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Monetary and macroprudential policies in an estimated model with financial intermediation

Paolo Gelain[a], Pelin Ilbas[b,*]

[a] Norges Bank, Norway
[b] National Bank of Belgium, Belgium

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ABSTRACT

We estimate the Smets–Wouters model featuring the Gertler–Karadi banking sector on US data using real and financial observables. We investigate the gains from coordination between a flexible inflation targeting central bank and a macroprudential regulator charged with safeguarding financial stability. The potential gains from coordination depend on how much importance is given to the output gap in the macroprudential mandate. Coordination conflicts can be avoided by assigning similar importance to this common objective in the respective mandates of both policies. When we derive optimal mandates for monetary and macroprudential policy under no-coordination, we find that both policy makers should place a higher weight than society on the output gap.

1. Introduction

The financial disruptions that started in the second half of 2007, and led to the most severe global crisis since the Great Depression, have highlighted the importance of financial stability in maintaining overall macroeconomic stability, and paved the way for economists and policy makers around the globe to think about setting up new regulatory frameworks to better monitor financial developments and to act preemptively in order to avoid the build-up of financial imbalances, and hopefully decrease the likelihood of future crises. The latter prescribes a macroprudential approach to monitoring the financial system and demands for an active intervention in the financial markets when necessary. However, the appropriate operational framework for the latter and the desirable degree of interaction with monetary policy is still a topic under active discussion in policy institutions and academic circles.

There is no consensus on either the appropriate tools and objectives for macroprudential policy, or whether monetary policy should play an active role in the pursuit of financial stability and, if any, which implications it would have for the standard inflation targeting framework. Some argue that loose monetary policy in the period prior to the crisis encouraged excessive risk-taking behavior. According to Borio and Zhu (2012), the "risk-taking channel" of monetary policy, which

* Corresponding author.
E-mail addresses: paolo.gelain@norges-bank.no (P. Gelain), pelin.ilbas@nbb.be (P. Ilbas).

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makes the explicit link between monetary policy and the risk perception of banks or their willingness to bear risk, may be significant enough to call for an active role for monetary policy in discouraging excessive risk-taking during an economic expansion (see also Adrian and Shin (2010)). The proponents of an active role for monetary policy in the new framework for macroprudential policy therefore share the view that the central bank should fulfill a broader task than a narrow focus on price stability. The opponents of incorporating financial stability concerns as an additional objective for monetary policy rely on the principle that specific macroprudential instruments (such as capital buffers, loan-to-value policies, minimum liquidity ratios, etc.) are much more effective at safeguarding financial stability than monetary policy. Svensson (2012) for example supports this view of separation of policies and instruments, and suggests that monetary and macroprudential policy should not be coordinated, and that monetary policy should only be concerned about financial stability to the extent that it affects its medium term forecasts of inflation and employment. This argument implies no change to the current inflation targeting framework.

This paper aims to contribute to these discussions by studying the implications of macroprudential policy in the context of a quantitative medium-scale DSGE model for the US featuring a financial intermediation sector subject to frictions. In our set-up, macroprudential policy aims at stabilizing nominal credit growth and the output gap by setting a lump-sum levy/subsidy on bank capital, and monetary policy pursues a standard inflation targeting mandate using the short term interest rate. We assume that the mandates of both policy makers are described in terms of quadratic loss functions to be minimized. The objective of this paper is twofold. First, we determine the individual gains and losses to each policy maker from operating within an institutional set-up that either imposes cooperative or non-cooperative behavior on them. By considering the two alternative solutions for a given mandate, we aim to provide useful policy guidance in terms of the individual policy maker's trade-offs, since both types of institutional mechanisms are either being considered or already in place in practice[1]. The second objective is to derive an optimal mandate for each policy maker by minimizing the society's loss function, given an institutional setup. We assume a non-cooperative setting in order to approach the particular case of the US. The resulting optimal mandates can then serve as a useful benchmark for comparison with the price and financial stability mandates that are currently defined or being considered in practice for monetary and macroprudential policy.

This paper provides two contributions to the literature on the interaction between monetary and macroprudential policy. The first contribution is the consideration of alternative macroprudential mandates in our analysis. In most of the related work on the optimal interaction between monetary and macroprudential policy using either a similar framework of ad-hoc loss functions (Bean et al. (2010) Angelini et al. (2012)), or a microfounded loss function (Lima et al. (2012); De Paoli and Paustian (2013); Rubio and Carrasco-Gallego (2014)), the assumption of a fixed hierarchy between the financial stability concern and other, non-financial objectives, such as output, is made when defining the macroprudential mandate. Therefore, in these papers the choice of the relative weights in the macroprudential loss is, together with the weights in the monetary policy loss, typically kept unchanged throughout the policy experiments while robustness checks to a few alternative weights are provided at best. Although for monetary policy there is a well-established framework to discuss objectives, and to which extent they should be traded off, this is not the case for macroprudential policy. Hence, even if it is clear why macroprudential policy should, for example, mainly pursue financial stability, it is far less obvious to which extent additional objectives, such as output, should matter in the macroprudential loss function and what the implications of the alternative assumptions are. Instead of taking as given a set of assumed preferences for stabilizing output and financial stability in the macroprudential loss like is done in the aforementioned papers, we consider a broad range of alternative weights assigned to the output gap in the policy makers' loss functions. Therefore, our analysis allows us to take a more general approach than the papers in the literature. Our results suggest that the choice of the weight assigned to the common objective, i.e., the output gap, in the macroprudential mandate affects the benefits from coordination between the two policy makers. This yields the following important policy insight. When both the macroprudential regulator and the central bank pursue to stabilize the output gap, and to the extent that this common objective receives similar importance in both mandates, both policies can achieve a lower loss under coordination than under no-coordination. When the weights assigned to the output gap in the respective loss functions diverge too much, however, coordination is not necessarily the most beneficial interaction scheme from the point of view of the individual policy makers. In the latter case, one authority gains, while the other might lose, from coordination, creating coordination conflicts that can be worsened particularly in the face of supply shocks. Therefore, the question of how monetary and macroprudential policy should interact optimally is interlinked with how the mandate of the latter is defined and the policy implications crucially depend on the weight assigned to the common output gap objective.

The second contribution to the literature on monetary and macroprudential interactions is that we derive optimal mandates for monetary and macroprudential policy, in similar spirit to the approach taken by Debortoli et al. (2015) who design an optimal flexible inflation targeting mandate for the Federal Reserve. We thereby assume that monetary and macroprudential policy are given the task to act independently, i.e., operate in a non-cooperative setting, and hence do not have the

[1] For example, the Bank of England is charged with macroprudential objectives, which can be considered as a case of full cooperation. The case of the Federal Reserve, who has a very limited role in the macroprudential decision making process, is an example of the opposite extreme of no-cooperation. The Chairman of the Federal Reserve Board is, together with 9 others, a non-privileged voting member to the Financial Stability Oversight Council, a body with a clear statutory mandate that is charged with accountability for identifying risks and responding to emerging threats to financial stability. Therefore, it can be stated that two different institutions, the central bank and the macroprudential authority, with clearly defined and separate mandates and instruments are operating. See also Angelini et al. (2012) for similar interpretation.

possibility to coordinate. We then search for the optimal weights in the respective quadratic loss functions of both policy makers that minimize society's quadratic (ad-hoc) loss function including both monetary policy and financial stability objectives. The main advantage of this procedure is that it allows for choosing a set of weights in the individual loss functions that do not need to be set arbitrarily, but are the outcome of an optimization procedure. Hence, the derived mandates allow the policy makers to approximate as best as possible the outcome that would be obtained if they were able to act jointly to minimize society's loss function. Our results suggest that both policy makers should place a higher weight than society on the output gap, and that macroprudential policy should place a slightly higher weight than society on the credit growth variable, in order to compensate for the costs of no-coordination in terms of increased volatility.

Adding to the papers already mentioned, a list of relevant papers in the literature includes Roger and Vlcek (2011), Darracq Pariès et al. (2011), Beau et al. (2012), Kannan et al. (2012), Ozkan and Unsal (2014), Quint and Rabanal (2014), Tayler and Zilberman (2015), Bailliu et al. (2015), and Collard et al. (forthcoming). These papers are generally related to our work given that they study the implications of macroprudential policy in a structural model, but there are substantial differences. First of all, as already stressed before, none of the existing papers in the literature have so far derived optimal mandates when both monetary and macroprudential policy are active. Second, the definition of the (non-)cooperative policy regimes in most of these papers differs from ours. In this paper, each policy maker is assigned a separate mandate defined in terms of quadratic loss functions to be minimized, and coordination in our context involves summing the two respective loss functions, while the no-coordination regime implies that each policy maker minimizes its own loss function. This framework allows us to evaluate strategic interactions between monetary and macroprudential policies. Quint and Rabanal (2014), Beau et al. (2012), Kannan et al. (2012), Ozkan and Unsal (2014) Tayler and Zilberman (2015), and Bailliu et al. (2015) conduct their analysis in terms of how the policy feedback rules, i.e., a Taylor type of rule and a macroprudential rule, are specified. The feedback rules are optimized with respect to welfare in these papers, except for Tayler and Zilberman (2015), who adopt a single ad-hoc loss function for monetary policy, and Beau et al. (2012), who do not optimize the feedback rule coefficients. Hence, these papers limit their focus on cooperative outcomes and look at the effects of augmenting the Taylor rule with a financial variable or the benefits of introducing a feedback rule for macroprudential policy in addition to monetary policy, while the non-cooperative setting is not considered. Roger and Vlcek (2011) focus on the effects of capital and liquidity requirements without considering optimal interactions with monetary policy and while Collard et al. (forthcoming) derive jointly Ramsey-optimal policies, the latter paper does not consider the non-cooperative setting either. Finally, another important feature that distinguishes this paper from most of the related literature mentioned above, with the exception of Angelini et al. (2012), Quint and Rabanal (2014) and Darracq Pariès et al. (2011), who focus on the Euro Area[2], is that we conduct coordination exercises in the framework of a realistic medium-scale DSGE model estimated for the US and fairly representative to the type of models used for policy analysis. Most papers in the literature typically consider small, calibrated models where the dynamics are driven by only a few shocks. An analysis based on an estimated model with richer dynamics, as conducted in this paper, however, is better at capturing the transmission of shocks and the trade-offs in the economy.

This paper is organized as follows. In the next section, we outline the modeling setup. The estimation procedure is discussed in Section 3, followed by a description of the monetary and macroprudential policy setup and the implied results from coordination exercises in Section 4. Section 5 discusses the case of discretion, followed by the design of the optimal mandates insection 6 and the conclusion.

2. The modeling framework

This section describes the standard Smets and Wouters (2007) model, augmented with the Gertler and Karadi (2011) financial intermediation sector, in its linearized form around the steady state balanced growth path. Steady state values are denoted by a star. Appendix A outlines the steady state implications of introducing the Gertler–Karadi financial sector to the original Smets-Wouters setup.

The household sector consumes, saves and supplies labor, and is composed of workers and bankers (or financial intermediaries). The fraction of each type remains constant over time. In order to prevent bankers from becoming self-financed over time, they have finite horizon, and workers can switch to become bankers with probability θ. Workers return their wages to the household they belong, bankers do the same regarding their retained earnings from banking activities. While households own the intermediaries they manage, they hold deposits in banks that belong to other households. Workers supply differentiated labor, which is sold by an intermediate labor union to perfectly competitive labor packers, who in turn resell labor to intermediate goods producers. The goods markets consist of intermediate goods producers that operate under monopolistic competition and final goods producers that are perfectly competitive. The producers of intermediate goods sell these to the final goods firms who package them into one final good which is resold to the households. The following consumption Euler equation is derived from the maximization of the households' non-separable utility function with two

[2] Darracq Pariès et al. (2011) derive optimal interest rate and capital requirement rules by minimizing an ad hoc loss function under full commitment in the context of an estimated DSGE model for the euro area with financially-constrained households and firms and an oligopolistic banking sector subject to capital constraints.

arguments, i.e., consumption and leisure:

$$c_t = c_1 c_{t-1} + (1-c_1)E_t c_{t+1} + c_2(l_t - E_t l_{t+1}) - c_3(r_t - E_t\pi_{t+1} + \varepsilon_t^b) \quad (1)$$

where

$$c_1 = \frac{\lambda/\gamma}{1+\lambda/\gamma}, c_2 = \frac{(\sigma_c - 1)(W_*^h L_*/C_*)}{\sigma_c(1+\lambda/\gamma)} \text{ and } c_3 = \frac{1-\lambda/\gamma}{\sigma_c(1+\lambda/\gamma)}$$

with γ the steady state growth rate and σ_c the intertemporal elasticity of substitution. Consumption c_t is expressed with respect to an external, time-varying, habit variable, leading to persistence in the consumption equation where λ is the nonzero habit parameter. Consumption is also affected by hours worked l_t, and, more precisely, is decreasing in the expected increase in hours worked $(l_t - E_t l_{t+1})$, and by the ex ante real interest rate $(r_t - E_t\pi_{t+1})$, where r_t is the period t nominal interest rate and π_t is the inflation rate. The disturbance term ε_t^b, which is an AR(1) process with i.i.d. normal error term ($\varepsilon_t^b = \rho_b\varepsilon_{t-1}^b + \eta_t^b$), captures the difference between the interest rate and the required return on assets owned by households.[3]

Wage setting by the intermediate labor union implies a standard equation for the real wage w:

$$w_t = w_1 w_{t-1} + (1-w_1)(E_t w_{t+1} + E_t\pi_{t+1}) - w_2\pi_t + w_3\pi_{t-1} - w_4\mu_t^w + \varepsilon_t^w \quad (2)$$

where

$$w_1 = \frac{1}{1+\beta\gamma^{1-\sigma_c}}, w_2 = \frac{1+\beta\gamma^{1-\sigma_c}\iota_w}{1+\beta\gamma^{1-\sigma_c}}, w_3 = \frac{\iota_w}{1+\beta\gamma^{1-\sigma_c}}$$
$$\text{and } w_4 = \frac{(1-\beta\gamma^{1-\sigma_c}\xi_w)(1-\xi_w)}{(1+\beta\gamma^{1-\sigma_c})\xi_w((\phi_w - 1)\varepsilon_w + 1)}$$

with β the households' discount factor and ξ_w the Calvo-probability that nominal wages cannot be re-optimized in a particular period, i.e., the degree of wage stickiness. Wages that cannot be re-optimized in a particular period are partially indexed, with a degree of ι_w, to the past inflation rate, leading to the dependence of wages on previous period's inflation rate. The symbol ε_w is the curvature of the Kimball labor market aggregator and $(\phi_w - 1)$ the constant mark-up in the labor market. The wage mark-up, i.e., the difference between the real wage and the marginal rate of substitution between consumption and labor, is represented as follows:

$$\mu_t^w = w_t - mrs_t = w_t - \left(\sigma_l l_t + \frac{1}{1-\lambda}(c_t - \lambda c_{t-1})\right) \quad (3)$$

with σ_l the elasticity of labor supply with respect to the real wage. The wage mark-up shock $\varepsilon_t^w = \rho_w\varepsilon_{t-1}^w + \eta_t^w - \mu_w\eta_{t-1}^w$ (with η_t^w an i.i.d. normal error).

The utilization rate of capital can be increased subject to capital utilization costs. Households rent capital services out to firms at a rental price. The investment Euler equation is represented as follows:

$$i_t = i_1 i_{t-1} + (1-i_1)E_t i_{t+1} + i_2 q_t + \varepsilon_t^i \quad (4)$$

where

$$i_1 = \frac{1}{1+\beta\gamma^{1-\sigma_c}}, i_2 = \frac{1}{(1+\beta\gamma^{1-\sigma_c})\gamma^2\varphi}$$

with φ the elasticity of the capital adjustment cost function in the steady state, and $\varepsilon_t^i = \rho_i\varepsilon_{t-1}^i + \eta_t^i$ an AR(1) investment specific technology shock with i.i.d. error term. The real value of capital (q_t) is given by:[4]

$$q_t = q_1 E_t q_{t+1} + (1-q_1)E_t r_{t+1}^k - (r_t - E_t\pi_{t+1} + \varepsilon_t^b) \quad (5)$$

where

$$q_1 = \beta\gamma^{-\sigma_c}(1-\delta) = \frac{(1-\delta)}{R_*^k + (1-\delta)}$$

[3] Note that, although we introduce an additional financial shock that captures similar effects, we keep this shock in the analysis in order to preserve the comovement in consumption and investment.

[4] In order to define the gross return to capital ret_t^k according to the more familiar real business formulation, it is possible to show that Eq. 5 can be replaced by the following fully equivalent two equations

$$ret_t^k = (1-q_1)r_t^k + q_1 q_t - q_{t-1} - \varepsilon_{t-1}^b$$

$$E_t ret_{t+1}^k = r_t - E_t\pi_{t+1}$$

In the model with financial frictions the relation between $E_t ret_{t+1}^k$ and $r_t - E_t\pi_{t+1}$ stated in the second equation is different due to the wedge (spread) created by imperfect capital markets. It also follows that in the model without financial frictions the steady state of the return on capital $\overline{ret}_*^k$ is equal to $R_*^k + (1-\delta)$. In Appendix C we show how that steady state changes when financial frictions are on.

with δ the capital depreciation rate, and r_t^k the rental rate of capital with steady state value R_*^k. Capital services used in current production (k_t^s) depend on capital installed in the previous period since newly installed capital becomes effective with a lag of one period:

$$k_t^s = k_{t-1} + z_t \tag{6}$$

with z_t the capital utilization rate, which depends positively on r_t^k:

$$z_t = z_1 r_t^k \tag{7}$$

where

$$z_1 = \frac{1-\psi}{\psi}$$

with ψ normalized between zero and one, a positive function of the elasticity of the capital utilization adjustment cost function. The capital accumulation equation is written as follows:

$$k_t = k_1 k_{t-1} + (1-k_1) i_t + k_2 \varepsilon_t^i \tag{8}$$

where

$$k_1 = \frac{(1-\delta)}{\gamma} \text{ and } k_2 = (1-(1-\delta)/\gamma)(1+\beta\gamma^{1-\sigma_c})\gamma^2\varphi$$

The monopolistically competitive intermediate goods producers set their prices in line with Calvo (1983), which leads to the following New-Keynesian Phillips curve:

$$\pi_t = \pi_1 \pi_{t-1} + (1-\pi_1) E_t \pi_{t+1} - \pi_2 \mu_t^p + \varepsilon_t^p \tag{9}$$

where

$$\pi_1 = \frac{\beta\gamma^{1-\sigma_c}\iota_p}{1+\beta\gamma^{1-\sigma_c}\iota_p} \text{ and } \pi_2 = \frac{(1-\beta\gamma^{1-\sigma_c}\xi_p)(1-\xi_p)}{(1+\beta\gamma^{1-\sigma_c}\iota_p)\xi_p((\phi_p-1)\varepsilon_p+1)}$$

and ι_p is the indexation parameter, ξ_p the degree of price stickiness in the goods market, ε_p the curvature of the Kimball aggregator and $(\phi_p - 1)$ the constant mark-up in the goods market. μ_t^p is the price mark-up, i.e., the difference between the marginal product of labor and the real wage:

$$\mu_t^p = mpl_t - w_t = \alpha(k_t^s - l_t) + \varepsilon_t^a - w_t \tag{10}$$

The price mark-up shock follows an ARMA(1,1) process: $\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p$ where η_t^p is an i.i.d. normal error term. The shock $\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \eta_t^a$ is the total factor productivity with an i.i.d. normal error term. The firms' cost minimization condition results into the following relation between the rental rate of capital, the capital-labor ratio and the real wage:

$$r_t^k = -(k_t^s - l_t) + w_t \tag{11}$$

Equilibrium in the goods market is represented as follows:

$$\begin{aligned} y_t &= c_y c_t + i_y i_t + z_y z_t + g_y \varepsilon_t^g \\ &= \phi_p(\alpha k_t^s + (1-\alpha) l_t + \varepsilon_t^a) \end{aligned} \tag{12}$$

where y_t represents aggregate output, $z_y = R_*^k k_y$, $c_y = 1 - g_y - i_y$ the steady state share of consumption in output, $i_y = (\gamma - 1 + \delta)k_y$ the steady state share of investment in output, k_y the steady state share of capital in output and g_y the ratio of exogenous spending over output. Exogenous spending is assumed to follow an AR(1) process, including an i.i.d. total factor productivity shock: $\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \eta_t^g + \rho_{ga}\eta_t^a$. Finally, ϕ_p equals one plus the share of fixed costs in production and α is the capital share in production.

For estimation purposes, we will represent monetary policy by the following interest rate rule

$$r_t = \rho_r r_{t-1} + (1-\rho_r)\left\{r_\pi \pi_t + r_y\left(y_t - y_t^p\right)\right\} + r_{\Delta y}\left[\left(y_t - y_t^p\right) - \left(y_{t-1} - y_{t-1}^p\right)\right] + \varepsilon_t^r \tag{13}$$

where the monetary policy shock ε_t^r follows a first-order autoregressive process with an i.i.d.-normal error term: $\varepsilon_t^r = \rho_R \varepsilon_{t-1}^r + \eta_t^r$. The output gap, $y_t - y_t^p$, is the deviation of output from its level in the absence of nominal rigidities and constant markups.

Financial intermediaries lend funds obtained from households to non-financial firms. Their balance sheet is composed as follows

$$q_t + s_t = n_S n_t + b_S b_t$$

where s_t is the quantity of financial (long-term) claims on non-financial firms that the intermediary holds, n_t is the amount of net worth that intermediaries have at the end of period t, b_t the short-term deposits the intermediary obtains from households, and

$$n_S = \frac{N_*}{S_*}, \text{ and } b_S = \frac{B_*}{S_*}$$

Given that $q_t + k_t$ is the value of capital acquired by firms and $q_t + s_t$ is the value of claims against this capital, arbitrage implies that $q_t + k_t = q_t + s_t$.

Deposits held by households with the intermediary at time t, pay the non-contingent real gross return rr_{t+1} at $t+1$, where $rr_t \equiv r_t - E_t\pi_{t+1}$. Intermediary assets earn the stochastic return ret^k_{t+1} over this period. The bankers' objective is to maximize expected terminal wealth, and their equity capital evolves as the difference between earnings on assets and interest payments on liabilities. As long as the expected discounted difference between ret^k_{t+1} and rr_{t+1} is positive, the intermediary has incentives to expand its assets by borrowing indefinitely from households. To limit its ability to do so, following moral hazard/costly enforcement problem is introduced by Gertler and Karadi (2011): at the start of each period, the banker can divert a fraction Γ_t of available funds and transfer it back to the household he or she belongs to, for example in the form of large dividends or bonuses. Depositors can in this case force the intermediary into bankruptcy in order to recover the remaining fraction $1-\Gamma_t$ of assets. However, depositors cannot recover the remaining fraction Γ_t of funds diverted by the intermediary due to the high associated costs. Differently from Gertler and Karadi (2011), who treat Γ_t as a constant, we follow Dedola et al. (2013) and Bean et al. (2010), by assuming that Γ_t is time varying. In particular, we model Γ_t as an AR(1) process $\Gamma_t = (1-\rho_\Gamma)\Gamma_* + \rho_\Gamma\Gamma_{t-1} + \eta^\Gamma_t$. We will interpret this as a financial shock, reflecting a change in the perceptions of the depositors regarding the extent to which they will be able to recover their deposits. Therefore, a positive shock to Γ_t captures an increase in the risk associated to holding deposits at the financial intermediary, and will make the moral hazard problem more severe, leading to disruptions in the financial intermediation process since less funds will be available to lend to non-financial firms.[5]

The agency problem between depositors and intermediaries restricts the leverage ratio of the latter to the point where the incentive to divert funds is exactly offset by the costs of doing so. Hence, the amount of assets that the banker can acquire will depend positively on the equity capital as follows

$$q_t + k^s_t = lev_t + n_t \tag{14}$$

where lev_t is intermediaries' leverage, defined as

$$lev_t = \eta_t - l_1\Gamma_t - l_2\upsilon_t \tag{15}$$

and

$$l_1 = \frac{\Gamma_*}{\Gamma_* - \upsilon_*}, \text{ and } l_2 = \frac{\upsilon_*}{\Gamma_* - \upsilon_*}$$

The variable υ_t can be interpreted as expected discounted marginal gain to the banker of expanding assets by a unit, holding net worth constant, while η_t is the expected discounted value of having another unit of net worth, holding assets constant, which can be expressed as

$$\eta_t = \eta_1(E_t\Lambda_{t+1} + rr_t) + \eta_2 E_t\left\{\Lambda_{t+1} + z^{GK}_{t,t+1} + \eta_{t+1}\right\} \tag{16}$$

$$\upsilon_t = \upsilon_1[(\overline{ret}^k_* E_t ret^k_{t+1} - \overline{RR}_* rr_t) + (\overline{ret}^k_* - \overline{RR}_*)E_t\Lambda_{t+1}] + \upsilon_2 E_t\{\Lambda_{t+1} + x_{t,t+1} + \upsilon_{t+1}\} \tag{17}$$

where

$$\eta_1 = \frac{\beta}{\gamma^{\sigma_c}}\frac{(1-\theta)\overline{RR}_*}{\eta_*}, \quad \eta_2 = \frac{\beta}{\gamma^{\sigma_c}}\theta Z^{GK}_*, \quad \upsilon_1 = \frac{\beta}{\gamma^{\sigma_c}}\frac{(1-\theta)}{\upsilon_*}, \text{ and } \upsilon_2 = \frac{\beta}{\gamma^{\sigma_c}}\theta X_*$$

and $x_{t,t+i}$ is the gross growth rate in assets between t and $t+i$, and $z^{GK}_{t,t+i}$ is the gross growth rate of net worth, expressed as follows

$$z^{GK}_{t-1,t} = z_1(\overline{ret}^k_* ret^k_t - \overline{RR}_* rr_{t-1}) + z_2 lev_{t-1} + z_3 rr_{t-1} \tag{18}$$

$$x_{t-1,t} = lev_t - lev_{t-1} + z^{GK}_{t-1,t}$$

where

$$z_1 = \frac{\overline{lev}_*}{Z^{GK}_*}, \quad z_2 = \frac{\overline{lev}_*(\overline{ret}^k_* - \overline{RR}_*)}{Z^{GK}_*}, \text{ and } z_3 = \frac{\overline{RR}_*}{Z^{GK}_*}$$

Finally, the stochastic discount factor Λ_t and the marginal utility of consumption $U'_{c,t}$ are defined as follows

$$\Lambda_t = U'_{c,t} - U'_{c,t-1} \tag{19}$$

$$U'_{c,t} = u_1 l_t - u_2 c_t + u_3 c_{t-1} \tag{20}$$

[5] Dedola et al. (2013) interpret a positive shock to Γ_t as a confidence loss.

where

$$u_1 = (\sigma_c - 1)L_*^{(1+\sigma_l)}, \ u_2 = \frac{\sigma_c}{1-\lambda}, \text{ and } u_3 = \frac{\sigma_c \lambda}{\gamma(1-\lambda)}$$

The law of motion for n_t, i.e. the sum of net worth of existing intermediaries (n_{et}) and the net worth of entering, or "new" intermediaries (n_{nt}), is given by

$$n_t = n_1 n_{et} + n_2 n_{nt} \tag{21}$$

where $n_1 = \overline{NE}_*/N_*$ and $n_2 = \overline{NN}_*/N_*$. Since the fraction θ of bankers at $t-1$ survive until the next period t, n_{et} is given by

$$n_{et} = z_{t-1,t}^{GK} + n_{t-1} \tag{22}$$

Each new banker receives a start-up fund from the household he or she belongs to. This fund is proportional to the funds managed by the exiting bankers, namely $(1-\theta)Q_t S_{t-1}$. Hence, the household transfers every period a fraction $\omega/(1-\theta)$ of this value to its newly entering bankers, leading in aggregate to

$$n_{nt} = q_t + k_t^s$$

Finally, the premium the banker earns on its assets is expressed as follows

$$Prem_t = E_t ret_{t+1}^k - rr_t \tag{23}$$

We do not rely on the presence of a macroprudential rule in the estimation process, as we do not regard this to be crucial for obtaining realistic estimates for the sample period considered in the next section.

3. Estimation

In this section, we elaborate on the choice of our estimation sample and the data set we composed to perform the estimations, followed by a brief discussion of the estimated parameters, the empirical fit, and the transmission of shocks.

3.1. Data and methodology

We use a quarterly dataset on the US containing following ten observables: log difference of the real GDP, log difference of real consumption, log difference of real investment, log difference of real wage, log of hours worked, log difference of the GDP deflator, the federal funds rate, the Gilchrist and Zakrajšek (2012) spread (GZ-spread, henceforth), log difference of the real net worth, and the return to capital constructed by Gomme et al. (2011). The first seven observables correspond to the dataset used in the estimation of Smets and Wouters (2007). We consider the GZ-spread as a reasonable proxy for the premium given that the authors show that the spread is closely related to measures of financial intermediary health, which makes the spread a good predictor of distress in the financial intermediation sector. For the computation of the GZ-spread, Gilchrist and Zakrajšek (2012) consider each loan obtained by each set of firms taken from the COMPUSTAT database. They compare for every single case the interest rate actually paid by the firm with what the US government would have paid on a loan with a similar maturity. In terms of default risk, their sample spans the entire spectrum of credit quality, from "single D" to "triple A" . The aggregate spread is accordingly an arithmetic average of the credit spreads on each single corporate bond. The return to capital series constructed by Gomme et al. (2011) is chosen due to its consistency with the model definition.[6] The net worth growth rate is computed using data on all commercial banks' real net worth. To obtain the latter, we started from all commercial banks' nominal credit and from all commercial banks' nominal deposit. The two nominal series are divided by the GDP deflator. The difference between real credit and real deposit is the real net worth.

Appendix B contains the details regarding the dataset. The estimation sample ranges over the period 1990:1-2007:4. The reason for not starting the estimation sample earlier is due to the availability of qualitative financial data, in particular the net worth series. We consider a training sample of 20 quarters (i.e., 5 years) to initialize the estimations. The estimation period is limited until 2007:4 due to the distortionary effects of the binding zero lower bound and the crisis period on the estimates of some of the structural parameters, such as the wage rigidities (see Galí et al. (2012). However, we find that the main results are not affected when we consider the post-crisis sample in order to account for the volatilities of structural shocks.

The structural equations are accompanied by eight structural shocks (ε_t^b, ε_t^w, ε_t^i, ε_t^p, ε_t^a, ε_t^g, ε_t^r, Γ_t), the standard errors of which are denoted by σ_b, σ_w, σ_i, σ_p, σ_a, σ_g, σ_r, σ_Γ, respectively, and two autoregressive measurement errors of order one accompanying the measurement equations of the GZ-spread and the return to capital.[7]

The observed quarterly growth rates in the real GDP, real consumption, real investment, and real wages are split into a common trend growth, $\bar{\gamma} = (\gamma - 1)100$, and a cycle growth. The quarterly growth rate of the real net worth is split into

[6] In particular, given that the GZ-spread is used as an observable for the premium, there is a gap between the model's definition for the premium, (23), which is based on the return to capital $E_t ret_{t+1}^k$, and the definition used to construct the data, which is not consistent with $E_t ret_{t+1}^k$. Therefore, the observable for ret_{t+1}^k is added in order to address this inconsistency.

[7] These measurement errors turn out to explain about one third of the variance in the spread and the return to capital, respectively.

a separate, constant growth, $\bar{\gamma}^n$ and a cycle growth. Hours worked in the steady state is normalized to zero. The quarterly steady state inflation rate $\bar{\pi} = (\Pi_* - 1)100$ serves the role of the inflation target, implying that monetary policy's objective is to stabilize inflation around its sample mean. In addition, we estimate $\bar{r} = (\frac{\gamma^{\sigma_c}\Pi_*}{\beta} - 1)100$ (the steady state nominal interest rate), the net worth growth in the steady state $\overline{cn} = (Z_*^{GK} - 1)100$ and the steady state of the net premium $\overline{PREM}_*$ according to $\overline{cs} = \overline{PREM}_* 100$. Finally, the steady state return to capital is estimated according to $\overline{crk} = (\overline{ret}_*^k - 1)100$. The estimation of these steady state values has implications for the number of parameters that can be freely estimated. We show in Appendix A that, given the estimated steady state values, parameter σ_c can be uniquely pinned down by steady state restrictions and therefore is not estimated. We use Bayesian methods to estimate the model in dynare.

3.2. Parameter estimates

Table 1 presents the prior assumptions and the estimation results. Further details on the priors are discussed in Appendix C. All estimated parameters are identified according to the Iskrev (2010) identification test. We focus mainly on the discussion of the parameter estimates related to the financial block, since the remaining structural parameters are broadly in line with those reported by Smets and Wouters (2007), except for the habit persistence and the investment adjustment cost parameters, which are somewhat lower than their estimated values.

The estimation results lead to the following values implied by the steady state restrictions (see Appendix A) on the intertemporal elasticity of substitution, $\sigma_c = 0.7082$, the steady state net premium, $\overline{PREM}_* = 0.0049$, the steady state leverage ratio, $\overline{LEV}_* = 3.7484$, the fraction of divertible bank capital, $\Gamma_* = 0.6782$, the survival rate of bankers, $\theta = 0.9704$, and the gross growth rate of bankers' net worth $Z_*^{GK} = 1.0227$.

Comparing the financial sector parameters to previously estimated values is a challenging task given that a number of studies adopting the Gertler–Karadi banking sector framework either calibrate the parameters concerning the financial sector (Lima et al. (2012) and Villa and Yang (2011)), or perform estimations in the absence of financial observables (Villa (2013)). To our knowledge, the only exception is Gortz and Tsoukalas (2012). The latter authors use two sector-specific spreads and a measure of bank equity in the set of observables but do not consider the information content provided by these variables on the steady state values of the endogenous variables and the restrictions imposed by the Gertler–Karadi framework on the steady state as described in Appendix A. Nevertheless, the implied share of divertible funds, $\Gamma_* = 0.6782$, turns out to be considerably higher than the value of 0.381 calibrated by Gertler and Karadi (2011), and similar values set by Dedola et al. (2013) and Gortz and Tsoukalas (2012) for the US. The steady state premium is estimated to be 0.0049, which implies 50 basis points on quarterly basis. This value differs from the Gertler–Karadi calibration of 0.002475 and is at the source of the high value implied for Γ_*. The remaining implied parameters are broadly in line with the values calibrated by Gertler and Karadi (2011).

In order to assess the relevance of the financial shock for real economic activity, the first line of Table 2 reports the variance decomposition of output at the infinite horizon. The investment specific shock explains together with the technology shock more than 50% of the volatility of output. The financial shock is the third most important shock and explains about 13% of the output volatility. This is in line with recent empirical studies in estimated models featuring financial frictions. For example, Jermann and Quadrini (2012) show in the context of an estimated model similar to Smets and Wouters (2007), featuring financial frictions and financial shocks, that credit shocks contribute to at least one-third of the variance of US output and labor, while Liu et al. (2010) show that between 5% and 12% of US output variability is explained by their collateral shock depending on the considered horizon. Inflation volatility is mainly driven by price and wage markup shocks. These two shocks explain around 80% of the volatility of inflation, as in Smets and Wouters (2007). Table 2 also reports the variance decomposition of the policy rate, which suggests that the largest share of the interest rate volatility can be explained by the demand shocks such as the risk premium and investment specific shocks, followed by the financial shock. The latter explains about 7% of the volatility in the interest rate.

3.3. Model fit

We assess the empirical fit of the estimated model by comparing the standard errors, auto- and cross-correlations of the observables to their counterparts implied by the posterior distribution. Table 3 shows the standard errors of the data against the 90% posterior intervals implied by the model. The latter is computed with the sampling method as described in Gertler et al. (2008). The model succeeds well in matching the volatilities of investment, hours worked, wages and inflation. While the model implied standard errors of output, consumption and the policy rate do not capture the actual volatilities, the latter lie fairly close to the interval bounds so that the fit can still be considered as rather satisfactory. Regarding net worth, return to capital and the premium, however, the model tends to overestimate their volatilities. Fig. 1 plots the autocorrelations up to the fifth order. The model, with the exception of the return to capital and net worth, does a good job at matching the persistence of all variables fairly well.

Finally, Table 4 reports the cross-correlation statistics for the observables. Regarding the observables we have in common with Smets and Wouters (2007), i.e., output, consumption, investment, real wage, hours worked, inflation and the policy rate, the model does a good job at capturing the cross-correlations observed in the data. The same conclusion holds for the financial observables, in particular for the premium and net worth. It is worth noting that the model manages to capture

Table 1
Priors and estimation results.

Marginal Likelihood (MHM)	−635.44					
	Prior			Posterior		
	Distr.	Mean	Std.	Mode	Mean	5–95th
structural parameters						
φ investment adjustment cost	N	4	1.5	2.97	3.31	1.85–4.69
λ habit persistence	B	0.70	0.1	0.27	0.28	0.20–0.35
ξ_w Calvo wage stickiness	B	0.50	0.1	0.76	0.73	0.59–0.85
σ_l elast. of labor wrt real wage	N	2	0.75	2.06	2.10	1.26–2.95
ξ_p Calvo price stickiness	B	0.50	0.10	0.74	0.74	0.65–0.82
ι_w wage indexation	B	0.50	0.15	0.48	0.49	0.25–0.74
ι_p price indexation	B	0.50	0.15	0.34	0.38	0.17–0.58
ψ capital utiliz. cost	B	0.50	0.15	0.82	0.81	0.70–0.92
ϕ_p (1+fixed costs in production)	N	1.25	0.12	1.43	1.43	1.27–1.59
$(\beta^{-1}-1)100$ const. discount	G	0.25	0.10	0.10	0.10	0.04–0.16
L_* constant labor supply	N	0	2	−0.13	−0.08	−1.36–1.18
$\bar{\gamma}$ constant growth rate	N	0.40	0.10	0.47	0.47	0.43–0.52
α share of capital in production	N	0.30	0.05	0.22	0.22	0.18–0.26
$\overline{crk}$ const. return to capital	IG	1.14	0.60	0.93	0.93	0.82–1.05
$\overline{cs}$ const. premium	IG	0.25	0.25	0.48	0.48	0.38–0.57
$\overline{cn}$ const. net worth growth	N	1.78	3.73	2.26	2.26	1.98–2.54
$\bar{\pi}$ const. inflation	G	0.62	0.10	0.55	0.55	0.46–0.65
ρ_r interest rate smoothing	B	0.75	0.10	0.85	0.85	0.81–0.88
r_π inflation coeff. Taylor rule	N	1.50	0.25	1.98	1.98	1.65–2.29
r_y output gap coeff. Taylor rule	N	0.12	0.05	0.08	0.08	0.03–0.13
$r_{\Delta y}$ output gap diff. Taylor rule	N	0.12	0.05	0.19	0.19	0.16–0.23
shock processes						
σ_a technology	IG	0.10	2	0.37	0.38	0.32–0.44
σ_b risk premium	IG	0.10	2	0.10	0.11	0.08–0.13
σ_g exogenous spending	IG	0.10	2	0.36	0.37	0.32–0.43
σ_I investment specific	IG	0.10	2	0.24	0.24	0.18–0.31
σ_p price mark-up	IG	0.10	2	0.10	0.10	0.08–0.13
σ_w wage mark-up	IG	0.10	2	0.33	0.33	0.26–0.40
σ_R mon. policy shock	IG	0.10	2	0.09	0.10	0.08–0.12
σ_Γ financial shock	IG	0.10	2	1.88	1.95	1.39–2.49
σ_{prem} meas. err. premium	IG	0.10	2	0.14	0.15	0.12–0.17
σ_{retk} meas. err. return to cap.	IG	0.10	2	0.97	0.99	0.83–1.14
ρ_a AR(1) technology	B	0.50	0.20	0.90	0.91	0.84–0.98
ρ_b AR(1) risk premium	B	0.50	0.20	0.85	0.85	0.81–0.89
ρ_g AR(1) exogenous spending	B	0.50	0.20	0.96	0.96	0.95–0.98
ρ_I AR(1) investment specific	B	0.50	0.20	0.95	0.95	0.92–0.99
ρ_p AR(1) price mark-up	B	0.20	0.20	0.79	0.73	0.55–0.91
ρ_w AR(1) wage mark-up	B	0.50	0.20	0.69	0.65	0.41–0.89
ρ_{ga} effect of technology on exports	B	0.50	0.20	0.52	0.52	0.35–0.70
μ_p MA(1) price mark-up	B	0.50	0.20	0.54	0.54	0.28–0.79
μ_w MA(1) wage mark-up	B	0.50	0.20	0.50	0.50	0.24–0.77
ρ_R AR(1) monetary policy	B	0.50	0.20	0.18	0.18	0.07–0.29
ρ_Γ AR(1) financial shock	B	0.50	0.20	0.98	0.98	0.98–0.99
ρ_{prem} AR(1) meas. err. premium	B	0.50	0.20	0.92	0.92	0.88–0.97
ρ_{retk} AR(1) meas. err. ret. to cap.	B	0.50	0.20	0.54	0.54	0.39–0.70

Note: The table reports the prior distribution (where N = Normal, B = Beta, G = Gamma, IG = inverse gamma), prior means and the prior standard errors for the structural parameters, the shock processes (where the standard errors of the shocks are denoted by σ and the AR (1) coefficients of the persistent shocks by ρ) and the monetary policy parameters, as well as the marginal likelihood (modified harmonic mean) and the posterior estimation results (the posterior mode, the posterior mean and the 5–95th percentiles) for the estimated parameters. The posterior estimation results are obtained with the Metropolis-Hastings sampling algorithm based on 400, 000 draws, from which the first 20% draws are discarded. The posterior mode is obtained from the numerical optimization of the posterior kernel.

the counter-cyclicality of the premium. Moreover, the co-movement between output, inflation and net worth is correctly captured by the model.

3.4. Transmission of shocks in the estimated model

Before introducing the coordination setup between monetary and macroprudential policy, it is useful to assess the potential role of macroprudential regulation in addressing financial frictions and the resulting trade-offs in the estimated model.

Table 2
Variance decomposition of output, inflation and the interest rate.

	techn. shock	risk premium	exog. spending	inv. specific shock	mon. pol. shock	price mark-up	wage mark-up	financial shock
Output	20.92	11.84	3.17	35.63	5.33	6.32	4.33	12.45
Inflation	2.51	7.85	0.36	2.98	5.03	55.77	24.45	1.05
Interest rate	4.29	64.29	1.23	13.33	3.07	2.18	5.01	6.60

Note: The Table reports the variance decompositions at the infinite horizon, based on the mode of the posterior distribution reported in Table 1.

Table 3
Volatlity comparison observables (Actual vs. Model).

Observable	Standard error	
	Data	Model (5–95*th* percentiles)
Output growth*	0.56	0.64–0.96
Consumption growth*	0.48	0.51–0.76
Investment growth**	1.73	1.95–3.43
Hours worked**	2.03	1.06–2.63
Wage growth**	0.71	0.60–0.91
Inflation**	0.23	0.21–0.40
Interest rate*	0.46	0.18–0.43
Net Worth growth	3.73	5.17–7.89
Return to Capital	0.52	1.73–2.46
Premium	0.20	0.37–0.81

Note: The table compares the standard errors of the observables based on the data to the corresponding 5–95*th* percentiles implied by the estimated model. The observables for which actual standard errors are matched by the model are denoted by a double star. The observables denoted by one star refer to the cases where the interval does not include the actual standard errors, but the value of the latter is close to the bounds of the interval.

In particular, we look at the transmission of a positive supply (technology) shock and a negative demand (financial) shock when no macroprudential regulator is present. Subsequently, we introduce the following instrument rule for macroprudential policy, in order to assess the extent to which this affects the transmission process of the shocks:

$$\tau_t = (y_t - y_{t-1}) + 0.1(credit_t - credit_{t-1}) \tag{24}$$

The instrument is a counteryclical lump-sum levy/subsidy on bank capital set in function of credit and business cycle indicators.[8] Therefore, the instrument directly affects the intermediary's balance sheet, which makes it an effective tool since the latter influences the credit flow to the private sector. As in Bean et al. (2010), we assume that the levy/subsidy captures the main policy effects of countercyclical bank capital buffers and limits to bank leverage that are exogenously imposed by regulators on banks. The rule could also capture the tax implications of the Dodd-Frank act and Basel III on bank capital. Given that we do not explicitly model the distortions that macroprudential policy should address (such as default, systemic risk or reducing the probabilities of tail events), we take for granted the presence of the macroprudential regulator. Although important progress has been made in the literature to explain the role for macroprudential policy (see Benigno et al. (2013), and Dewachter and Wouters (2014), and references therein), it currently remains a challenge to incorporate these features in a more elaborated and realistic model setting that can be used for policy exercises. Therefore, we focus on how the transmission of shocks and volatilities of main macroeconomic variables are affected in the presence of macroprudential policy and its interaction with monetary policy. Despite the fact that credit cycles do not appear endogenously, the amplification mechanism caused by the moral hazard problem in the banking sector gives rise to a credit cycle triggered by financial shocks, which can eventually lead to large drops in output. For this reason, our specific macroprudential tool (24) potentially plays a beneficial role, i.e., by addressing the effects of financial shocks directly, and therefore making it a more effective tool than the interest rate.

Panel a of Fig. 2 shows the responses when the economy is hit by a positive technology shock, leading to an increase in output and credit, but lower inflation due to a lower output gap (not shown) as the increase in output is smaller than its potential counterpart. Monetary policy reacts by cutting the policy rate (but not enough to close the negative output gap) which, in the absence of macroprudential policy, is relatively small and short-lived. When the countercyclical macroprudential rule is activated, it tightens in order to slow down credit growth. The latter weakens demand and enhances the

[8] The coefficient on credit growth is set to a low value because higher reaction coefficients tend to magnify the benefits of the macroprudential rule.

Table 4
Cross-Correlations Observables (Actual vs. Model)

	output	consumption	investment	hours worked	wages	inflation	interest rate	net worth	return to capital	premium
output	1.00									
consumption	0.63*	1.00								
	(0.14–0.62)									
investment	0.63**	0.50	1.00							
	(0.56–0.82)	(−0.31–0.26)								
hours worked	0.17**	0.30**	0.16**	1.00						
	(0.03–0.34)	(−0.24–0.30)	(0.02–0.45)							
wages	−0.05*	0.18**	−0.01 **	0.27**	1.00					
	(−0.04–0.40)	(−0.20–0.24)	(−0.06–0.40)	(−0.01–0.41)						
inflation	−0.42 **	−0.50 **	−0.31 **	−0.34	−0.25 **	1.00				
	(−0.48–0.06)	(−0.50– −0.01)	(−0.43–0.25)	(−0.29–0.51)	(−0.32–0.17)					
interest rate	−0.14 **	−0.07 **	−0.26 **	0.6**	0.18**	0.16**	1.00			
	(−0.32–0.23)	(−0.30–0.21)	(−0.30–0.32)	(−0.07–0.83)	(−0.23–0.23)	(0.13–0.72)				
net worth	0.18**	0.20	0.31**	0.04**	−0.11	−0.14 **	−0.07 **	1.00		
	(0.26–0.62)	(0.29–0.65)	(0.00–0.43)	(−0.22–0.12)	(−0.06–0.34)	(−0.27–0.11)	(−0.25–0.10)			
return to capital	−0.03	−0.26	0.06**	−0.18 **	−0.18	0.16*	−0.21 **	0.06	1.00	
	(0.17–0.57)	(0.21–0.60)	(−0.06–0.42)	(−0.25–0.23)	(−0.08–0.33)	(−0.31–0.15)	(−0.25–0.23)	(0.71–0.90)		
premium	−0.24 **	−0.17 **	−0.31 **	−0.06 **	0.08**	−0.13 **	−0.39 **	−0.16 **	0.07**	1.00
	(−0.48– −0.02)	(−0.27–0.25)	(−0.61– −0.07)	(−0.85– −0.02)	(−0.34–0.11)	(−0.52–0.27)	(−0.76–0.14)	(−0.22–0.11)	(−0.31–0.16)	

Note: The table compares the cross-correlation coefficients of the observables based on the data to the corresponding $5th - 95th$ percentiles, reported below the actual values in brackets, implied by the estimated model. The observables for which the cross-correlation coefficients are matched by the model are denoted by a double star. The observables denoted by one star refer to the cases where the interval does not include the actual cross-correlation coefficient, but the value of the latter is close to the bounds of the interval.

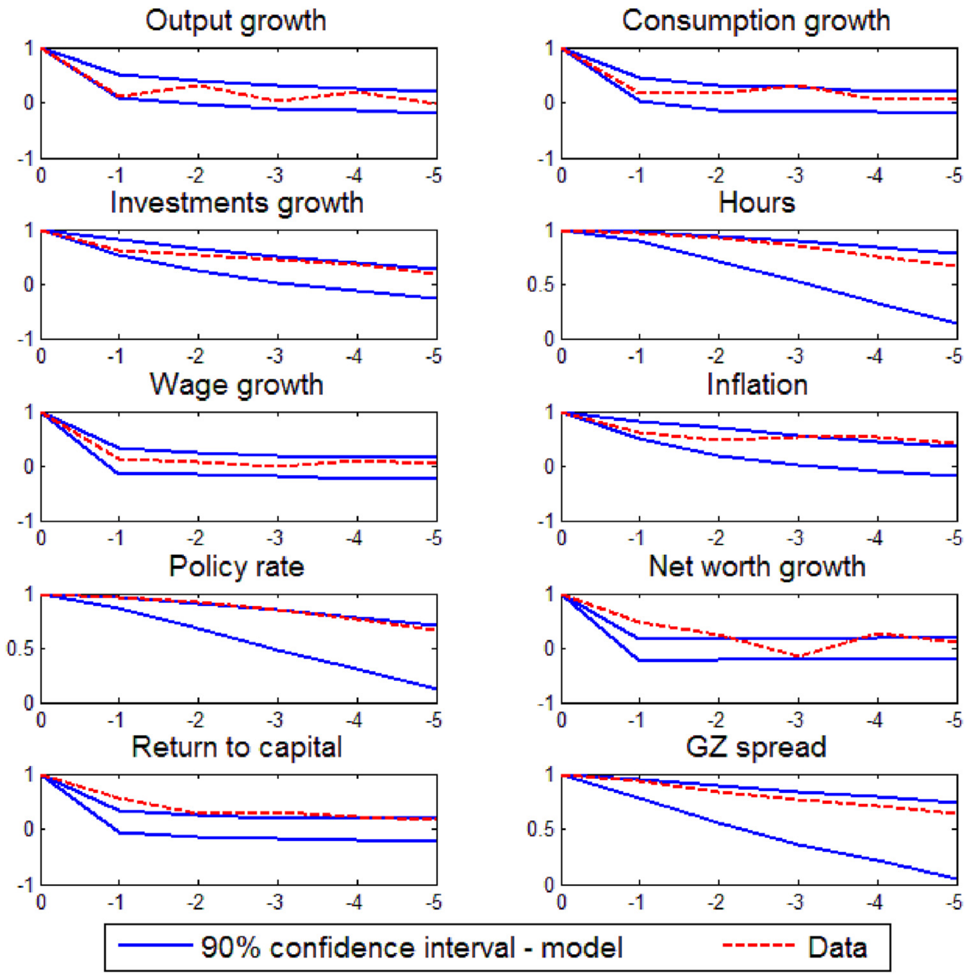

Fig. 1. Autocorrelations Observables (Actual vs. Model) *Note:* The figure plots the autocorrelations of the observables up to the fifth order, where the dashed line refers to the data and the solid lines represent the 5–95*th* percentiles.

downward pressure on prices and, therefore, leading to further loosening of the monetary policy instrument. Also note that the drop in the countercyclical bank leverage ratio is smaller when the macroprudential instrument is activated. Since both policies respond to the shock in opposite directions, one policy partly offsetting the effect of the other, there is a conflict between the monetary and macroprudential policy objectives and potential coordination failures (and related costs) are important in this case. This result resembles the "push me- pull you" effect referred to in Bean et al. (2010) and Angelini et al. (2012). Panel b of Fig. 2 shows the case of a negative demand shock, i.e., a financial shock, leading to a reduction in output (gap), credit and inflation. Monetary policy reacts to lower inflation and output by cutting the policy rate, while the macroprudential rule (when activated) also loosens its instrument in response to lower credit. In fact, in presence of the macroprudential instrument, less monetary policy accommodation is needed, since the drop in credit is partly offset by the macroprudential instrument (subsidy in this case), whose intervention moderates the recession by leading to smaller decreases in output and inflation. Given that both policies respond to the shock in the same direction, re-enforcing each other, there is little or no conflict between the monetary and macroprudential objectives in face of a financial shock. This makes both policies more complementary and less likely to face huge costs from coordination failures.

4. The interplay between monetary and macroprudential policy

4.1. Objectives and instruments

The central bank is assumed to minimize the following discounted intertemporal loss function:

$$L_t^{CB} = E_t \sum_{i=0}^{\infty} \delta_{CB}^i \left[(\pi_{t+i}^a)^2 + \lambda_y^{CB} (y_{t+i} - y_{t+i}^p)^2 + \lambda_r^{CB} (r_{t+i}^a)^2 \right] \tag{25}$$

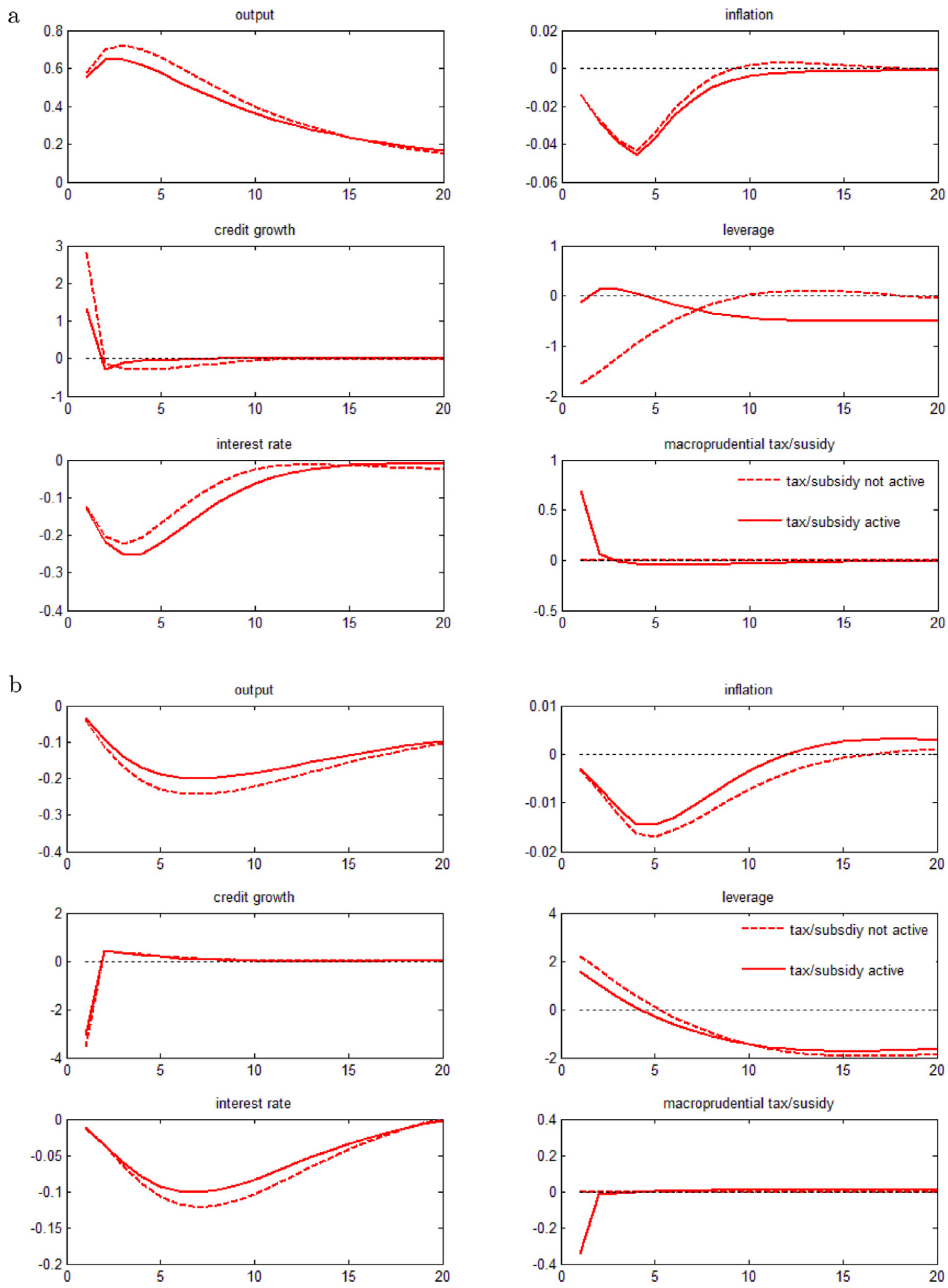

Fig. 2. (a) Impulse Responses Estimated Model - Positive Technology Shock. (b) Impulse Responses Estimated Model - Financial Shock. *Note:* The figure plots the impulse responses to a positive technology shock (upper panel) and a negative financial shock (lower panel) in the estimated version of the model where monetary policy is represented by a Taylor rule and macroprudential is not active (dashed line), and where an ad hoc macroprudential policy rule in the form of a bank capital tax/subsidy $\tau_t = (y_t - y_{t-1}) + 0.1(credit_t - credit_{t-1})$ is activated (solid line)

with $\delta_{CB} = 0.99$ the monetary policy discount factor and E_t the expectation operator conditional on information available at time t. The central bank is assumed to adopt a flexible inflation targeting regime: the main objective is to stabilize annual inflation around the (steady state) target, and to keep output as close as possible to its potential level. We assume that, to some extent, the central bank also would like to keep some stability in the annual interest rate. The weight on the inflation target is normalized to one, hence the weights on output gap and interest rate volatility are relative weights. The central bank optimizes only once in the initial period, and the resulting optimal rule is applied not only in the initial period, but also in the periods following that. The value of the loss function (25) is minimized, given the structural model restrictions (1)–(23) excluding equation (13), with respect to the coefficients of the following Taylor type of rule with interest rate smoothing:[9]

$$r_t = \rho r_{t-1} + \alpha_\pi \pi_t + \alpha_y (y_t - y_t^p) \tag{26}$$

The macroprudential regulator has been assigned its own loss function. It is a challenging task to propose a set of objectives that can be considered as standard, since there is no established practice of representing macroprudential policy in the form of an ad hoc loss function. As noted by Galati and Moessner (2012), there is no common definition of financial stability objectives that should be pursued by macroprudential policy. We therefore closely follow recent work by Angelini et al. (2012) in considering the following discounted intertemporal loss function for the macroprudential regulator:

$$L_t^{mp} = E_t \sum_{i=0}^{\infty} \delta_{mp}^i \left[\lambda_y^{mp} (y_{t+i} - y_{t+i}^p)^2 + \lambda_{\Delta c}^{mp} (credit_{t+i} - credit_{t+i-1})^2 \right] \tag{27}$$

with $\delta_{mp} = 0.99$ the macroprudential discount factor. We assume that the macroprudential regulator receives a double mandate, i.e. stabilizing the real economy by assigning weight to deviations of output from potential, and the financial sector, which is expressed in terms of nominal credit growth.[10] The presence of the output gap in the macroprudential loss function reflects the concern to stabilize the indirect effects originating from disruptions to financial variables that are not included in the loss function, but could affect the real economy even in the presence of price stability. Moreover, the Basel III regulation refers to "reducing the risk of spillover from the financial sector to the real economy" as one of the main objectives of the regulatory reforms. If we assume that both objectives receive equal weights, i.e., $\lambda_y^{mp} = \lambda_{\Delta c}^{mp} = 0.5$, the macroprudential regulator assigns equal importance to financial stability and output stabilization. In the simulation exercises, we will consider alternative values for λ_y^{mp} in order to include cases in which the financial objective becomes relatively more and less important than output stability, respectively.

As a macroprudential instrument, we adopt the lump-sum levy/subsidy on bank capital introduced in the previous section:[11],[12]

$$\tau_t = \beta_y (y_t - y_{t-1}) + \beta_c (credit_t - credit_{t-1}) \tag{28}$$

In analogy with the central bank's optimization problem, the macroprudential regulator seeks to minimize the loss function (27), given the structural model restrictions (1)–(23) excluding equation (13), to compute the optimal values of β_y and β_c. The bank capital equation is accordingly modified by the addition of τ_t:

$$n_t = n_1 n_{et} + n_2 n_{nt} - \tau_t \tag{29}$$

In the following, we set out the alternative coordination schemes between the central bank and the macroprudential regulator considered in the simulation exercises. The computational procedure followed to find the optimal coefficients of (26) and (28) is described in detail in Dennis (2004).

4.2. Alternative coordination schemes

We distinguish between two alternative interaction schemes, i.e., coordination and no-coordination. In the coordination case, the respective optimization problems of the two policies are merged into a joint optimization problem[13]:

$$L_t^{CB+mp} = E_t \sum_{i=0}^{\infty} \delta^i \left[(\pi_{t+i}^a)^2 + (\lambda_y^{CB} + \lambda_y^{mp})(y_{t+i} - y_{t+i}^p)^2 + \lambda_r^{CB} (r_{t+i}^a)^2 + \lambda_{\Delta c}^{mp} (credit_{t+i} - credit_{t+i-1})^2 \right] \tag{30}$$

with $\delta^i = 0.99$. We treat the above problem as one of a single policymaker with the task to minimize the joint loss function, having two instruments at disposal, i.e. the interest rate rule (26) and the bank levy/subsidy (28). We leave aside the institutional setup and practical implementation of the full coordination case, since this is beyond the scope of this paper. One interpretation of the joint loss function is to charge the central bank with macroprudential objectives, implying an adjustment to its mandate of flexible inflation targeting.

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[9] Note that this rule is more simplified than the estimated Taylor rule (13) in order to restrict the number of coefficients to be optimized. The qualitative results remain, however, unchanged when we consider the rule (13) instead.

[10] The results discussed in the next section are robust to two alternative financial stability objectives in the macroprudential loss function (27): the credit-to-GDP ratio as a proxy for bank leverage (in deviation from steady state values), as suggested by Angelini et al. (2012) and Quint and Rabanal (2014), and the spread measure following the (micro-founded) loss function derived by Cecchetti and Kohler (2014).

[11] In the baseline exercises, we opt for growth rates in both output and credit variables as arguments in the macroprudential instrument in order to contain the responsiveness of the tax/subsidy policy. Replacing the output growth term by the level (or the first difference) of the more volatile output gap does neither affect the qualitative results, nor the policy implications obtained in the rest of the paper.

[12] Unlike the monetary policy rule, we do not assume smoothing of the macroprudential instrument. The reason is that, when allowed for smoothing, the optimal smoothing parameter always turns out to be very close or equal to zero.

[13] As discussed by Debortoli et al. (2015), although in theory society should assign a microfounded loss function to policy makers, in practice the latter would include a high number of variables in the framework of the model we use, which would challenge communication about policy decisions. In addition, the utility-based welfare criterion is usually unknown to the policy maker, who is typically assigned a simple mandate in terms of only a few variables (see survey on central banks' mandates in Reis (2013) and Svensson (2010)). A simple mandate expressed in terms of a quadratic loss function is also more robust to model uncertainty than a utility-based welfare criterion.

In the no-coordination case, we adopt a dynamic setting where the macroprudential policy maker moves first[14] and sets the macroprudential rule that minimizes (27) by taking the monetary policy rule (26) as given, to which monetary policy reacts in setting the interest rate by minimizing (25) and taking the macroprudential rule (28) as given. In the next stage, the optimal reaction of monetary policy is taken into account by macroprudential policy, etc. This process continues until the coefficients in both rules (26) and (28) have reached convergence. This approach is comparable to the one adopted by Angelini et al. (2012). The formal procedure and the algorithms for the no-coordination problem are based on Dennis (2004) and explained in detail in Appendix D.

4.3. Gains and losses from coordination vs. no-coordination

This section examines how monetary and macroprudential policy can gain from coordination under alternative assumptions regarding the importance of the output gap in the loss function (27) of the macroprudential regulator. The aim of this exercise is therefore to assess how altering the policy preference for output gap stabilization affects the performance of policy under the institutional set-up of coordination and no-coordination. By assuming that the mandates of the policy makers are chosen first, we can learn about the individual trade-offs and determine which interaction scheme is more beneficial under the given mandate.

Although it might appear to be somewhat unusual to assume that the mandates are taken as given when assessing the gains from coordination, the exercise is useful since the assumption that mandates are chosen first applies realistically to the case of monetary policy. The central bank in practice is assigned a well-defined price stability mandate by law, which has been established long before the onset of the financial crisis and hence needs to be taken as given by the government when introducing a new policy institution in charge of macroprudential policy in response to the needs caused by the financial crisis. This implies that the government needs to decide on both the mandate of macroprudential policy as well as the cooperative setting within which it should interact with monetary policy. While the monetary policy mandate is well established and generally represented in the literature by a loss function of type (25), this is currently not the case of macroprudential policy. Although it is straightforward to assume a high weight for the financial stability concern, it is far less clear whether and to which extent additional non-financial objectives such as output should be included as an explicit concern when defining the macroprudential mandate. We however rely, as mentioned in Section 4.1, on the Basel III regulation to consider the output gap as an additional concern to be included in the mandate of macroprudential policy. This approach is also taken by Angelini et al. (2012), who base their choice of output fluctuations in the macroprudential loss function on the Committee on the Global Financial System (2010), which states that macroprudential policy should aim to address financial disruption in order to avoid negative real economy effects. We capture the real economy concerns of macroprudential policy in terms of the output gap, which leads to a common objective with monetary policy. Importantly, this reflects the realistic setting where the government does not necessarily want to assign strictly separated mandates to both policy makers.

With the introduction of macroprudential policy as a new player into the post-crisis policy scene, the government needs to decide on a new institutional setup within which macroprudential policy should operate and interact with monetary policy. Since, as noted in the introduction, there is a strong debate in academic and policy circles on whether (and, if yes, to which extent) the two policy makers should cooperate, it is useful to compare the two extreme cases of coordination vs. no-coordination. Moreover, both settings are present in reality as the institutional features differ across countries. For example, the Bank of England is fully responsible for macroprudential policy, while in the US the Federal Reserve has a very limited role in setting the macroprudential stance. Therefore, considering the two extremes can provide useful guidance for policy in these alternative cases.

We will consider a wide range of realistic values for the weight on the common output gap objective in assessing the gains from coordination, which complements the approach usually taken in the literature and allows for a more complete and robust analysis. For this exercise, we perform a grid-search, varying the relative importance of the output gap component λ_y^{mp} between $[0 - 1.5]$ in the macroprudential loss function (27). Given that there is limited evidence in the literature that could be used as guideline, we have chosen the range of possible values for λ_y^{mp} to be sufficiently broad in order to allow for the most interesting potential mandates for macroprudential policy. Therefore, we consider the case of no importance assigned to output gap at all, implying credit growth to be the only macroprudential objective, to the other extreme where the importance given to output is much higher. We keep the preference parameters in the monetary policy loss function (25) fixed at $\lambda_y^{CB} = 0.5$ and $\lambda_r^{CB} = 0.1$ throughout the exercise. These values are in line with empirical evidence on the preferences of an inflation targeting central bank (see, e.g. Ilbas (2012), and the references therein). We further perform the exercise in the presence of all the shocks.[15]

Fig. 3 illustrates the results of the grid-search in terms of percentage changes obtained in the individual policy maker's losses when moving from coordination towards no-coordination. The main result that stands out from the figure is that

[14] Although in practice it does not make a difference to the obtained results whichever policy maker moves first, as the procedure convergences to the same numerical results.

[15] Given that it might be hard to detect the nature of the circumstances, for example when several shocks are hitting the economy at the same time, we find it more realistic to keep all shocks present. However, isolated shocks are considered when assessing the extent to which their transmission is affected under alternative coordination schemes.

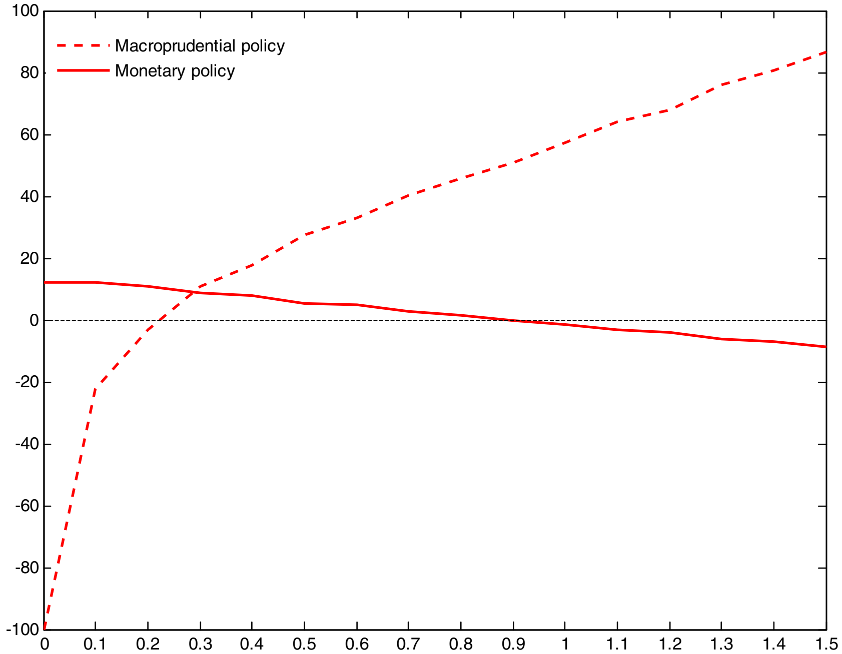

Fig. 3. Percentage change in the loss when moving from Coordination to No-Coordination (y-axis) for varying λ_y^{mp} (x-axis). *Note:* The figure plots the percentage changes in loss obtained under no-coordination with respect to coordination for monetary (solid line) and macroprudential (dashed line) policy, respectively, for alternative values of the relative weight on the output gap (λ_y^{mp}) in the macroprudential loss function (27), while keeping the weights in the monetary policy loss function (25) fixed.

macroprudential policy would incur a decrease in loss of 100% under the no-coordination scheme with respect to the coordination alternative when the macroprudential mandate does not assign any weight to the output gap. Hence, no-coordination is clearly the most beneficial scheme for macroprudential policy. This result is not surprising, given that the financial stability mandate is clearly separated from the inflation targeting mandate (with no common objectives), and the regulator has one tool at disposal to effectively offset all fluctuations in its sole financial stability objective. Hence, the Tinbergen principle, which states that policy is more effective when separate instruments are used to reach separate targets, applies to the regulator. This implies that specific macroprudential instruments are much more effective at safeguarding financial stability than monetary policy. Using monetary policy to achieve financial stability would be suboptimal and lead to poorer outcomes for financial stability. Monetary policy, however, gains from coordination. This is because coordination helps the central bank to stabilize its own objectives and maintain a less volatile policy rate and output gap under a single policy maker.

The trade-off between the gains for both policy makers remains present for positive but low values for λ_y^{mp}. The macroprudential regulator is indifferent between coordinating and not coordinating with the central bank when λ_y^{mp} reaches a value of around 0.2. For values higher than $\lambda_y^{mp} = 0.2$, i.e., when the output gap starts playing a more prominent role in the regulator's mandate, the coordination conflict disappears given that it becomes costly for both policies (in terms of increase in loss) not to coordinate. Therefore, both can achieve a lower loss when they are required to coordinate and act as a single policy maker. This can be done by assigning the macroprudential policy task to the central bank, for example, by augmenting its standard objectives of price and output stability by financial stability in line with the Woodford (2012) proposal of a "natural extension of flexible inflation targeting". Recall that the importance attached to the output gap in the loss of the central bank is fixed at $\lambda_y^{CB} = 0.5$ throughout the simulations. It is therefore intuitive to see why there is no conflict when the regulator also places a "moderate" weight on the output gap. In particular, the gains from coordination for macroprudential policy keep on increasing with the value of λ_y^{mp}: as the figure shows, the more important output gap becomes relative to the financial stability objective, the more costly the lack of coordination with the central bank becomes because the latter clearly contributes to achieving a more stable output gap. On the other hand, when the output gap objective starts becoming more dominant in the macroprudential loss, the coordination alternative becomes less appealing this time for the central bank since the latter would achieve a decrease in loss under no-coordination as the result of a more stable inflation, its primary objective, and interest rate. For example, at $\lambda_y^{mp} = 1.1$ inflation volatility would be twice as high under coordination compared to no-coordination. Therefore, the coordination conflict re-appears around this value of λ_y^{mp}, albeit in the reverse sense: at higher values of λ_y^{mp}, the central bank can better achieve its objectives, while the regulator performs worse, when no-coordination is imposed on the policy makers.

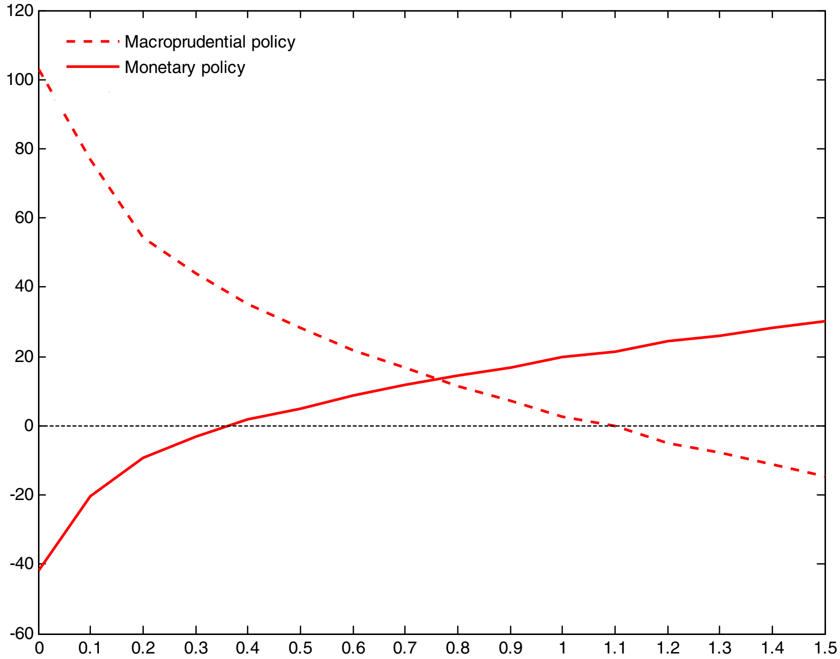

Fig. 4. Percentage change in the loss when moving from Coordination to No-Coordination (y-axis) for varying λ_y^{CB} (x-axis). *Note:* The figure plots the percentage changes in loss obtained under no-coordination with respect to coordination for monetary (solid line) and macroprudential (dashed line) policy, respectively, for alternative values of the relative weight on the output gap (λ_y^{CB}) in the monetary policy loss function (25), while keeping the weights in the macroprudential loss function (27) fixed.

Another interesting question is what happens when the preference weights in the macroprudential loss are fixed at values $\lambda_y^{mp} = \lambda_{\Delta c}^{mp} = 0.5$, hence assuming equal weights for output gap and credit growth objectives, while the weight on the output gap (λ_y^{CB}) in the monetary policy's loss function (25) varies between $[0 - 1.5]$ instead. This range is consistent with the values considered and proposed in the literature. It includes the most interesting cases, such as the value of 0.048 proposed by Woodford (2003), the value of 0.25 proposed by Yellen (2012) and the optimized weight of 1 found in Debortoli et al. (2015). Fig. 4 illustrates the results from this exercise.

The figure shows that a hawkish central bank benefits from a setting that imposes no-coordination with a regulator that assigns quite a considerable weight on stabilizing the output gap, which is not surprising as in the absence of coordination the central bank can focus much better on price stability, and therefore will tolerate a relatively more volatile output gap, without having to worry about the regulator's objectives. In contrast, the regulator would clearly have (a lot) to lose under the no-coordination alternative. The reason is that under coordination with the central bank, the regulator would benefit from using the monetary policy instrument, in addition to the macroprudential instrument, to stabilize the output gap. Although the regulator could achieve a much more stable credit growth without coordination with the central bank, this would be offset by the increase in the volatility of the output gap, an equally important macroprudential objective. The more weight the central bank assigns to the output gap, the smaller the coordination conflict with the regulator becomes, until it disappears and lack of coordination becomes costly for both policy makers (given the increase in the loss of both policy makers under no-coordination with respect to coordination in the figure). This happens around values λ_y^{CB} between 0.4 and 1.1. This is largely consistent with the previous conclusion that assigning a similar weight on the objective it has in common with the other policy maker can lead to mutual gains from coordination. Not surprisingly, the more dovish the central bank becomes, the more it will gain from coordination, while the regulator will start losing (beyond the value of $\lambda_y^{CB} = 1.1$), as it would have to accept an increasing volatility in the growth of credit. As we have seen before, the coordination conflict re-appears when the relative importance attached to the common objective in one policy's loss function deviates too much from the relative weight assigned to it in the other policy's loss function.

The general message from this section is that having a common objective that is given similar importance in the respective mandates leads to mutual gains from cooperation and can help to avoid coordination conflicts. These conclusions might seem in contrast with those obtained by Angelini et al. (2012), who show for the euro area that during "normal times" (economy driven by supply shocks), coordination between both policies is more beneficial than no-coordination, although the coordination gains achieved by introducing a macroprudential policy maker per se are limited compared to "crisis times" (dominated by financial and housing market shocks). However, all results in Angelini et al. (2012) are conditional on macroprudential loss assigning a dominant weight on financial stability. Even in their robustness exercise, the weights on the output gap in the respective loss functions vary at the same time, implying no change in the relative importance of this objective for both policy makers. Instead, we consider alternative mandates for macroprudential policy where the importance of financial stability varies and cause discrepancies between the alternative objectives. When the financial stability objective becomes less prominent in the macroprudential loss in Angelini et al. (2012), the coordination conflict in the face of the supply shocks disappears. This is consistent with Fig. 3, which shows the increasing gain from coordination for macroprudential policy when λ_y^{mp} in (27) is increased.[16]

4.4. Transmission of shocks under alternative coordination schemes

Fig. 5 shows the responses of selected variables to a technology and a financial shock, respectively, in order to assess how the alternative coordination schemes affect the transmission of shocks and the trade-offs between the objectives. The responses are obtained under the standard loss function assumption for monetary policy (25) and a dominant financial stability objective for macroprudential policy, i.e., $\lambda_y^{mp} = 0.1$ in (27).

Following a positive technology shock (panel a), the regulator responds more strongly to credit developments, its main objective, under no-coordination than under coordination. As a result, credit growth stabilizes relatively quickly after an initial decrease, while under coordination the macroprudential tax increases by less and it takes somewhat longer for credit growth to stabilize since it has to be traded off with the objectives of the central bank. The interest rate also responds more strongly to the fall in inflation in the no-coordination case, since the central bank too is more able to act according to its own mandate than under coordination. Although the effect of the alternative coordination regimes on output is quite similar, the effect on bank leverage is higher under no-coordination because the response of net worth (not shown) to the shock is more restricted since the macroprudential regulator reacts more to increasing credit in the form of higher taxes on bank capital. As a consequence, while the bank leverage is countercyclical in the benchmark estimated model without macroprudential policy (as in Gertler and Karadi (2011)), it turns procyclical when optimal macroprudential tax policy is introduced. Therefore, based on Fig. 5a, we can conclude that after a positive technology shock, a lack of coordination between the two policy makers results in a more expansionary monetary policy, while macroprudential policy is more restrictive. Although credit is much more stable under no-coordination, both policy instruments are more volatile and they are moved in opposite directions due to separated objectives, giving rise to costly coordination conflicts if authorities do not coordinate, as in Angelini et al. (2012). Therefore, coordination in this case becomes more challenging but also more important.

Panel b of the figure shows that, after a financial shock, the bank capital subsidy is, as expected, much higher under no-coordination in response to financial stability concerns, which alleviates and almost completely offsets the initial drop in credit and as a result leads to a lower drop in output. Consequently, less monetary policy accommodation is needed than would be the case under coordination. Given that there is no conflict between the objectives as we have seen in Section 3.4, both policies work in the same direction in response to the financial shock. Although coordination would require monetary policy to be more, and the regulator to be less, accommodative than under no-coordination, the policies are nevertheless more compatible and a strong coordination is less essential for the effectiveness of both policies.

The conclusions in this section resemble those from previous findings based on monetary-fiscal interactions, such as Dixit and Lambertini (2003). Therefore, their recommendations in setting up effective delegation schemes also hold in our case. In particular, given the lower frequency at which macroprudential decisions are expected to be taken in function of the financial cycle, which typically lasts longer than the business cycle, an appropriate scheme could be one where monetary policy sets the interest rate taking the stance of macroprudential policy as given, i.e., act as a follower to the decisions made by the regulatory authorities (=leader). This set up is considered by De Paoli and Paustian (2013). It is important to keep in mind, however, that in practice it might be hard to detect the exact nature of the circumstances, that is, when several shocks are hitting the economy at the same time. It is for this reason that having a common target, which both policy makers care about to a more or less similar extent, is essential to prevent potentially costly coordination problems, as concluded from the previous section based on the multi-shock scenario.

5. The case of discretion

The focus of our discussion so far has been in the context of commitment by policy makers. While Dixit and Lambertini (2003) and De Paoli and Paustian (2013) compare the gains/losses from coordination under alternative degrees of commitment in detail, an interesting question in our context is how our results would be affected if both authorities did not have the ability to commit with respect to the private sector. To the best of our knowledge, the discretionary case in presence of multiple policy makers has so far been mainly explored in the setup of small calibrated models, as in the above mentioned papers, in addition to Bean et al. (2010) and Lima et al. (2012). While Angelini et al. (2012) also consider a quantitatively richer setup for their coordination exercises, they limit their analysis to commitment. However, there is some empirical

[16] We have repeated the exercise in this section by replacing the estimated values of the standard errors of all the shocks in the model by their values corresponding to the period 2008:1-2010:3. For this purpose, we have evaluated the estimated model using all available data, i.e. the sample up to 2010:3, in order to obtain the smoothed series of the shocks for the post-crisis period 2008:1-2010:3, and their corresponding volatilities. We find that our conclusions remain robust when taking into account the post-crisis volatilities of the shocks.

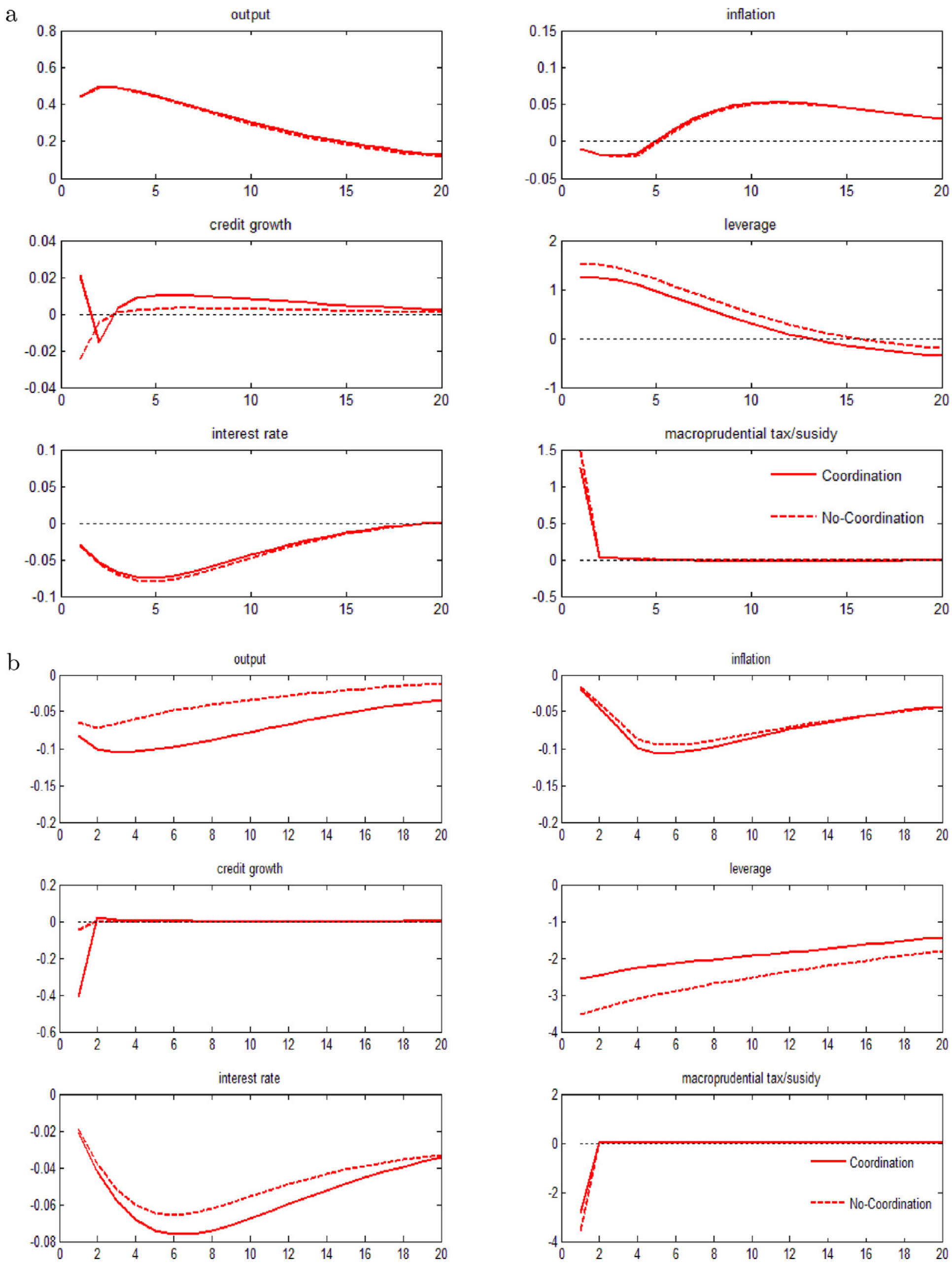

Fig. 5. (a) Impulse Responses Optimal Model - Positive Technology Shock. (b) Impulse Responses Optimal Model - Financial Shock. *Note:* The figure plots the impulse responses to a positive technology shock (upper panel) and a negative financial shock (lower panel) under coordination (solid line) and no-coordination (dashed line). The responses for both coordination and no-coordination cases are obtained under the standard loss function assumption for monetary policy (25) and a low weight on the output gap relative to credit growth in the macroprudential mandate, i.e., the macroprudential loss function (27) with $\lambda_y^{mp} = 0.1, \lambda_{\Delta c}^{mp} = 0.5$.

evidence pointing towards discretionary policy by the central bank (see, e.g. Givens (2012)). We therefore aim to shed some light in this section on the consequences of assuming discretion instead of commitment.

We redo the grid-search by varying the relative importance of the output gap component λ_y^{mp} in the macroprudential loss (27), while keeping the preference parameters in the monetary policy loss function (25) fixed as previously, under the assumption that both policy makers now act under discretion. The equilibrium under the Nash (i.e., no-coordination) game does not exist for values of λ_y^{mp} below 0.2. For higher values of λ_y^{mp}, the differences in the obtained total loss between the cooperative and non-cooperative solutions are much higher in magnitude than in the previous commitment solution due to higher volatilities of inflation and the instruments. Since the volatilities and the losses from the Nash game are so

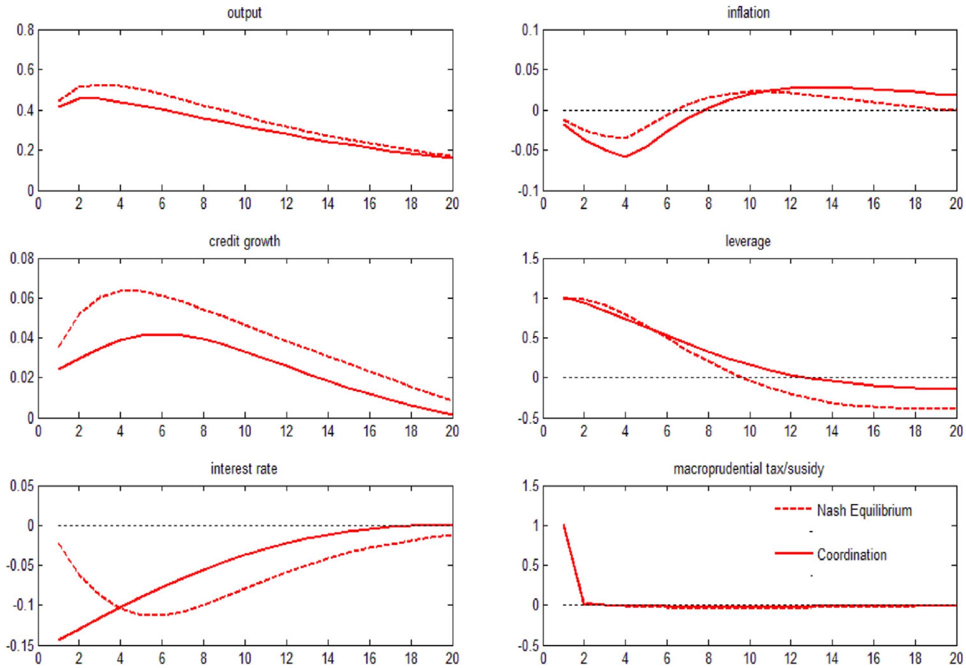

Fig. 6. Impulse Responses under Discretion - Positive Technology Shock. *Note:* The figure plots the impulse responses to a positive technology shock under full coordination (solid line) and nash equilibrium (dashed line) under discretion. The responses for both coordination and no-coordination cases are obtained under the standard loss function assumption for monetary policy (25) and a low weight on the output gap relative to credit growth in the macroprudential mandate, i.e., the macroprudential loss function (27) with $\lambda_y^{mp} = 0.2$, $\lambda_{\Delta c}^{mp} = 0.5$.

high, we do not report those values, but at least for the range of values of λ_y^{mp} for which we are able to compute the nash solution, there is no indication of coordination conflicts between the two policy makers and both have a lot to lose under the Nash game. This result is consistent with our previous conclusion under commitment, and not surprising given that we are limited to considering values for λ_y^{mp} that are relatively close to the importance attached to the output gap by the central bank. Hence, full coordination under a common objective helps to avoid extreme outcomes and coordination conflicts between both policy makers because large losses that would otherwise be obtained under the Nash game can be avoided. The conclusion that common goals reduce coordination problems when commitment is not possible is in line with Dixit and Lambertini (2003) and De Paoli and Paustian (2013).

Fig. 6 further illustrates the impulse responses to a technology shock when $\lambda_y^{mp} = 0.2$, the lowest possible value for which we are able to obtain a Nash solution. Unlike the case of commitment, where the differences between the alternative coordination schemes are smaller, figure 6 highlights the bigger differences between the coordination and the Nash outcomes under discretion. Although on impact the interest rate responds less to lower inflation under Nash, it remains accommodative for longer, which results into higher output and credit, but helps inflation to get back on target sooner than under coordination. Since the difference in the initial macroprudential tax response under the Nash game with respect to the cooperative solution is hardly detectable, credit growth is higher as a result of the lower interest rate that persists for longer. Coordination, however, results into more stable instruments, the improvement being mostly noticeable in the interest rate, and more stable credit and output, which comes at the cost of a slightly more volatile inflation.

6. Optimal mandates in non-cooperative setting

In this section, we reverse the assumptions of the exercise performed in Section 4.3, where the policy mandates are set first, and the cooperative solution is compared to the non-cooperative solution in order to assess which interaction scheme is mostly beneficial to the individual policy makers. In the exercise below, we instead assume that the institutional setup within which policy makers operate is given, and that it is consistent with no-coordination because of practical implementability concerns due to, e.g., accountability. The assumption of setting policy in a non-coordinated way is also representative of the case of the US, where various agencies are assigned with financial stability related mandates, and it is realistic to assume that macroprudential policy is performed in a non-coordinated fashion vis-a-vis monetary policy. It is also consistent with the European institutional architecture for macroprudential policy, where the ECB and national authorities share macroprudential competences but the responsibilities of the former are limited to imposing stricter capital requirements, and the conduct of monetary policy is exclusively assigned to the ECB. Within the assumed no-coordination framework, we will derive the optimal mandate for each policy maker in terms of optimal weights[17] by minimizing the society's loss function, in similar spirit to Debortoli et al. (2015) who design an optimal simple mandate for the Federal Reserve, which is expressed as follows:

$$L_t^S = E_t \sum_{i=0}^{\infty} \delta^i \left[(\pi_{t+i}^a)^2 + 0.5(y_{t+i} - y_{t+i}^p)^2 + 0.1(r_{t+i}^a)^2 + 0.5(credit_{t+i} - credit_{t+i-1})^2 \right] \tag{31}$$

The above equation is similar to the coordination problem (30) considered previously, where the weights in the loss function are fixed to values consistent with the assumed preferences of society. The loss function (31) realistically captures the (joint) mandate of the central bank and the regulator in terms of the most relevant variables. We assume that society's choice of weights on output gap and interest rate volatility is consistent with the Federal Reserve's dual mandate policy augmented with interest rate stability concerns. As noted earlier, given that these values are in line with empirical evidence on the preferences of an inflation targeting central bank, it is reasonable to assume that they are a good approximation for society's preferences. In the light of the financial frictions featured by the model, we further assume that society assigns a weight of 0.5 on credit growth, which is the same value used in the exercises performed previously. However, when we consider a value of 1 instead, the qualitative results and conclusions remain unaffected.

We assume that society minimizes the loss function (31) with respect to the interest rate rule (26) and the bank levy/subsidy (28), which yields the loss L_t^S under coordination and serves as the benchmark outcome.[18] Within the imposed institutional framework of no-coordination between the central bank and the macroprudential regulator, society assigns the following loss function to the central bank, to be minimized with respect to (26):

$$L_t^{CB} = E_t \sum_{i=0}^{\infty} \delta_{CB}^i \left[(\pi_{t+i}^a)^2 + \lambda_y^{*CB}(y_{t+i} - y_{t+i}^p)^2 + \lambda_r^{*CB}(r_{t+i}^a)^2 \right] \tag{32}$$

while the regulator is charged with the following loss function, to be minimized with respect to (28):

$$L_t^{mp} = E_t \sum_{i=0}^{\infty} \delta_{mp}^i \left[\lambda_y^{*mp}(y_{t+i} - y_{t+i}^p)^2 + \lambda_{\Delta c}^{*mp}(credit_{t+i} - credit_{t+i-1})^2 \right] \tag{33}$$

and where the weights λ_y^{*CB}, λ_r^{*CB}, λ_y^{*mp} and $\lambda_{\Delta c}^{*mp}$ are set in order to minimize society's loss (31). This approach can also be considered as a delegation problem, and will yield optimal mandates for monetary and macroprudential policy. Hence, the weights in the individual policy makers' loss functions (32) and (33) are chosen optimally in order to approximate the benchmark outcome that would be obtained if both policy makers were able to coordinate.

We find that the following values of weights minimize the benchmark (society's) loss: $\lambda_y^{*CB} = 0.55$, $\lambda_r^{*CB} = 0.1$, $\lambda_y^{*mp} = 0.75$ and $\lambda_{\Delta c}^{*mp} = 0.55$. The optimal weight on the output gap in the central bank's loss function, i.e., $\lambda_y^{*CB} = 0.55$, is slightly higher than the weight assigned by society. The delegation problem, however, implies an additional weight on the output gap of $\lambda_y^{*mp} = 0.75$ in the regulator's mandate. The reason is that the lack of coordination tends to increase the volatility of the output gap considerably. As a result, a higher concern for output gap stabilization, particularly in the regulator's mandate, is needed in order to approach the outcome that would be obtained under coordination. The finding that policy makers should respond strongly to the output gap is in line with the result of Debortoli et al. (2015), who report an optimal weight of 1 on the output gap in the central bank's loss function. The optimal weight on interest rate stabilization, i.e., $\lambda_r^{*CB} = 0.1$, is in line with society's preference. It is important to note, however, that the implied variance of the interest rate is 2.02, which is somewhat high compared to the data (1.84). It cannot be ruled out that the interest rate turns occasionally negative. As is the case for most of the closely related papers in the literature adopting a similar framework, we focus mainly on the study of the optimal/appropriate policy set-ups rather than their implementability when the zero lower bound constraint becomes binding. The latter is an important concern that should be addressed appropriately in a perturbation framework. This implies an extension to our current framework that we would like to leave for future work. Finally, the optimal weight on the credit growth term, i.e., $\lambda_{\Delta c}^{*mp} = 0.55$, in the macroprudential regulator's loss function is slightly higher than society's weight in order to compensate for the increase in the volatility of this variable due to the relatively high weight assigned to the output gap. To summarize, policy makers should place a higher weight than society on the output gap and the credit growth variable when they are not able to coordinate with each other in order to compensate for the increased volatility.

7. Conclusion

This paper studies the implications of introducing macroprudential policy, and its interactions with monetary policy, in the context of a quantitative medium-scale DSGE model for the US featuring financial frictions on the supply side of

[17] Note that we assume that the objectives are already specified, and focus on finding the optimal weights only. Altering the objectives to improve on the outcome could be an interesting exercise, which we leave for future work.

[18] Alternatively, one could adopt the quadratic approximation of the households' objective function instead of (31) as a useful benchmark, which is the approach followed by Debortoli et al. (2015). However, this type of exercise is beyond the scope of the current paper.

credit. We use our framework to perform two types of exercises. First, inspired by the newly emerged institutional set-ups for macroprudential policy that differ across countries, we compare cooperative solutions to non-cooperative ones for varying degrees of importance attached to the output gap stabilization in the individual mandates. By considering alternative mandates in our analysis, we take into account the fact that macroprudential preferences are not yet well established in practice. Under the assumption that the regulator aims to maintain financial stability, while the central bank pursues price stability, we find that the individual gains from coordination can be high in cases where the government requires both policy makers to attach similar importance to output gap stabilization in addition to their core objectives. A coordination conflict arises when there is a divergence in the importance attached to this common objective, for example when financial stability highly dominates in the macroprudential policy's mandate. In the latter case, macroprudential policy can achieve a lower loss in the absence of coordination, while the central bank gains from coordination. Second, we use our framework to derive optimal mandates under the assumption that both policy makers are operating within a non-cooperative institutional setup, i.e., a mechanism that is fairly representative of monetary and macroprudential interactions in the US. Our results suggest that both policy makers should place a higher weight than society on the output gap, and that macroprudential policy should place a slightly higher weight than society on the credit growth variable, in order to achieve the best possible outcome from society's point of view under no-coordination.

The policy implications in this paper are conditional on the modeling framework and the empirical estimates and, therefore, need not necessarily hold in the context of other economies or more realistic settings in which nonlinearities and endogenous build-up of systemic risk are taken explicitly into account. Neither are the conditions imposed by the zero lower bound on the interest rates considered explicitly. These are important concerns which we intend to address in future work.

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Appendix A. Steady State

This appendix outlines the implications of introducing financial frictions for the steady state of the original Smets–Wouters model. Although most of the Smets and Wouters (2007) steady state derivations are unaffected, some exceptions are important to point since they also affect the estimation process. In the following, we abstract from reporting those relationships that remain unaffected, and refer to the technical appendix accompanying Smets and Wouters (2007) instead. Therefore, we only repeat the steady state relations that need to be adjusted, together with the set of steady state assumptions that we have added, the latter relating to the Gertler–Karadi block.

The estimation of the three constants $\overline{cn}$, $\overline{cs}$, $\overline{crk}$ yields the steady state values of the corresponding variables, namely the gross net worth growth rate, the net premium, and the gross return on capital, as follows

$$Z_*^{GK} = 1 + \frac{\overline{cn}}{100}$$

$$\overline{PREM}_* = \frac{\overline{cs}}{100}$$

$$\overline{ret}_*^k = 1 + \frac{\overline{crk}}{100}$$

According to equation (23), the presence of the premium implies the following relationship between the return to capital and the real interest rate

$$\overline{RR}_* = \frac{\overline{ret}_*^k}{1 + \overline{PREM}_*}$$

For the consumption Euler equation to be satisfied, parameter σ_c has to respect the following steady state restriction

$$\sigma_c = \frac{log\left(\overline{RR}_*\right) + log(\beta)}{log(\gamma)}$$

where, as in Smets–Wouters, $\gamma = 1 + \overline{\gamma}/100$ and $\beta = 1/(1 + constebeta/100)$. The remaining steady state variable from the original Smets–Wouters framework affected by the presence of financial frictions is the rental rate of capital. In particular, we need the following to hold

$$\overline{ret}_*^k = \left(1 + \overline{PREM}_*\right)\overline{RR}_*$$

$$\overline{ret}^k_* = R^k_* + (1-\delta)$$

As a result,

$$R^k_* = \left(1 + \overline{PREM}_*\right)\overline{RR}_* - 1 + \delta$$

where $\overline{RR}_*$ is also equal to $\beta^{-1}\gamma^{\sigma_c}$.

Using the Smets–Wouters steady state values for W_*, c_y, k_y , and l_k (i.e. the labor to capital ratio), we proceed with the Gertler–Karadi block. We compute the consumption to capital ratio c_k

$$c_k = \frac{c_y}{k_y}$$

and use this in order to compute the steady state level of capital K_*

$$K_* = -\frac{(1-\sigma_c)W_*}{c_k\left(1-\frac{\lambda}{\gamma}\right)(\sigma_c - 1)(l_k)^{\sigma_l}}$$

The implied steady state of hours worked is

$$L_* = l_k K_*$$

Regarding the Gertler–Karadi block, the steady state of leverage is

$$\overline{LEV}_* = \frac{(Z^{GK}_* - \overline{RR}_*)}{\overline{PREM}_*}$$

which implies the following value for θ

$$\theta = \frac{1 - \omega\overline{LEV}_*}{\overline{PREM}_*\overline{LEV}_* + \overline{RR}_*}$$

Using the fact that, by definition, $X_* = Z^{GK}_*$, we compute the remaining steady state values

$$\upsilon_* = \frac{\beta}{\gamma^{\sigma_c}}\frac{(1-\theta)\overline{PREM}_*}{1 - \frac{\beta}{\gamma^{\sigma_c}}\theta X_*}$$

$$\eta_* = \frac{\beta}{\gamma^{\sigma_c}}\frac{(1-\theta)\overline{RR}_*}{1 - \frac{\beta}{\gamma^{\sigma_c}}\theta Z^{GK}_*}$$

$$\Gamma_* = \frac{\eta_*}{\overline{LEV}_*} + \upsilon_*$$

$$N_* = K_*\overline{LEV}_*$$

$$\overline{NE}_* = \theta Z^{GK}_* N_*$$

$$NN_* = \omega K_*$$

Appendix B. Data appendix

Following series are used as observables: real GDP, consumption, investment, hours worked, real wages, the GDP deflator measure of inflation, the Gilchrist and Zakrajšek (2012) spread (GZ-spread, henceforth), net worth, return to capital and the federal funds rate. The source of the series on GDP, nominal personal consumption and fixed private investments is the Bureau of Economic Analysis database of the US Department of Commerce. The GZ-spread is taken from the dataset accompanying the publication on the AER website (http://www.aeaweb.org/content/articles/articles_detail.php?doi=10.1257/aer.102.4.1692). For the computation of the GZ-spread, Gilchrist and Zakrajšek (2012) consider each loan obtained by each set of firms taken from the COMPUSTAT database. They compare for every single case the interest rate actually paid by the firm with what the US government would have paid on a loan with a similar maturity. In terms of default risk, their sample spans the entire spectrum of credit quality, from “single D” to “triple A” . The aggregate spread is accordingly an arithmetic average of the credit spreads on each single corporate bond. Return to capital is based on the series provided in Gomme et al. (2011). The net worth growth rate is computed using data on all commercial banks’ real net worth. To obtain the latter, we started from all commercial banks’ nominal credit (Board of Governors of the Federal reserve system database, Assets and Liabilities of Commercial Banks in the United States, table H8/H8/B1001NCBAM) and from all commercial banks’ nominal deposit (Board of Governors of the Federal reserve system database, Assets and

Liabilities of Commercial Banks in the United States, table H8/H8/B1058NCBAM). Both series can also be downloaded from the FRED database with codes TOTBKCR and DPSACBW027SBOG, respectively. The two nominal series are divided by the GDP deflator. The difference between real credit and real deposit is the real net worth. Real GDP is expressed in terms of 1996 chained dollars. Consumption, investment and net worth are deflated with the GDP deflator. The log difference of the Implicit price deflator is used to compute inflation. Hours worked and hourly compensation for the non farming business sector for all persons are obtained from the Bureau of Labor Statistics. Real wage is computed by dividing the latter series by the GDP price deflator. The average hours index is multiplied with Civilian Employment figures of 16 years and over in order to correct for the limited coverage of the non farming business sector with respect to the GDP. The federal funds rate is downloaded from the FRED database of the Federal Reserve Bank of St-Louis. Inflation, interest rate, return to capital and the GZ-spread are expressed in quarterly terms. Remaining variables are expressed in 100 times log. In order to express the real variables in per capita terms, we divide them by the population over 16. All series are seasonally adjusted.

Appendix C. Prior assumptions

Following Smets and Wouters (2007), we fix the annual depreciation rate on capital at 10% , i.e., $\delta = 0.025$, the ratio of exogenous spending to GDP, g_y, at 0.18, the mark-up in the labor market in the steady state (λ_w) at 1.5 and the curvature of the Kimball aggregator in both goods and labor markets (ε_p and ε_w) at 10. The proportional transfer to entering bankers, ω, is set at 0.002. The prior assumptions for the remaining parameters are reported in Table 1.

The prior assumptions regarding the structural parameters corresponding to the Smets and Wouters (2007) are kept unchanged. The standard errors of all the error terms, including the measurement errors, are assumed to have an inverted gamma distribution with 2 degrees of freedom and a mean of 0.10 . The persistence parameters of all shock processes and the MA coefficients are assumed to have a beta distribution with a prior mean of 0.5 and a prior standard error of 0.2. The steady state inflation rate is assumed to be gamma-distributed with a quarterly mean of 0.62% and standard error of 0.1, as in Smets and Wouters (2007). The prior assumptions for the remaining steady state parameters, i.e. return to capital, premium and net worth growth, are chosen according to the properties of the corresponding series in the sample.

Appendix D. Solution under the no-coordination case

The structural equations (1)–(23) can be represented by the following form:

$$A_0 Y_t = A_1 Y_{t-1} + A_2 E_t Y_{t+1} + A_3 u_t^{CB} + A_4 u_t^{mp} + \nu_t, \qquad \nu_t \sim iid[0, \Sigma] \tag{D.1}$$

under the condition that A_0 is invertible, with Y_t the vector of endogenous variables, u_t^{CB} and u_t^{mp} the respective vectors of monetary policy and macroprudential policy variables, and ν_t the stochastic innovations. The policy makers' objective functions can be written in the following general form:

$$L_t^{CB} = E_t \sum_{i=0}^{\infty} \delta_{CB}^i \left[Y'_{t+i} W^{CB} Y_{t+i} + u_t'^{CB} Q^{CB} u_t^{CB} \right] \tag{D.2}$$

and

$$L_t^{mp} = E_t \sum_{i=0}^{\infty} \delta_{CB}^i \left[Y'_{t+i} W^{mp} Y_{t+i} + u_t'^{mp} Q^{mp} u_t^{mp} \right] \tag{D.3}$$

which are the loss functions for the central bank and the regulator, respectively, where W^{CB}, W^{mp}, Q^{CB} and Q^{mp} are positive, semi-definite, time-invariant matrices of policy weights. The simple rules may take the following general form adopted by Dennis (2004), allowing for forward-looking rules:

$$u_t^{CB} = \varrho_1^{CB} Y_{t-1} + \varrho_2^{CB} Y_t + \varrho_3^{CB} E_t Y_{t+1} + \varrho_4^{CB} \nu_t \tag{D.4}$$

$$u_t^{mp} = \varrho_1^{mp} Y_{t-1} + \varrho_2^{mp} Y_t + \varrho_3^{mp} E_t Y_{t+1} + \varrho_4^{mp} \nu_t \tag{D.5}$$

with ϱ_1^{CB}, ϱ_2^{CB}, ϱ_3^{CB}, ϱ_4^{CB}, ϱ_1^{mp}, ϱ_2^{mp}, $\varrho_3^{mp}$and ϱ_4^{mp} restricted matrices. Defining $\varrho^{CB} = \left[\varrho_1^{CB} \quad \varrho_2^{CB} \quad \varrho_3^{CB} \quad \varrho_4^{CB} \right]$ and $\varrho^{mp} = \left[\varrho_1^{mp} \quad \varrho_2^{mp} \quad \varrho_3^{mp} \quad \varrho_4^{mp} \right]$, under the assumption that sufficient restrictions are placed on ϱ^{CB} and ϱ^{mp} to ensure unique feedback matrices, and augmenting (D.1) with (D.4) and (D.5) yields:

$$\begin{bmatrix} A_0 & -A_3 & -A_4 \\ -\varrho_2^{CB} & I & 0 \\ -\varrho_2^{mp} & 0 & I \end{bmatrix} \begin{bmatrix} Y_t \\ u_t^{CB} \\ u_t^{mp} \end{bmatrix} = \begin{bmatrix} A_1 & 0 & 0 \\ \varrho_1^{CB} & 0 & 0 \\ \varrho_1^{mp} & 0 & 0 \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ u_{t-1}^{CB} \\ u_{t-1}^{mp} \end{bmatrix} + \begin{bmatrix} A_2 & 0 & 0 \\ \varrho_3^{CB} & 0 & 0 \\ \varrho_3^{mp} & 0 & 0 \end{bmatrix} E_t \begin{bmatrix} Y_{t+1} \\ u_{t+1}^{CB} \\ u_{t+1}^{mp} \end{bmatrix} + \begin{bmatrix} I & 0 & 0 \\ \varrho_4^{CB} & 0 & 0 \\ \varrho_4^{mp} & 0 & 0 \end{bmatrix} \begin{bmatrix} \nu_t \\ 0 \\ 0 \end{bmatrix} \tag{D.6}$$

which, after solving for the rational expectations equilibrium, gives the following solution:

$$\begin{bmatrix} Y_t \\ u_t^{CB} \\ u_t^{mp} \end{bmatrix} = \begin{bmatrix} \theta_1 & 0 & 0 \\ F_1^{CB} & 0 & 0 \\ F_1^{mp} & 0 & 0 \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ u_{t-1}^{CB} \\ u_{t-1}^{mp} \end{bmatrix} + \begin{bmatrix} \theta_2 & 0 & 0 \\ F_2^{CB} & 0 & 0 \\ F_2^{mp} & 0 & 0 \end{bmatrix} \begin{bmatrix} \nu_t \\ 0 \\ 0 \end{bmatrix}$$

As proven by Dennis (2004), the value of the loss function for each policy maker can be written as:

$$L_t^{CB}(\varrho^{CB}) = Y_t' P^{CB} Y_t + u_t'^{CB} Q^{CB} u_t^{CB} + \frac{\delta_{CB}}{(1-\delta_{CB})} tr\left[(\theta_2' P^{CB} \theta_2 + F_2'^{CB} Q^{CB} F_2^{CB})\Phi\right] \tag{D.7}$$

$$L_t^{mp}(\varrho^{mp}) = Y_t' P^{mp} Y_t + u_t'^{mp} Q^{mp} u_t^{mp} + \frac{\delta_{mp}}{(1-\delta_{mp})} tr[(\theta_2' P^{mp} \theta_2 + F_2'^{mp} Q^{mp} F_2^{mp})\Phi] \tag{D.8}$$

where Φ is the variance–covariance matrix of the innovations and P^{CB} and P^{mp} are, respectively:

$$P^{CB} = W^{CB} + \delta_{CB} F_1'^{CB} Q^{CB} F_1^{CB} + \delta_{CB} \theta_1' P^{CB} \theta_1 \tag{D.9}$$

$$P^{mp} = W^{mp} + \delta_{mp} F_1'^{mp} Q^{mp} F_1^{mp} + \delta_{mp} \theta_1' P^{mp} \theta_1 \tag{D.10}$$

which can be solved for using fixed-point algorithms.

The computational procedure to solve for the optimal simple rules[19] under no-coordination, where the regulator moves first, is as follows:

1. Choose initial values for $\varrho^{CB} = \overset{\circ}{\varrho}{}^{CB}$ and $\varrho^{mp} = \overset{\circ}{\varrho}{}^{mp}$ and solve for θ_1, θ_2, F_1^{CB}, F_2^{CB}, F_1^{mp}, F_2^{mp} using standard solution methods for rational expectations
2. Given θ_1, θ_2, F_1^{CB}, F_2^{CB}, F_1^{mp}, F_2^{mp}, evaluate $L_t^{mp}(\varrho^{mp})$ according to (D.10) and (D.8)
3. Minimize $L_t^{mp}(\varrho^{mp})$ with respect to the macroprudential feedback parameters in ϱ^{mp}, yielding the optimal coefficients $\overset{\sim}{\varrho}{}^{mp}$
4. Set $\varrho^{CB} = \overset{\circ}{\varrho}{}^{CB}$ and $\varrho^{mp} = \overset{\sim}{\varrho}{}^{mp}$ and solve for θ_1, θ_2, F_1^{CB}, F_2^{CB}, F_1^{mp}, F_2^{mp}
5. Given θ_1, θ_2, F_1^{CB}, F_2^{CB}, F_1^{mp}, F_2^{mp}, evaluate $L_t^{CB}(\varrho^{CB})$ according to (D.9) and (D.7)
6. Minimize $L_t^{CB}(\varrho^{CB})$ with respect to the monetary policy feedback parameters in ϱ^{CB}, yielding the optimal coefficients $\overset{\sim}{\varrho}{}^{CB}$
7. Set $\varrho^{CB} = \overset{\sim}{\varrho}{}^{CB}$ and $\varrho^{mp} = \overset{\sim}{\varrho}{}^{mp}$ and repeat steps 1–3 to obtain new optimal values for $\varrho^{mp} = \overset{\approx}{\varrho}{}^{mp}$
8. Given $\overset{\approx}{\varrho}{}^{mp}$ and $\overset{\sim}{\varrho}{}^{CB}$, repeat steps 4–6 to obtain new optimal values for $\varrho^{CB} = \overset{\approx}{\varrho}{}^{CB}$
9. repeat steps 7-8 until convergence of the optimal feedback parameters ϱ^{CB} and ϱ^{mp}

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