D}{\partial \overline{\omega}} = \frac{\frac{F}{\sigma_\omega\overline{\omega}^2}\left[\varphi\left(\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right) - \sigma_\omega\Phi\left(\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right)\right] + \frac{G}{\sigma_\omega\overline{\omega}^2}\varphi\left(-\frac{log\overline{\omega}}{\sigma_\omega} - \frac{\sigma_\omega}{2}\right)}{(G/\overline{\omega} + F)^2} > 0 \tag{D.5}$$

and hence $\frac{dR^D}{drr} < 0$.

$$(L^B)^\varphi = \frac{\gamma}{1-\varepsilon^B}\left(1 + \frac{\delta + G + \left(F - \frac{1}{R^L}\right)\overline{\omega}}{\Gamma^B}\right) \tag{D.6}$$

Thus L^B increases with $G + (F - \frac{1}{R^L})\overline{\omega} = (1 - \beta^b)(G + \overline{\omega}F)$; the derivative of this with respect to $\overline{\omega}$ is $\left(1 - \beta^b)F > 0\right)$, and hence $\frac{dL^B}{drr} < 0$.

The steady state equations for Q and L are given by

$$\gamma\left(1-\frac{1}{\sigma}\right)\left(\frac{\lambda}{1-\varepsilon}+\frac{1-\lambda}{1-\varepsilon^B}(L/L^B)^{\varphi}\right)\left(\alpha+(1-\alpha)Q^{1+\frac{1}{\iota_L}}\right)=\alpha L^{\varphi}((1-\lambda)L^B+\lambda L) \tag{D.7}$$

$$\left(1-\alpha+\alpha Q^{-1-\frac{1}{\iota_L}}\right)\gamma\delta\left(1-\frac{1}{\sigma}\right)\left(\frac{\lambda}{(1-\varepsilon)\Gamma}+\frac{1-\lambda}{(1-\varepsilon^B)\Gamma^B}(L/L^B)^{\varphi}\right)=(1-\alpha)L^{\varphi}((1-\lambda)L^B+\lambda L) \tag{D.8}$$

where

$$\Gamma=\frac{\gamma(1-\beta(1-\delta))}{\beta(1-\gamma)(1-\varepsilon)}\qquad \Gamma^B=\frac{\gamma(1-\beta^B(1-\delta))}{\beta^B(1-\gamma)(1-\varepsilon^B)} \tag{D.9}$$

One can eliminate Q by multiplying (D.8) by $Q^{1+\frac{1}{\iota_L}}$ and then adding to (D.7), to obtain

$$\begin{aligned}(1-\lambda)L^B+\lambda L \quad &- \quad \gamma\left(1-\frac{1}{\sigma}\right)\left(\frac{\lambda}{1-\varepsilon}L^{-\varphi}+\frac{1-\lambda}{1-\varepsilon^B}(L^B)^{-\varphi}\right)\\ &- \quad \gamma\delta\left(1-\frac{1}{\sigma}\right)\left(\frac{\lambda}{(1-\varepsilon)\Gamma}L^{-\varphi}+\frac{1-\lambda}{(1-\varepsilon^B)\Gamma^B}(L^B)^{-\varphi}\right)=0\end{aligned} \tag{D.10}$$

and it is clear from this that $\frac{dL}{drr}>0$.

Dividing (D.7) by (D.8) yields

$$(1-\alpha)\left(\frac{\lambda}{1-\varepsilon}+\frac{1-\lambda}{1-\varepsilon^B}(L/L^B)^{\varphi}\right)Q^{1+\frac{1}{\iota_L}}=\alpha\delta\left(\frac{\lambda}{(1-\varepsilon)\Gamma}+\frac{1-\lambda}{(1-\varepsilon^B)\Gamma^B}(L/L^B)^{\varphi}\right) \tag{D.11}$$

By inspection, we see that if $\Gamma=\Gamma^B$, then Q, the price ratio, is a constant. Noting that

$$\Gamma-\Gamma^B=\frac{\gamma}{1-\gamma}\left(\frac{1/\beta-1+\delta}{1-\varepsilon}-\frac{1/\beta^B-1+\delta}{1-\varepsilon^B}\right) \tag{D.12}$$

and that a lower discount factor β^B is likely to be associated with a smaller habit parameter ε^B, the implication is that $\Gamma-\Gamma^B$ is small, and therefore that there is little variation in Q.[17] Treating $\frac{dQ}{drr}$ as negligible, it follows from the equations

$$C^B=W^C\frac{\gamma}{1-\varepsilon^B}(L^B)^{-\varphi}(\alpha+(1-\alpha)Q^{1+1/\iota_L})^{\iota_L/(1+\iota_L)} \tag{D.13}$$

$$C=W^C\frac{\gamma}{1-\varepsilon}L^{-\varphi}(\alpha+(1-\alpha)Q^{1+1/\iota_L})^{\iota_L/(1+\iota_L)} \tag{D.14}$$

$$D^B=C^B/\Gamma^B/Q\qquad D=C/\Gamma/Q; \tag{D.15}$$

with $W^C=1-1/\sigma$, that C^B and D^B increase with rr, and C, D decrease. With steady state utilities given by

$$\begin{aligned}U\quad &=\gamma log(C-\varepsilon C)+(1-\gamma)log(D)-\frac{L^{1+\varphi}}{1+\varphi}\\ U^B\quad &=\gamma log(C^B-\varepsilon^B C^B)+(1-\gamma)log(D^B)-\frac{(L^B)^{1+\varphi}}{1+\varphi}\end{aligned} \tag{D.16}$$

it is evident that the effect of an increase in reserve ratios, as given by rr, is to raise the utility U^B for the borrowers and reduce utility U for the savers.

E. Long-run IRF's and additional results

[17] Indeed, the percentage change in Q in the simulations is around 100 times smaller than those of any of the changes in the other variables.

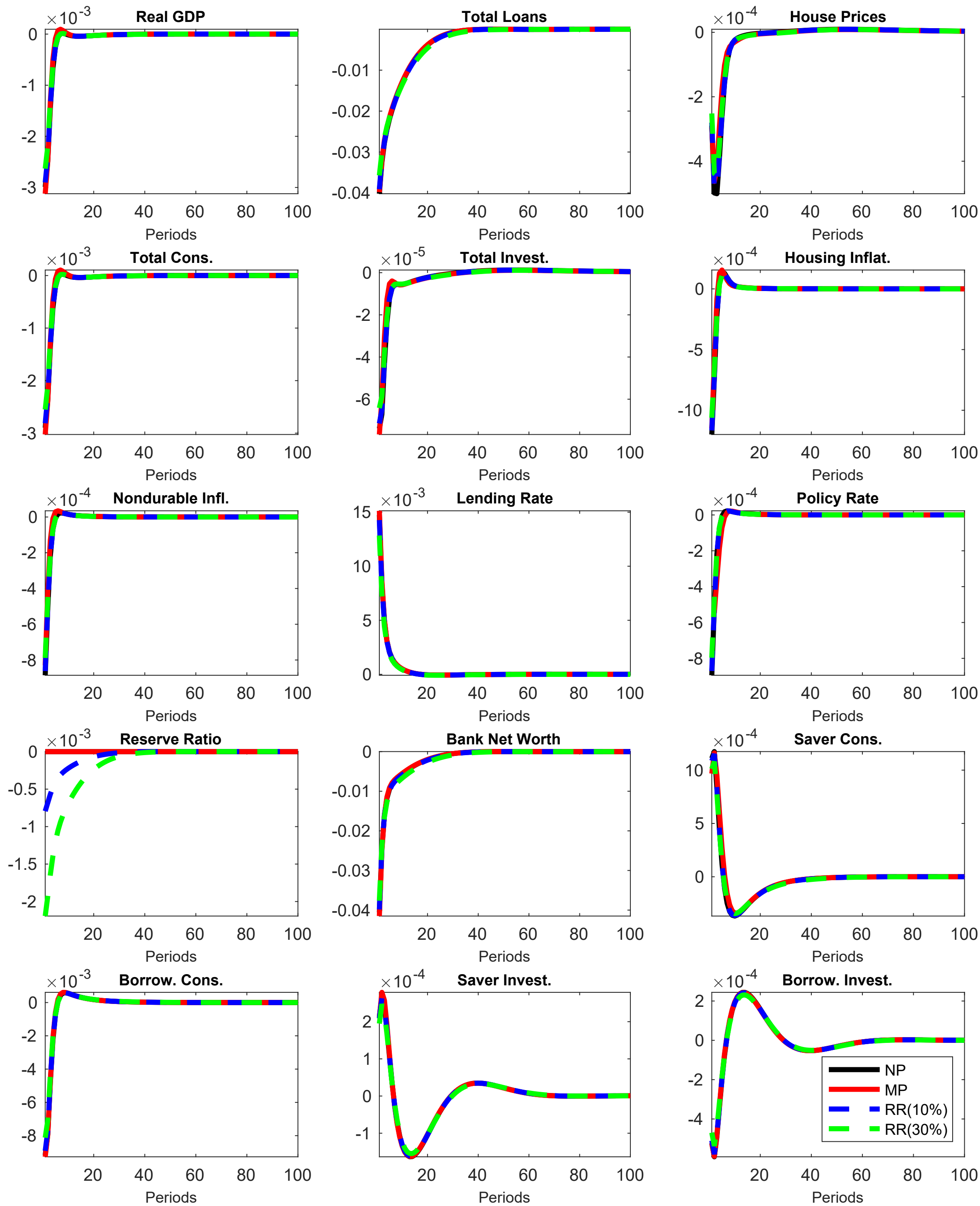

Fig. 13. IRFs with housing risk shock (deviations from steady state).

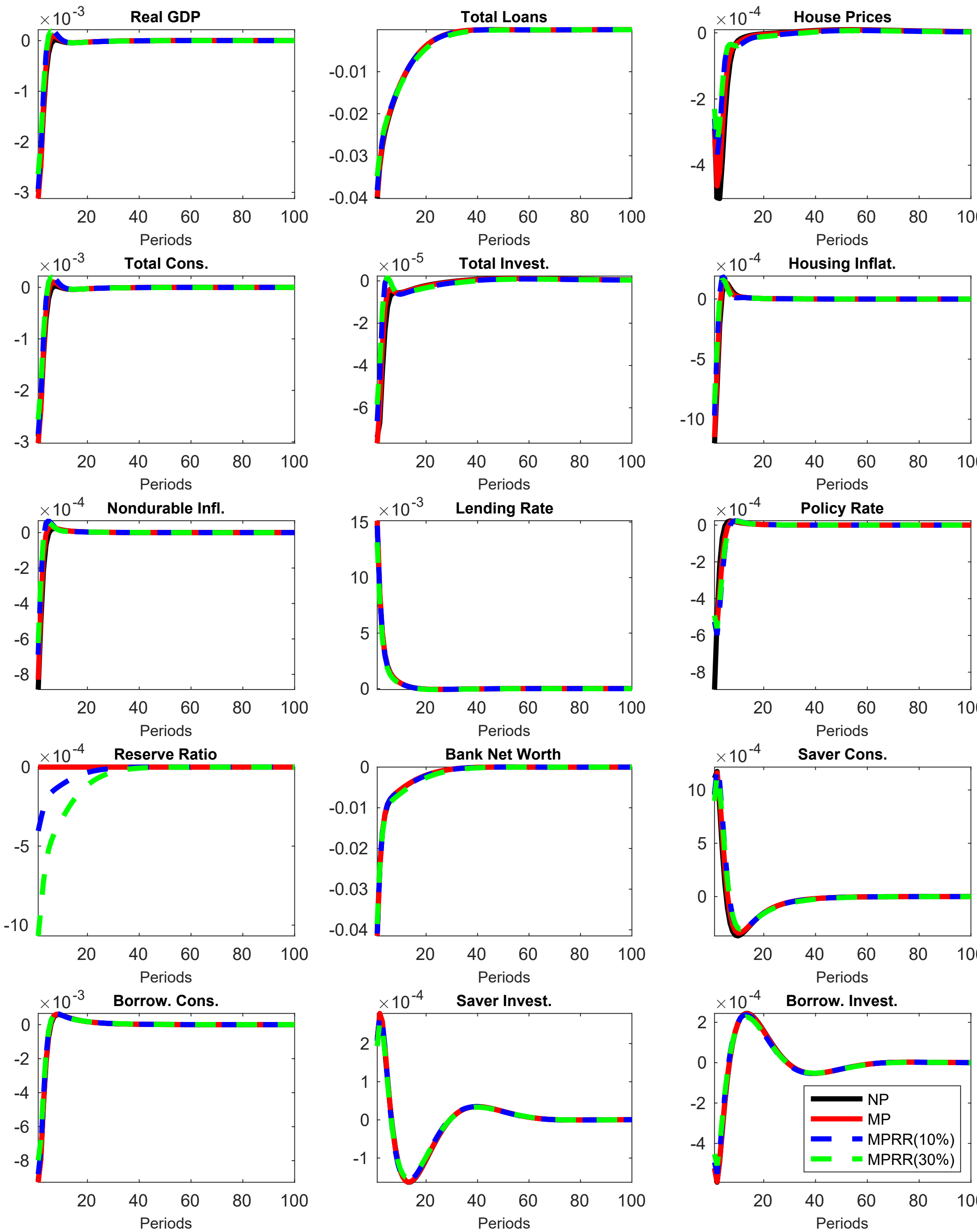

Fig. 14. IRFs with housing risk shock (deviations from steady state).

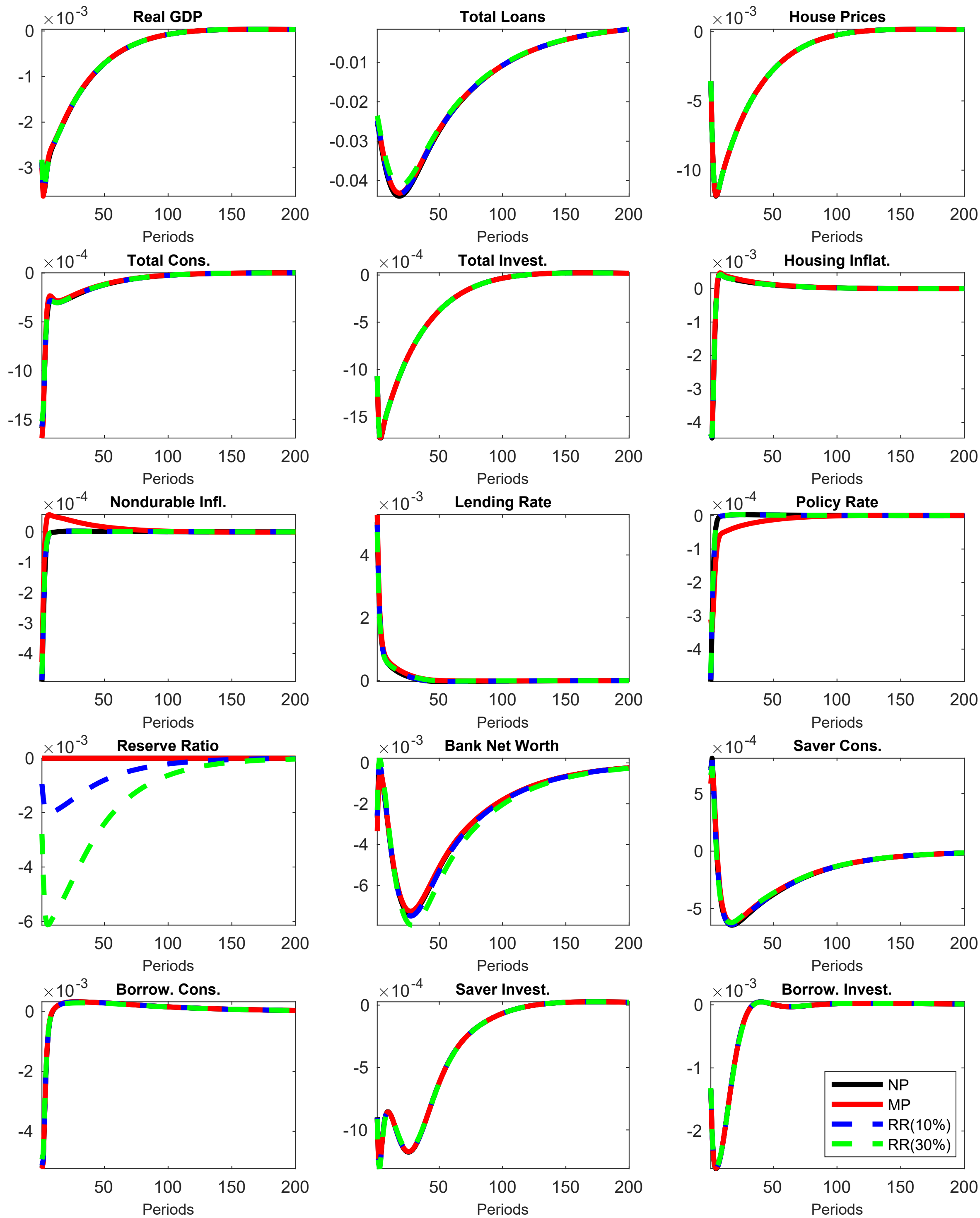

Fig. 15. IRFs with housing demand shock (deviations from steady state).

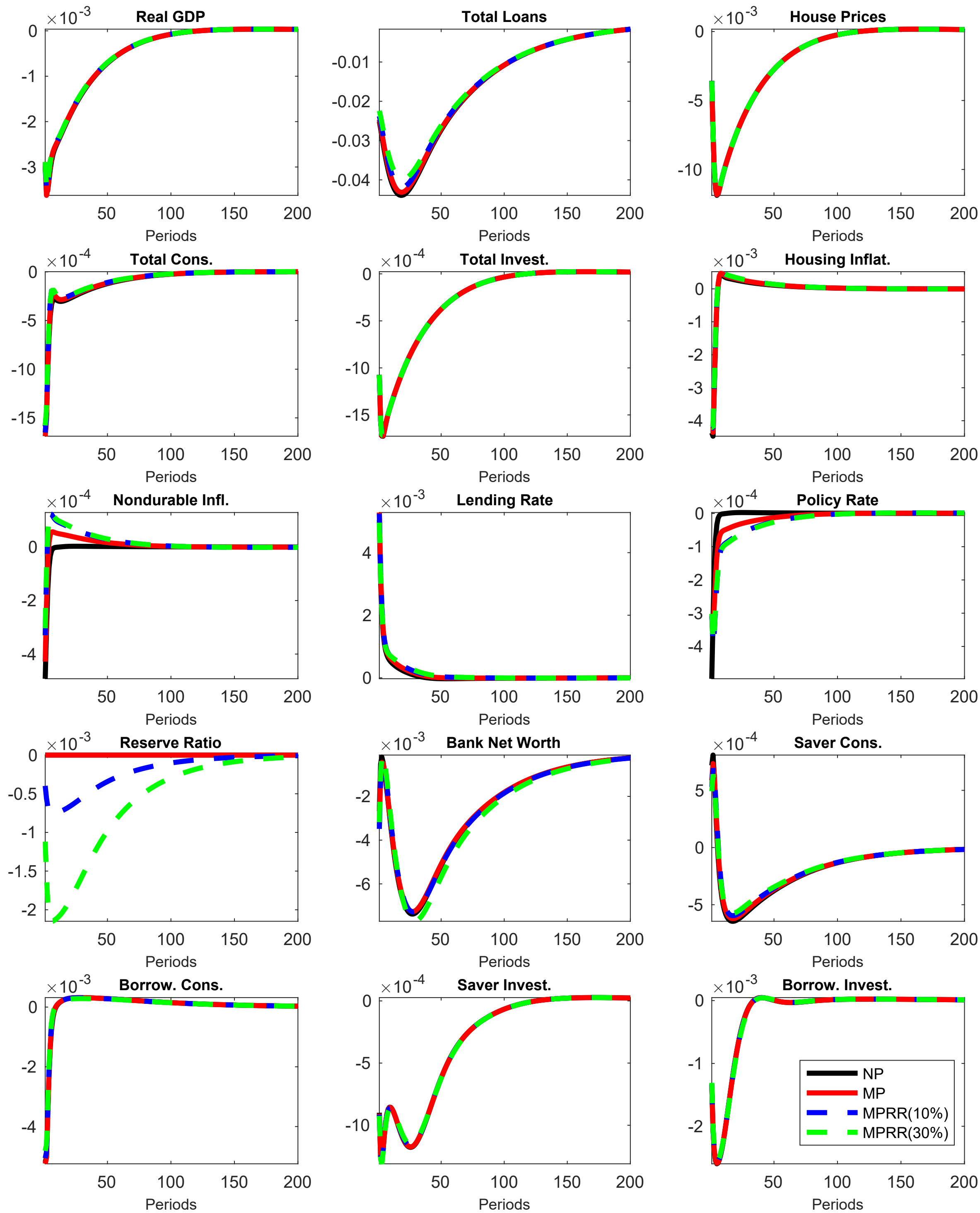

Fig. 16. IRFs with housing demand shock (deviations from steady state).

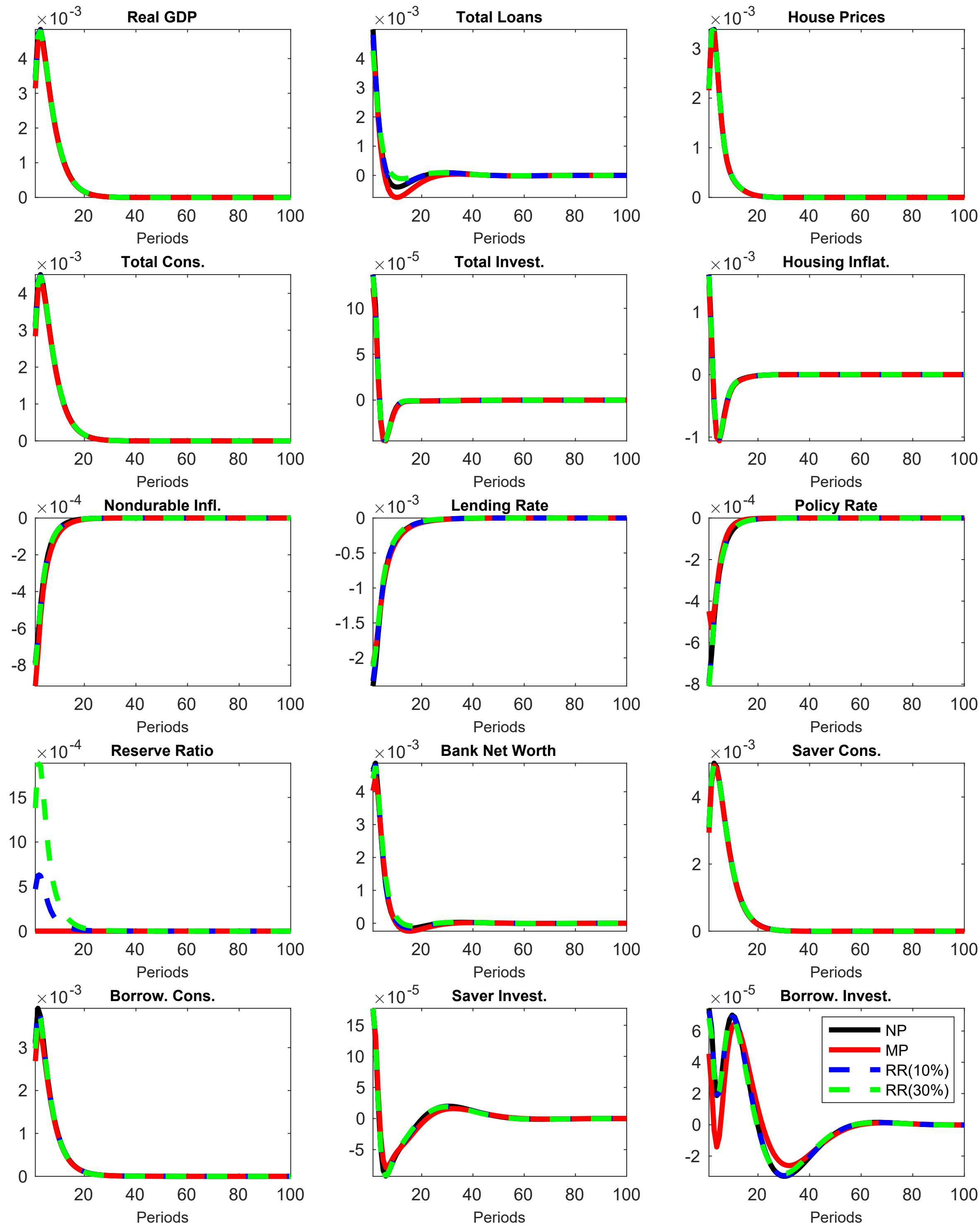

Fig. 17. IRFs with non-durable technology shock (deviations from steady state).

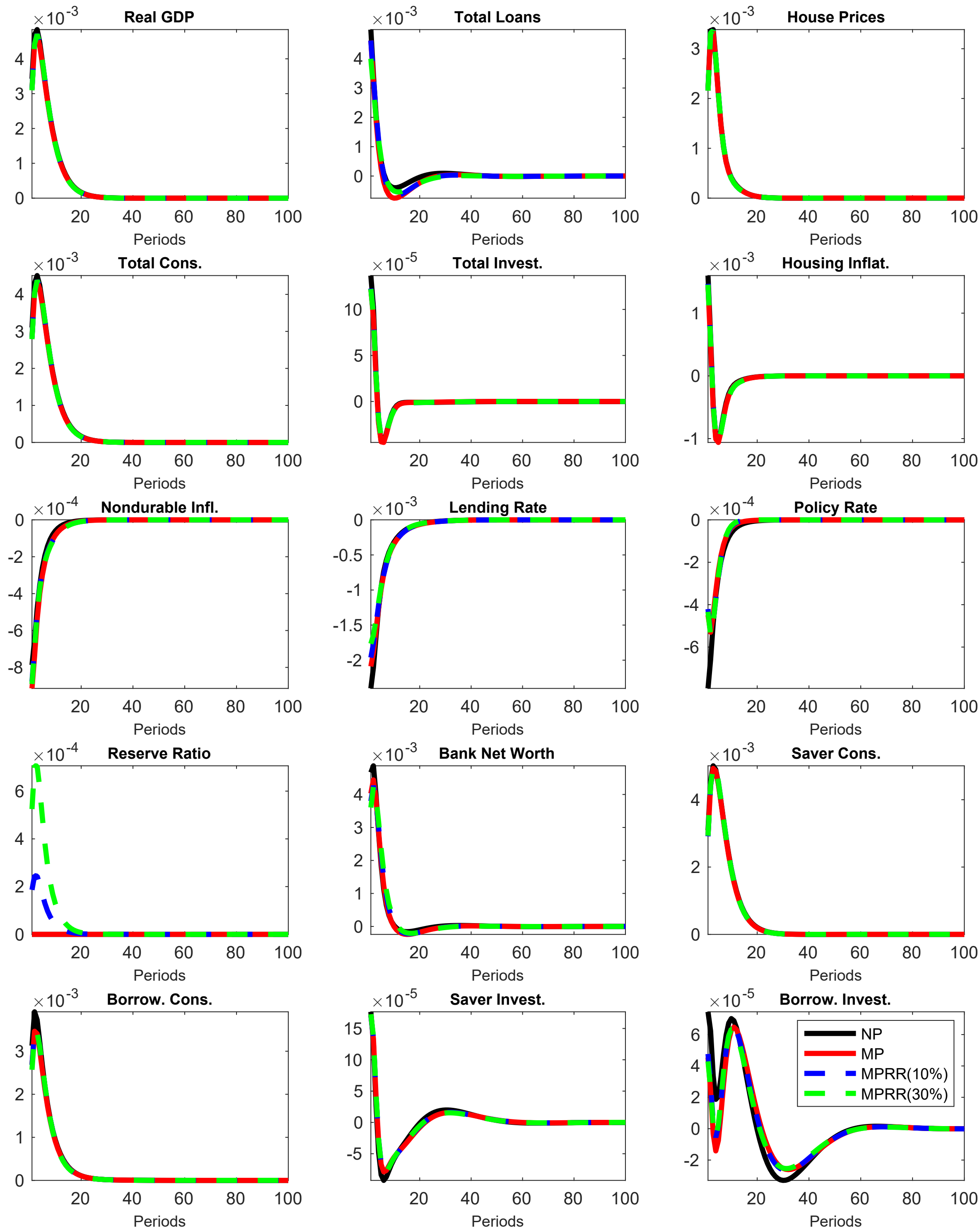

Fig. 18. IRFs with non-durable technology shock (deviations from steady state).

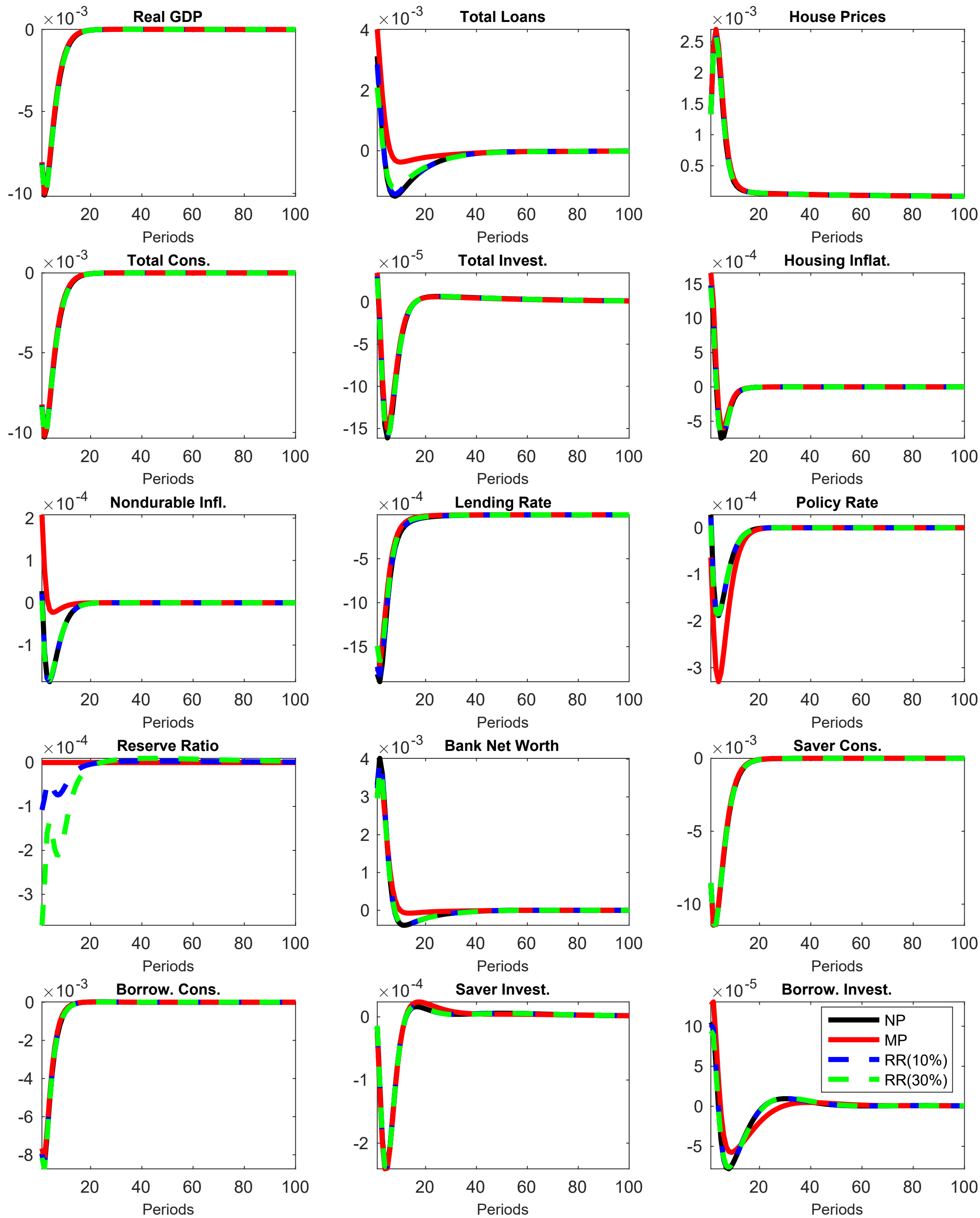

Fig. 19. IRFs with non-durable demand shock (deviations from steady state).

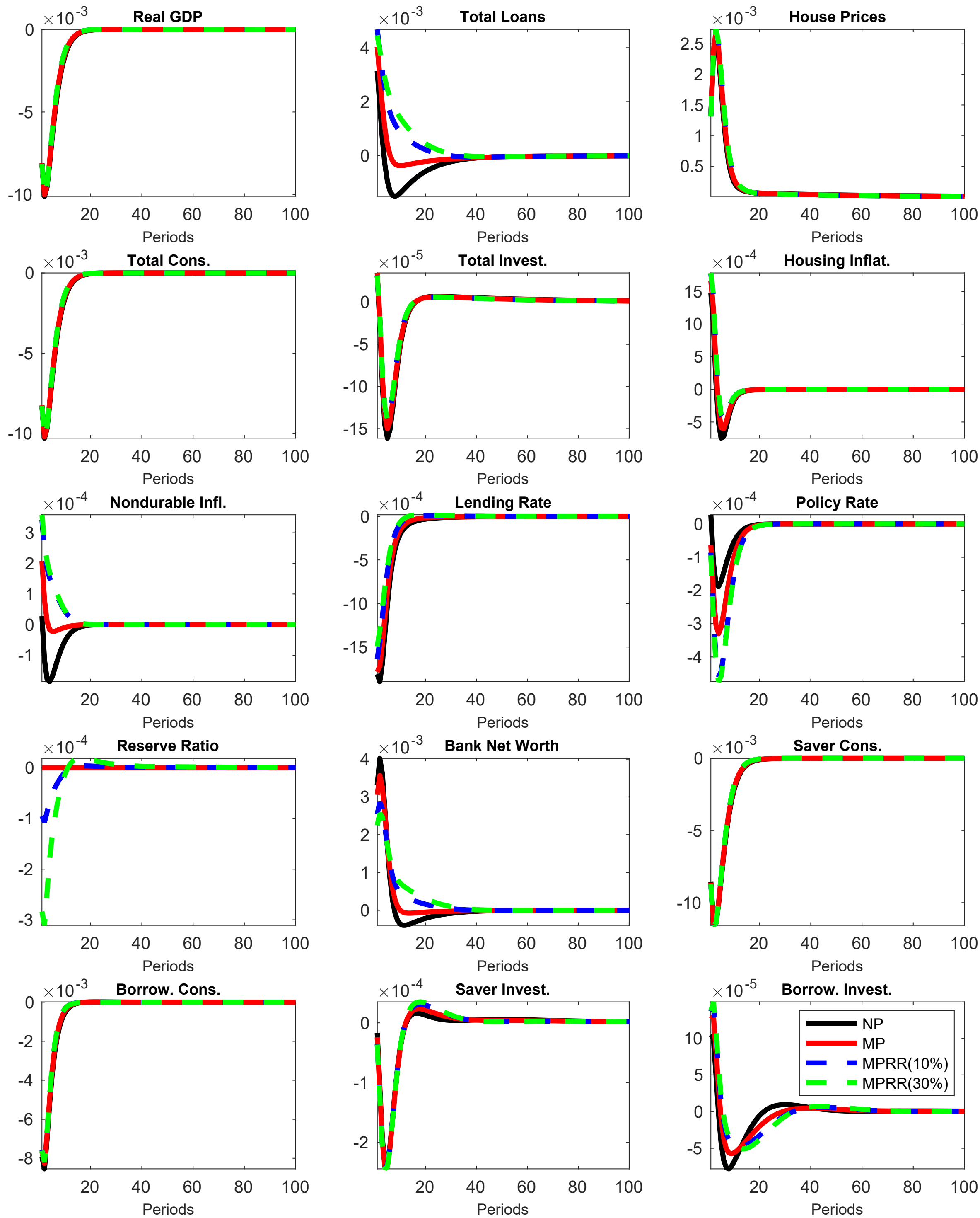

Fig. 20. IRFs with non-durable demand shock (deviations from steady state).

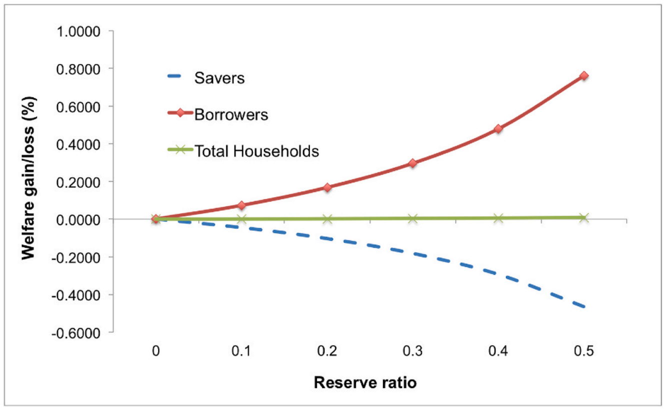

Fig. 21. Welfare in consumption equivalent in deterministic model.

References

Agenor, R.P., Alper, K., Da Silva, L.P., 2018. Capital regulation, monetary policy, and financial stability. Int. J. Cent. Bank. 9 (3), 198–243.

Andre, Christophe, Caraiani, Petre, Calin, Adrian Cantemir, Gupta, Rangan, 2022. Can monetary policy lean against housing bubbles? Econ. Modell. 110.

Angelini, P., Neri, S., Panetta, F., 2014. The interaction between capital requirements and monetary policy. J. Money Credit Bank. 46 (6), 1073–1112.

Angeloni, I., Faia, E., 2013. Capital regulation and monetary policy with fragile banks. J. Monetary Econ. 60 (3), 311–324.

Ascari, G., Ropele, T., 2012. Disinflation in a DSGE perspective: sacrifice ratio or welfare gain ratio? J. Econ. Dynam. Control 36 (2), 169–182.

Bailliu, J., Meh, C., Zhang, Y., 2015. Macroprudential rules and monetary policy when financial frictions matter. Econ. Modell. 50, 148–161.

Beau, D., Clerc, L., Mojon, B., 2012. Macroprudential Policy and the Conduct of Monetary Policy. Banque de France Working Paper.

Benes, J., Kumhof, M., 2015. Risky bank lending and countercyclical capital buffers. J. Econ. Dynam. Control 58, 58–80.

Bernanke, B.S., Gertler, M., Gilchrist, S., 1999. The financial accelerator in a quantitative business cycle framework. Handb. Macroecon. 1, 1341–1393.

Briault, C., Haldane, A., King, M., 1996. Central Bank Independence and Accountability: Theory and Evidence. Bank of England Quarterly Bulletin, pp. 63–68.

Brzoza-Brzezina, Michał, Makarski, Krzysztof, 2011. Credit crunch in a small open economy. J. Int. Money Finance 30 (7), 1406–1428.

Brzoza-Brzezina, M., Kolasa, M., Makarski, K., 2015. Macroprudential policy and imbalances in the euro area. J. Int. Money Finance 51, 137–154.

Calvo, G.A., 1983. Staggered prices in a utility-maximizing framework. J. Monetary Econ. 12 (3), 383–398.

Cantore, C., Levine, P., Melina, G., Pearlman, J., 2019. Optimal fiscal and monetary policy, debt crisis, and management. Macroecon. Dyn. 23 (3), 1166–1204.

Carlson, M., 2015. Lessons from the historical use of reserve requirements in the United States to promote bank liquidity. Int. J. Cent. Bank. 11 (1), 191–224.

Christensen, I., Dib, A., 2008. The financial accelerator in an estimated New Keynesian model. Rev. Econ. Dynam. 11 (1), 155–178.

Christensen, I., Meh, C., Moran, K., 2011. Bank Leverage Regulation and Macroeconomic Dynamics. Bank of Canada.

Christiano, L., Eichenbaum, M., Evans, C., 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. J. Polit. Econ. 113 (1), 1–45.

Collard, F., Dellas, H., Diba, B., Loisel, O., 2017. Optimal monetary and prudential policies. Am. Econ. J. Macroecon. 9 (1), 40–87.

De Paoli, B., Paustian, M., 2017. Coordinating monetary and macroprudential policies. J. Money Credit Bank. 49 (2–3), 319–349.

Erceg, C., Levin, A., 2003. Imperfect credibility and inflation persistence. J. Monetary Econ. 50 (4), 915–944.

Feinman, J., 1993. Reserve requirements: history, current practice, and potential reform. Fed. Reserv. Bull. 79, 569.

Gelain, P., Lansing, K.J., Mendicino, C., 2013. House prices, credit growth, and excess volatility: implications for monetary and macroprudential policy. Int. J. Cent. Bank. 9 (2), 219–276.

Gerali, A., Neri, S., Neri, L., Signoretti, F., 2010. Credit and banking in a DSGE model of the euro area. J. Money Credit Bank. 42 (s1), 107–141.

Gertler, M., Kiyotaki, N., 2010. Financial intermediation and credit policy in business cycle analysis. In: Handbook of Monetary Economics, vol. 3. Elsevier, pp. 547–599.

Gertler, M., Karadi, P., 2011. A model of unconventional monetary policy. J. Monetary Econ. 58 (1), 17–34.

Gertler, M., Kiyotaki, N., Queralto, A., 2012. Financial crises, bank risk exposure and government financial policy. J. Monetary Econ. 59, S17–S34.

Goodfriend, M., Hargraves, M., 1983. A historical assessment of the rationales and functions of reserve requirements. FRB Richmond Econ. Rev. 69 (2), 3–21.

Gray, S., 2011. Central bank balances and reserve requirements. In: International Monetary Fund IMF Working Papers 2011/036.

Kannan, P., Rabanal, P., Scott, A.M., 2012. Monetary and macroprudential policy rules in a model with house price booms. B E J. Macroecon. 12 (1), 1–44.

Keynes, J.M., 1936. The General Theory of Interest, Employment and Money. MacMillan, London.

Lambertini, L., Mendicino, C., Punzi, M.T., 2013. Leaning against boom–bust cycles in credit and housing prices. J. Econ. Dynam. Control 37 (8), 1500–1522.

Leamer, E.E., 2008. Housing Is the Business Cycle. Federal Reserve Bank of Kansas City.

Leamer, E.E., 2015. Housing really is the business cycle: what survives the lessons of 2008–09? J. Money Credit Bank. 47 (S1), 43–50.

Leith, C., Moldovan, I., Rossi, R., 2012. Optimal monetary policy in a New Keynesian model with habits in consumption. Rev. Econ. Dynam. 15 (3), 416–435.

Levine, P., McAdam, P., Pearlman, J., 2012. Probability models and robust policy rules. Eur. Econ. Rev. 56 (2), 246–262.

Medina, J.P., Roldós, J., 2018. Monetary and macroprudential policies to manage capital flows. Int. J. Cent. Bank. 14 (1), 201–257.

Musso, A., Neri, S., Stracca, L., 2011. Housing, consumption and monetary policy: how different are the US and the euro area? J. Bank. Finance 35 (11), 3019–3041.

Ozkan, F.G., Unsal, D.F., 2013. On the Use of Monetary and Macroprudential Policies for Financial Stability in Emerging Markets. Department of Economics and Related Studies, University of York.

Paries, M.D., Sørensen, C.K., Rodriguez-Palenzuela, D., 2018. Macroeconomic propagation under different regulatory regimes: evidence from an estimated dsge model for the euro area. Int. J. Cent. Bank. 7 (4), 49–113.

Pearlman, J., 2015. A Stylized Model of European Monetary Union for Analysing Coordination Games for Monetary and Aacroprudential Policy. MACFINROBODS working paper.

Quint, D., Rabanal, P., 2014. Monetary and macroprudential policy in an estimated DSGE model of the Euro Area. Int. J. Cent. Bank. 10 (2), 169–236.

Rubio, M., Carrasco-Gallego, J.A., 2014. Macroprudential and monetary policies: implications for financial stability and welfare. J. Bank. Finance 49, 326–336.

Rubio, M., Carrasco-Gallego, J.A., 2015. Macroprudential and monetary policy rules: a welfare analysis. Manch. Sch. 83 (2), 127–152.

Silvo, A., 2019. The interaction of monetary and macroprudential policies. J. Money Credit Bank. 51 (4), 859–894.

Smets, F., Wouters, R., 2003. An estimated dynamic stochastic general equilibrium model of the euro area. J. Eur. Econ. Assoc. 1 (5), 1123–1175.

Smets, F., Wouters, R., 2007. Shocks and frictions in US business cycles: a Bayesian DSGE approach. Am. Econ. Rev. 97 (3), 586–606.

Suh, H., 2012. Macroprudential Policy: Its Effects and Relationship to Monetary Policy. FRB of Philadelphia working paper.

Suh, H., 2014. Dichotomy between macroprudential policy and monetary policy on credit and inflation. Econ. Lett. 122 (2), 144–149.

Tavman, Y., 2015. A comparative analysis of macroprudential policies. Oxf. Econ. Pap. 67 (2), 334–355.

Tayler, W.J., Zilberman, R., 2016. Macroprudential regulation, credit spreads and the role of monetary policy. J. Financ. Stabil. 26, 144–158.

Unsal, F., 2013. Capital flows and financial stability: monetary policy and macroprudential responses. Int. J. Cent. Bank. 9 (1), 233–285.