Optimal Monetary and Macroprudential Policy in a Currency Union*

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Abstract

The financial crisis proved strikingly that stabilizing the price level is a necessary but not a sufficient condition to ensure macroeconomic stability. The obvious candidate for addressing systemic risk is macroprudential policy. In this paper we study the optimal (Ramsey) monetary and macroprudential policy mix in a currency union in the case of different kinds of aggregate and idiosyncratic shocks. The monetary and macroprudential instruments are modelled as independent tools. With a union-wide macroprudential tool, full absorption on the aggregate level is possible, but welfare losses due to fluctuations in relative variables prevail. With country-specific macroprudential tools, full absorption of shocks is always possible. But it is only optimal as long as there is no difference in the financing of production factors. Evaluating the performance of different policy regimes shows that the additional welfare gain from having country-specific macroprudential tools vanishes as the ability of the central bank to commit decreases.

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1 Introduction

The financial crisis proved strikingly that stabilizing the price level is a necessary but not a sufficient condition to ensure macroeconomic stability. Many economists as Blanchard et al. (2014) and Woodford (2014) stressed that central bank policy has to move from a one target, one instrument approach to a many targets, many instruments approach. Accordingly, the focus of central banks should be expanded to include not only inflation and output but also financial stability. Several studies have investigated the question whether central bank should include some kind of financial stability measure in an augmented Taylor Rule.[1] However, this inevitably creates new trade-offs between targets for one given instrument - the nominal interest rate. According to the Tinbergen principle (Tinbergen, 1952), policymakers have to expand the instrument set as well. Macroprudential policy seems to be the appropriate candidate for addressing financial stability, which can be measured by asset prices (e.g. Bernanke and Gertler, 1999; Cecchetti et al., 2002), credit aggregates (e.g. Agénor et al., 2013; Christiano et al., 2010), credit spreads or leverage (e.g. Cúrdia and Woodford , 2009; Carlstrom et al., 2010; De Paoli and Paustian, 2013; Ueda and Valencia, 2014; Smets, 2014). In the context of the euro-area, the interaction of monetary and macroprudential policy is of particular interest. With the introduction of the Single Supervisory Mechanism (SSM) the ECB already regulates all significant credit institutions of its member countries besides conducting the common monetary policy.[2]

In this paper we study welfare-based optimal (Ramsey) monetary and macroprudential policy in a two-country currency union model. Along the standard New Keynesian distortions coming from price rigidity and monopolistic competition, our model is characterized by financial frictions in the form of a cost channel and a credit channel. We incorporate a financial sector as in Gertler and Karadi (2011) into a standard currency union model, which leads to credit frictions when firms need to finance parts of their production in advance (as in Ravenna and Walsh (2006)). The interest rate as well as an endogenous credit spread, arising from a costly enforcement problem between depositors and bankers, enter the marginal costs of firms when they need external finance. In order to derive an expression for a microfounded welfare function we abstract from capital accumulation, but apply variable capital utilization instead (as in Carlstrom et al., 2010; De Paoli and Paustian, 2013). The quadratic loss functions features along the standard target variables (output, aggregate and national inflation, terms of trade gap), also (country-specific) credit market distortions. As the interest rate is too blunt of a tool to be cost-effective there is a rationale for the use of macroprudential policy

[1] See Käfer (2014) for a literature review on augmented Taylor Rules with financial stability objectives.

[2] Formally, the SSM is an independent unit within the ECB organizational's structures.

as a stabilization tool.

The advantage of macroprudential policy over an interest-rate policy is the possibility to design it almost infinitely granular. We introduce macroprudential policy as a subsidy/tax scheme that affects banks' balance sheets and works like a countercyclical capital requirement (as in Gertler et al., 2012). Macroprudential tools can be targeted to specific markets, geographical areas or loan-types. Hence, we show how the introduction of (country-specific) macroprudential policy alters the conduct of the optimal central bank policy in response to aggregate and idiosyncratic shocks.

A large part of the literature agrees that macroprudential policy already has an active role in dynamically stabilizing the business cycle but the frequency depends on the type of the instrument. These tools include for example countercyclical capital buffers introduced by Basel III[3], capital requirements by the central bank or caps on loan-to-value (LTV-) ratios which are both adjusted periodically (Angelini et al., 2014; Bank of England, 2009; Committee on the Global Financial System, 2010; Lim et al., 2011). Since financial stability is multidimensional and each financial cycle has its own specific properties, it will be very hard to find a Taylor-like rule that fits for all cases. The uncertainties around macroprudential assessment will therefore make a certain degree of discretion indispensable. Lim et al. (2011) show that some macroprudential instruments (especially caps) need to be adjusted discretionary. Other researchers are more skeptical about time-varying discretionary tools. Cecchetti and Kohler (2014) find that the transmission mechanisms of monetary policy and time-varying capital requirements are nearly identical. Cecchetti (2015) therefore argues that both instruments are nearly perfect substitutes and policymakers should shy away from discretionary regulatory policy. In contrast to these concerns, there is empirical evidence supporting the importance of macroprudential policy alongside monetary policy. Since the effectiveness of the latter depends on the capitalization of banks (Gambacorta, 2008) both policies could be complements for addressing inflation. Regarding systemic risk, De Nicolò et al. (2010) find that monetary policy has ambiguous effects on the risk taking behavior of banks (also depending on capitalization) which implies a trade-off between the targets price stability and financial stability. Hence, macroprudential policy can complement monetary policy. Borio and Zhu (2012) obtain similar results.

The independence of instruments - as suggested by the Tinbergen principle - implies no perfect substitutability. As Cecchetti and Kohler (2014) emphasizes, both monetary and macroprudential policy could have similar transmission channels (through lending rates) by affecting the demand and supply for credits.[4] But this does not mean that

[3]In the Basel III framework the choice of adjusting the capital buffer is decided discretionary by national authorities. Increasing the capital buffer has to be pre-announced by 12 months; decreasing the buffer takes immediate effect. Both decisions are made public.

[4]See, among others, Aiyar et al. (2014) and Akram (2014) for empirical evidence.

these instruments have to be perfect substitutes. Even when capital requirements may have similar effects as monetary policy, there is a rich set of macroprudential tools in practice [5]. Some of these instruments may be nearly perfect substitutes while others such as LTV- or debt-to-income caps are far away from perfect substitution. Our analysis focuses on the latter. Hence, irrespective of the type of the shock, monetary and macroprudential policies are independent. This result originates in our modelling approach of the monetary and macroprudential transmission mechanisms which are clearly not identical. The former influences households' and firms' behavior while the latter only affects the borrowing costs of firms.

The literature on the mix of monetary and macroprudential policy has been booming in the recent years, but there are only few studies that derive the optimal (Ramsey) policy.[6] Most studies consider (optimal) simple rules as the policy framework: Kannan et al. (2012) study monetary and macroprudential rules in a New Keynesian model with a housing market. The macroprudential instrument is introduced by assuming that the central bank is able to affect the spread between the lending rate and the deposit rate (e.g. due to capital requirements). Using macroprudential policy improves welfare in the case of a financial or housing demand shock, but not under productivity shocks. Quint and Rabanal (2014) consider a similar model but for a two-country currency union. The authors confirm the results of Kannan et al. (2012). Angelini et al. (2014) study the interaction between capital requirements and monetary policy. The availability of both policy instruments yields significant welfare gains, especially in the case of financial shocks. Levine and Lima (2015) implement macroprudential policy into the model of Gertler and Karadi (2011) and study the interaction of optimal monetary and macroprudential rules. Even when both authorities are independent and have different targets, there are welfare gains from introducing macroprudential policy.

Only few studies consider optimal policies: Cecchetti and Kohler (2014) show that a coordinated approach improves welfare as both instruments serve to enhance macroeconomic stability. Collard et al. (2012) study locally Ramsey-optimal interactions between monetary and macroprudential policy where the latter sets bank capital requirements. In their framework, interest-rate policy does not affect the risk-taking behavior of banks. For shocks that do not influence risk-taking, monetary policy should move while prudential policy should be inactive. For shocks affecting the risk-taking behavior, prudential policy should stabilize the shock while monetary policy should mitigate the negative externalities of the prudential policy.

Our model is an extension of De Paoli and Paustian (2013) and includes a two-country currency union. De Paoli and Paustian (2013) study the strategic interaction

[5] See, for instance, Bank of England (2009), Hahm et al. (2012) and Lim et al. (2011) for a list of possible and already implemented macroprudential tools.

[6] A comprehensive list of relevant literature can be found in Loisel (2014).

of a monetary and macroprudential authority while we assume that all policy is conducted under the roof of the central bank. Our focus lies on the optimal policy mix in the case of different kind of aggregate and idiosyncratic shocks. We show that macroprudential policy is able to fully absorb fluctuations of the economies on the union level for a large set of different scenarios which improves welfare significantly. The additional welfare gain from introducing country-specific macroprudential tools is small even though variations of relative target variables can be reduced. This result may seem counterintuitive but stems from the fact that our microfoundation suggests that the relative variables have a small weight in the welfare objective. Our final analysis compares different policy regimes. Evaluating their performance shows that the implementation of a union-wide macroprudential tool leads to significant welfare improvements, whereas additional welfare gains from having country-specific macroprudential policy vanishes as the ability of the central bank to commit decreases.

The organization of the paper is as follows. In Section 2 we outline our model; the building blocks are households, banks, and firms. Section 3 frames the joint policy problem of the monetary and macroprudential authority. In Section 4, we present and discuss the inflation and output dynamics of various shocks. In Section 5 we perform a welfare analysis and compare different policy regimes. Section 6 concludes.

2 Model

Our model is a standard two-country version of a monetary union, such as Benigno (2004), extended by financial intermediation as in Gertler and Karadi (2011). The model consists of households, intermediate goods firms, retail firms and financial intermediaries. In order to derive an expression for a microfounded welfare function we abstract from capital accumulation, but apply variable capital utilization instead. As in Carlstrom et al. (2010) and De Paoli and Paustian (2013), households supply labor and capital services to intermediate goods firms, where one of these production factors is credit constrained. Similar to Dedola et al. (2013), financial intermediaries within each country collect deposits from domestic households and provide loans to domestic intermediate goods producers. The transfer of funds is constrained by a costly enforcement problem between households and financial intermediaries, which leads to a manifestation of a credit distortion that depends on the banks' incentive to divert assets. Intermediate goods firms combine both inputs in a constant-returns-to-scale production function and sell their products to retailers. These sticky-price firms are monopolistically competitive and use a linear production function to produce final goods, which are traded without any barriers. The financial distortion leads to countercyclical shifts in credit spreads. This friction motivates the introduction of a (country-specific) macroprudential policy instrument, which affects the funding costs of financial intermediaries in order to stabilize the business cycle. In the spirit of Gertler et al. (2012), De Paoli and Paustian (2013), and Levine and Lima (2015), the instrument is set by a (country-specific) regulatory authority and works like a countercyclical capital requirement. In contrast to De Paoli and Paustian (2013), we do not take into account game theoretical considerations, arising from multiple policymakers. Instead, we restrict our analysis to the case of perfect cooperation and thus full optimization, which is equivalent to the case of a joint optimal monetary and macroprudential policy problem, solved by a single authority - the central bank. The total population is normalized to one, so that the population on the segment $[0, \gamma)$ belongs to (H)ome, while the population on $[\gamma, 1]$ belongs to (F)oreign. Otherwise the two countries are symmetrical. In the following we present the home country model block.

2.1 Households

Within each country there is a continuum of identical infinitely-lived households that consume, save and supply labor and capital services. Every household consists of $1 - f$ workers and f bankers. While workers supply both input factors, each banker manages one of the financial intermediaries, i.e. banks. Workers and bankers transfer their earnings back to the family, and in order to retain the representative agent framework there is perfect consumption insurance within the household. Every period banks are shut down with i.i.d. probability $1 - \theta$ and the corresponding bankers become workers. To ensure that the fraction of each family member stays constant at any moment in time, $(1 - \theta) f$ workers become bankers. Upon exit, bankers transfer their retained earnings to their respective family, while new bankers receive startup funds from their respective households.

The representative household will seek to maximize the following utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \epsilon_{d,t}^H \left[\frac{(C_t^H)^{1-\sigma}}{1-\sigma} - \frac{(L_t^H)^{1+\varphi}}{1+\varphi} - \frac{(u_t^H)^{1+\varphi}}{1+\varphi} \right], \qquad (1)$$

where C_t^H denotes consumption of the final good, L_t^H and u_t^H denote the constrained labor input and capital utilization services, respectively. The typical household owns the capital stock, which is, as already mentioned, assumed to be fixed, but utilization is costly. $\beta \in [0, 1]$ is the discount factor, σ is the inverse of the intertemporal elasticity of substitution, and φ is the inverse Frisch elasticity. Following Gali (2015), the demand shock $\epsilon_{d,t}^H$ can be interpreted as an exogenous preference shifter that changes the household's discount factor and, hence, affects intertemporal choices while having no influence on the consumption/labor/capital allocation within a period. This country-specific shock is assumed to follow an AR(1) process.

The Home private composite consumption index is defined as $C_t^H \equiv \left[\frac{(C_{H,t}^H)^\gamma (C_{F,t}^H)^{1-\gamma}}{\gamma^\gamma (1-\gamma)^{1-\gamma}}\right]$, where $C_{H,t}^H$ and $C_{F,t}^H$ are the (Home) bundles of Home and Foreign goods, given by $C_{H,t}^H \equiv \left[\int_0^1 C_t^H(\chi_H)^{\frac{\varepsilon-1}{\varepsilon}} d\chi_H\right]^{\frac{\varepsilon}{\varepsilon-1}}$ and $C_{F,t}^H \equiv \left[\int_0^1 C_t^H(\chi_F)^{\frac{\varepsilon-1}{\varepsilon}} d\chi_F\right]^{\frac{\varepsilon}{\varepsilon-1}}$. The parameter $\varepsilon > 1$ denotes the elasticity of substitution between any two varieties. The Cobb-Douglas specification implies that the so-called "macro" Armington elasticity, i.e. the elasticity of substitution between the two bundles of goods, $C_{H,t}^H$ and $C_{F,t}^H$, is restricted to unity.[7] There are no trade barriers, so the law of one price holds for each brand. And since preferences are assumed to be identical in the entire union, the consumer price index of the final good P_t is identical across countries: $P_t = P_t^H = P_t^F$. The consumer price index is given by $P_t = (P_{H,t})^\gamma (P_{F,t})^{1-\gamma}$, where $P_{H,t}$ $(P_{F,t})$ is the producer price index in country H (F). It is useful to define the terms of trade as the relative price of the Foreign bundle of goods in terms of the Home bundle, i.e. $Q_t \equiv P_{F,t}/P_{H,t}$.

Households have access to two types of one-period riskless financial assets: deposits D_t^H, held at domestic banks (others than their own), and internationally traded bonds B_t^H, in particular state-contingent claims. These perfect substitutes pay out the gross nominal return R_t from t to $t+1$, which is also the interest rate set by the central bank. We introduce internationally traded bonds to ensure perfect international risk-sharing (see, for instance, Clarida et al., 2002). Thus, at the union level, bonds are in zero net supply: $B_t^H + B_t^F = 0$.

Let w_t^H and r_t^H be the real prices of both input factors. At period t the representative household receives nominal factor income $P_{H,t}(w_t^H L_t^H + r_t^H u_t^H)$, nominal returns on its financial assets $R_{t-1}(D_{t-1}^H + B_{t-1}^H)$, and decides its deposit and bond holdings $D_t^H + B_t^H$ and its consumption expenditure $P_t C_t^H$. The budget constraint is given by

$$\begin{aligned} P_t C_t^H + D_t^H + B_t^H &= (1+\omega_w^H) P_{H,t} w_t^H L_t^H + (1+\omega_r^H) P_{H,t} r_t^H u_t^H + \Pi_t^H \\ &\quad + R_{t-1}(D_{t-1}^H + B_{t-1}^H) - T_t^H, \end{aligned} \tag{2}$$

where Π_t^H is the payment from exiting bankers net of startup funds provided to new

[7] Recent research justifies this unitary assumption. In particular, Feenstra et al. (2014) use a nested CES preference structure and show that there may be differences between the "micro" Armington elasticity, i.e. the elasticity between foreign varieties, and the "macro" Armington elasticity, i.e. the elasticity between foreign and domestic goods. They found a macro elasticity that is not significantly different from unity for the U.S. This is in sharp contrast to the estimated macro elasticity of about 6 in Imbs and Méjean (2015), who only use imports instead of matching the data with domestic production. Thus, their aggregate elasticity is still a micro elasticity that is just a weighted average of sectoral elasticities.

bankers plus dividends from ownership of retail firms, T_t^H is a lump-sum tax, and ω_w^H and ω_r^H are steady-state factor payment subsidies. The steady-state subsidies, financed by lump-sum taxes, are used to offset the distortions arising from price rigidity and the credit channel.

The representative household maximizes utility (1) subject to the budget constraint (2). By rearranging the resulting first-order conditions, we get

$$
\begin{aligned}
C_{H,t}^H &= \gamma Q_t^{1-\gamma} C_t^H && (3)\\
C_{F,t}^H &= (1-\gamma) Q_t^{-\gamma} C_t^H && (4)\\
\frac{(L_t^H)^{\varphi}}{(C_t^H)^{-\sigma}} &= (1+\omega_w^H) w_t^H Q_t^{\gamma-1} && (5)\\
\frac{(u_t^H)^{\varphi}}{(C_t^H)^{-\sigma}} &= (1+\omega_r^H) r_t^H Q_t^{\gamma-1} && (6)\\
E_t \Lambda_{t,t+1}^H R_t &= 1, && (7)
\end{aligned}
$$

where $\Lambda_{t,t+i}^H$ denotes the stochastic discount factor, given by

$$
\Lambda_{t,t+i}^H = \beta^i \left(\frac{\epsilon_{d,t+i}^H}{\epsilon_{d,t}^H} \right) \left(\frac{C_t^H}{C_{t+i}^H} \right)^{\sigma} \left(\frac{P_t}{P_{t+i}} \right).
$$

2.2 Intermediate Goods Firms

Competitive intermediate firms use both inputs to produce an intermediate good according to the Cobb-Douglas production function $x_t^H = (L_t^H)^{\alpha}(u_t^H)^{1-\alpha}$. Due to information asymmetry between workers and firms, the wage bill for the labor input has to be paid before selling goods (as in Ravenna and Walsh, 2005). Thus, the parameter α determines the fraction of the credit-constrained labor input in the production process - the share of production that is financed in advance. If $\alpha = 0$, there will be no need for financing factors in advance and the model will collapse to a standard two-country version of a currency union. If the whole production has to be financed in advance ($\alpha = 1$), the cost channel will be in place but there will be no distortions in terms of allocation of resources between input factors. Intermediate goods producers supply only the respective domestic market and intermediate goods are not traded internationally. Profits are given by

$$
profits_t^H = p_t^H x_t^H - R_{s,t}^H w_t^H L_t^H - r_t^H u_t^H, \tag{8}
$$

where p_t^H is the relative price of the intermediate good. For the purpose of paying the wage bill for the constrained labor input, firms have to take out loans $s_t^H = w_t^H L_t^H$ from financial intermediaries at the gross (nominal) lending rate $R_{s,t}^H$. We assume that loans are supplied and repaid within a period. This feature is known as the cost channel, whose strength is determined by α (see, for instance, Palek, 2016). By assumption, the process of obtaining funds from banks works perfectly: (in contrast to workers) financial intermediaries face no friction in evaluating and monitoring firms and enforcing payoffs. Thus, firms borrow exclusively from banks. In contrast, banks face frictions in obtaining deposits from households, so that the supply of funds (loans s_t^H) and the lending rate intermediate goods producers have to pay, depend on these frictions. This results in a credit channel which amplifies the existing cost channel.

The first-order conditions for both input factors are

$$\alpha p_t^H \frac{x_t^H}{L_t^H} = R_{s,t}^H w_t^H, \tag{9}$$

$$(1-\alpha) p_t^H \frac{x_t^H}{u_t^H} = r_t^H. \tag{10}$$

2.3 Retail Firms

Monopolistically competitive retailers produce final goods y_t^H. For the sake of simplicity, we assume that each firm simply labels the intermediate good at no cost with its own specific brand according to the technology $y_t^H = x_t^H$. Thus, p_t^H reflects real marginal cost. Price setting follows a Calvo (1983) scheme of price adjustment where each firm may reset its price with a probability $1 - \zeta^H$ in any given period. Assuming that the steady state is characterized by zero inflation, the evolution of the producer inflation rate is given by the marginal cost based (log-linearized) Phillips curve:

$$\pi_t^H = \beta E_t \pi_{t+1}^H + \kappa^H (\widehat{p}_t^H + \widehat{\epsilon}_{\pi,t}^H), \tag{11}$$

where the composite parameter κ^H is given by $\kappa^H \equiv \frac{(1-\zeta^H)(1-\beta\zeta^H)}{\zeta^H}$ (see, e.g., Gali, 2015), and $\widehat{\epsilon}_{\pi,t}^H$ is a country-specific exogenous markup shock, which is assumed to follow an AR(1) process.[8] Retail firms' profits are paid out as (lump-sum) dividends to households.

[8] A "^" symbol is used to denote the percentage deviation of a variable from its steady-state value.

2.4 Financial Intermediaries

Competitive financial intermediaries channel funds from savers (households) to investors (intermediate goods firms) and thereby capture the entire banking system. Every period a banker j combines (own) net worth $N_{j,t}^H$ and deposits $D_{j,t}^H$ obtained from households to provide loans $S_{j,t}^H$ to intermediate firms, where $S_t^H = P_{H,t}s_t^H$ is the value of claims in nominal terms. Accordingly, the balance sheet identity is given by

$$S_{j,t}^H = N_{j,t}^H + D_{j,t}^H. \tag{12}$$

Net worth $N_{j,t}^H$ at (the beginning of) period t is determined by earnings on assets that the bank receives at the end of period $t-1$ net of interest payments on deposits raised at $t-1$ and paid back at the beginning of t, i.e. before obtaining new deposits and making new loans:

$$\begin{aligned} N_{j,t}^H &= R_{s,t-1}^H S_{j,t-1}^H - R_{t-1} D_{j,t-1}^H \\ N_{j,t}^H &= (R_{s,t-1}^H - R_{t-1}) S_{j,t-1}^H + R_{t-1} N_{j,t-1}^H. \end{aligned} \tag{13}$$

As long as the return on loans is higher than the cost of borrowing, $E_t\Lambda_{t,t+i}^H \left(R_{s,t+i}^H - R_{t+i}\right) > 0$, the banker will have an incentive to provide loans (indefinitely) by raising additional deposits until being shut down. Hence, the objective of the bank j is to retain all earnings and maximize expected discounted future terminal wealth:

$$V_{j,t}^H = E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \Lambda_{t,t+1+i}^H N_{j,t+1+i}^H, \tag{14}$$

which can be written recursively as the Bellman equation:

$$V_{j,t}^H = E_t \Lambda_{t,t+1}^H \left[(1-\theta) N_{j,t+1}^H + \theta V_{j,t+1}^H\right], \tag{15}$$

where the stochastic discount factor $\Lambda_{t,t+i}^H$ is used here since bankers are members of households.

The following costly enforcement problem between financial intermediaries and households ensures that the ability of the former to obtain deposits from the latter is limited. Every period, after borrowing funds, the banker may divert the fraction λ_t^H of assets and transfer them to his or her respective household. In doing so, the financial intermediary goes bankrupt and since it is too costly to reclaim all assets, the depositors can only recover the fraction $1-\lambda_t^H$ of funds. Thus, in order to stay in business and supply loans, the franchise value of the bank $V_{j,t}^H$ must exceed the gain from bankruptcy. It follows that households will only deposit funds if the following incentive constraint holds:

$$V_{j,t}^H \geq \lambda_t^H S_{j,t}^H, \tag{16}$$

which, as we will see, can be interpreted as a market-based leverage constraint. There may be a country-specific exogenous shock $\epsilon_{\lambda,t}^H$ to the fraction $\lambda_t^H = \lambda^H \epsilon_{\lambda,t}^H$, which is assumed to follow an AR(1) process.

The bank j maximizes (15) subject to (13) and (16). This optimization problem can be solved by guessing a linear solution for the Bellman equation (15) as follows:

$$V_{j,t}^H = \nu_t^H S_{j,t}^H + \eta_t^H N_{j,t}^H, \tag{17}$$

where ν_t^H is the expected discounted excess return on additional deposits and η_t^H is the expected discounted marginal value of net worth, i.e. the reduction of borrowing costs due to another (a subtracted) unit of net worth (deposits). The former (ν_t^H) describes the gain of a balance sheet extension, while the latter (η_t^H) shows the gain of a reallocation. Let $\phi_t^H = S_{j,t}^H / N_{j,t}^H$ be the (maximum) leverage ratio (loan-to-net-worth ratio) that satisfies the incentive constraint (16), i.e. the maximum leverage ratio depositors are willing to accept, we obtain

$$S_{j,t}^H = \phi_t^H N_{j,t}^H = \frac{\eta_t^H}{\lambda_t^H - \nu_t^H} N_{j,t}^H. \tag{18}$$

By combining (17) and (18), the bank's optimization problem leads to

$$\begin{aligned} V_{j,t}^H &= E_t \Lambda_{t,t+1}^H \Omega_{t+1}^H N_{j,t+1}^H \\ V_{j,t}^H &= E_t \Lambda_{t,t+1}^H \Omega_{t+1}^H \left[(R_{s,t}^H - R_t) S_{j,t}^H + R_t N_{j,t}^H \right], \end{aligned} \tag{19}$$

where Ω_{t+1}^H denotes the shadow value of an additional unit of net worth, given by

$$\Omega_{t+1}^H = 1 - \theta + \theta \left(\eta_{t+1}^H + \phi_{t+1}^H \nu_{t+1}^H \right). \tag{20}$$

Due to financial frictions, bankers discount returns by the effective discount factor $\Lambda_{t,t+1}^H \Omega_{t+1}^H$, while households, facing no constraints, use $\Lambda_{t,t+1}^H$. To verify that the initial guess satisfies the Bellman equation, we compare (17) with (19) which determines ν_t^H and η_t^H as follows:

$$\nu_t^H = E_t \Lambda_{t,t+1}^H \Omega_{t+1}^H (R_{s,t}^H - R_t), \tag{21}$$

$$\eta_t^H = E_t \Lambda_{t,t+1}^H \Omega_{t+1}^H R_t. \tag{22}$$

Equations (18), (21), and (22), show the two pivotal features of the financial intermediation process. First, assuming that the incentive constraint binds, the net worth of a bank limits the amount of loans that can be provided through a market-based leverage constraint. Second, the (market-based) leverage ratio ϕ_t^H is increasing in the discounted excess return on assets η_t^H and the discounted marginal value of net worth ν_t^H, while the ratio is decreasing in λ_t^H, the fraction of assets that can be diverted. The first two factors lead to an increase in the franchise value of the bank, which increases the banker's incentive to continue to operate, making households willing to deposit more funds. An increase in λ_t^H leads to the opposite effect resulting in a deleveraging process, i.e. a simultaneous contraction in deposits and loans.

Note that ϕ_t^H, ν_t^H, η_t^H, and λ_t^H do not depend on specific factors of bank j. Hence, we can aggregate over all banks to obtain the law of motion for total net worth. The evolution of aggregate net worth is given by the sum of the net worth of existing bankers and the net worth of entering intermediaries

$$N_t^H = \theta\left[(R_{s,t-1}^H - R_{t-1})\phi_{t-1}^H + R_{t-1}\right] N_{t-1}^H + \xi S_{t-1}^H, \tag{23}$$

where bankers, who continue to operate with probability θ, retain net worth according to (13), while new bankers receive the constant fraction $\xi/(1-\theta)$ of the assets of exiting bankers $(1-\theta)S_{t-1}^H$ as startup funds.

2.5 Macroprudential Policy

As already mentioned, the credit friction motivates the implementation of macroprudential policy. We introduce (country-specific) macroprudential policy as a subsidy/tax scheme that works like a countercyclical capital requirement and leading to modifications in the structure of the banks' liability side in the balance sheet. In particular, a subsidy $\tau_{s,t}^H$ on net worth, financed by a tax τ_t^H on deposits, alters the incentive to (overly) rely on deposits. The balance sheet identity is now given by

$$S_{j,t}^H = \left(1 + \tau_{s,t}^H\right) N_{j,t}^H + \left(1 - \tau_t^H\right) D_{j,t}^H, \tag{24}$$

so that net worth evolves according to

$$N_{j,t}^H = (R_{s,t-1}^H - R_{t-1} - \tau_{t-1}^H) S_{j,t-1}^H + (R_{t-1} + \tau_{t-1}^H) N_{j,t-1}^H. \tag{25}$$

Assuming the same guess as before (see (17)), the expression for the franchise value of the bank (19) changes to

$$V_{j,t}^H = E_t \Lambda_{t,t+1}^H \Omega_{t+1}^H \left[(R_{s,t}^H - R_t - \tau_t^H) S_{j,t}^H + (R_t + \tau_t^H) N_{j,t}^H\right]. \tag{26}$$

Similar to Gertler et al. (2012) but in contrast to De Paoli and Paustian (2013), where only a subsidy is introduced, and Levine and Lima (2015), we assume that the subsidy/tax scheme is revenue-neutral. Accordingly, macroprudential policy faces the following balanced budget condition:

$$\tau_t^H D_t^H = \tau_{s,t}^H N_t^H. \tag{27}$$

Gertler et al. (2012) study the impact of outside equity and incorporate thereby more balance sheet items. While loans get taxed and outside equity gets subsidized, they also propose a revenue-neutral regulatory scheme.

Finally, comparing (17) with (26) results in

$$\nu_t^H = E_t \Lambda_{t,t+1}^H \Omega_{t+1}^H (R_{s,t}^H - R_t - \tau_t^H), \tag{28}$$
$$\eta_t^H = E_t \Lambda_{t,t+1}^H \Omega_{t+1}^H \left(R_t + \tau_t^H\right). \tag{29}$$

Equations (28) and (29) clearly show that this kind of macroprudential policy has an impact on the optimal leverage ratio (see (18)) by lowering the profitability of lending and increasing the attractiveness of raising net worth. With macroprudential policy in place, aggregate net worth evolves according to

$$N_t^H = \theta \left[(R_{s,t-1}^H - R_{t-1} - \tau_{t-1}^H)\phi_{t-1}^H + R_{t-1} + \tau_{t-1}^H \right] N_{t-1}^H + \xi S_{t-1}^H. \tag{30}$$

2.6 Equilibrium Dynamics

Goods market clearing in both countries implies

$$\gamma Y_t^H = \gamma C_{H,t}^H + (1-\gamma) C_{H,t}^F, \tag{31}$$
$$(1-\gamma) Y_t^F = (1-\gamma) C_{F,t}^F + \gamma C_{F,t}^H. \tag{32}$$

Due to perfect risk-sharing and by combining (31) and (32) with the households' demand curves for Home and Foreign goods (see (3), (4), and analogue conditions for Foreign), aggregate demands can be written as

$$Y_t^H = Q_t^{1-\gamma} C_t^W, \; Y_t^F = Q_t^{-\gamma} C_t^W. \tag{33}$$

Before we describe the dynamics of the model by log-linearizing the equilibrium conditions around the steady state, some simplifying notation is useful. An aggregate (union) variable $\widehat{x}_t^w$ is defined as the weighted average of the national variables, $\widehat{x}_t^W \equiv \gamma \widehat{x}_t^H + (1-\gamma)\widehat{x}_t^F$, while a relative variable $\widehat{x}_t^R$ is defined as $\widehat{x}_t^R \equiv \widehat{x}_t^H - \widehat{x}_t^F$.

The standard Home and Foreign IS curves can be obtained by combining the Euler equation (7) with the aggregate demand functions (33):

$$\widehat{y}_t^H = (1-\gamma)\widehat{Q}_t + E_t\widehat{y}_{t+1}^W - \sigma^{-1}(\widehat{R}_t - E_t\pi_{t+1}^W) + \sigma^{-1}(\widehat{\epsilon}_{d,t}^H - \widehat{\epsilon}_{d,t+1}^H), \quad (34)$$

$$\widehat{y}_t^F = -\gamma\widehat{Q}_t + E_t\widehat{y}_{t+1}^W - \sigma^{-1}(\widehat{R}_t - E_t\pi_{t+1}^W) + \sigma^{-1}(\widehat{\epsilon}_{d,t}^F - \widehat{\epsilon}_{d,t+1}^F). \quad (35)$$

By definition, the current period terms of trade is a function of its past value, thus it is a state variable:

$$\widehat{Q}_t = \widehat{Q}_{t-1} - (\pi_t^H - \pi_t^F). \quad (36)$$

Factor markets clearing, i.e. equating factor demand (see (9) and (10)) and factor supply (see (5) and (6)), together with the production function yields

$$\widehat{p}_t^H = (\sigma+\varphi)\widehat{y}_t^H + (1-\gamma)(1-\sigma)\widehat{Q}_t + \alpha\widehat{R}_{s,t}^H. \quad (37)$$

Similarly, we obtain for Foreign:

$$\widehat{p}_t^F = (\sigma+\varphi)\widehat{y}_t^F - \gamma(1-\sigma)\widehat{Q}_t + \alpha\widehat{R}_{s,t}^F. \quad (38)$$

Let $\Delta_t^i = R_{s,t}^i/R_t$ and $\widehat{\Delta}_t^i = \widehat{R}_{s,t}^i - \widehat{R}_t$ denote the premium or credit spread that banks claim. Inserting the relative price of the intermediate good (37) into (11) delivers the Home and in a similar vein the Foreign Phillips curve:

$$\pi_t^H = \beta E_t\pi_{t+1}^H + \kappa^H\left[(\sigma+\varphi)\widehat{y}_t^H + (1-\gamma)(1-\sigma)\widehat{Q}_t + \alpha\left(\widehat{R}_t + \widehat{\Delta}_t^H\right) + \widehat{\epsilon}_{\pi,t}^H\right], \quad (39)$$

$$\pi_t^F = \beta E_t\pi_{t+1}^F + \kappa^F\left[(\sigma+\varphi)\widehat{y}_t^F - \gamma(1-\sigma)\widehat{Q}_t + \alpha\left(\widehat{R}_t + \widehat{\Delta}_t^F\right) + \widehat{\epsilon}_{\pi,t}^F\right]. \quad (40)$$

In addition to the common features of the Phillips curve (income and terms of trade), the term $\widehat{R}_{s,t}^i$ is a substantial component. This term is composed of the interest rate $\widehat{R}_t$ and the credit spread $\widehat{\Delta}_t^i$ and thereby reflects the cost channel and the credit channel. Due to these frictions, monetary policy and distortions in the financial sphere will lead to fluctuations in $\widehat{R}_{s,t}^i$ and thereby have an impact on the supply side of the economy. In particular, a rise in the nominal interest rate or the credit spread increases the cost of obtaining loans. The profit maximizing intermediate goods firm passes the higher costs through by increasing the relative price of the intermediate good - marginal costs of the retailers rise as well as inflation. Hence, macroprudential policy, which affects the credit spread, and monetary policy serve as perfect substitutes regarding their impact via the supply side of the economy (as long as the cost channel is present). In general equilibrium, this supply-side effect remains but only monetary policy affects aggregate demand (see (34) and (35)).

Next, we proceed with the financial sector. Combining the loan demand according to the wage bill that results from the labor demand (9) with (37) yields

$$\widehat{\phi}_t^H + \widehat{n}_t^H = (1+\sigma+\varphi)\widehat{y}_t^H + (1-\gamma)(1-\sigma)\widehat{Q}_t - (1-\alpha)\left(\widehat{R}_t + \widehat{\Delta}_t^H\right), \quad (41)$$

$$\widehat{\phi}_t^F + \widehat{n}_t^F = (1+\sigma+\varphi)\widehat{y}_t^F - \gamma(1-\sigma)\widehat{Q}_t - (1-\alpha)\left(\widehat{R}_t + \widehat{\Delta}_t^F\right), \quad (42)$$

where the left-hand side is the loan amount, rewritten by using (18), whereby $\widehat{n}_t^i$ denotes real net worth. Since wages have to be paid in advance, equations (41) and (42) show the link between the production and the banking sector.

Log-linearizing the law of motion for aggregate net worth (30) results in

$$\widehat{n}_t^H = \widehat{n}_{t-1}^H - \pi_t^H + \frac{\theta\phi^H\Delta^H}{\beta}\widehat{R}_{s,t-1}^H + \frac{\beta-\theta}{\beta}\widehat{\phi}_{t-1}^H - \frac{\theta(\phi^H-1)}{\beta}\left(\widehat{R}_{t-1} + \beta\widehat{\tau}_{t-1}^H\right), \quad (43)$$

$$\widehat{n}_t^F = \widehat{n}_{t-1}^F - \pi_t^F + \frac{\theta\phi^F\Delta^F}{\beta}\widehat{R}_{s,t-1}^F + \frac{\beta-\theta}{\beta}\widehat{\phi}_{t-1}^F - \frac{\theta(\phi^F-1)}{\beta}\left(\widehat{R}_{t-1} + \beta\widehat{\tau}_{t-1}^F\right). \quad (44)$$

An increase in lending rates as well as being more leveraged leads to higher returns on assets, making net worth accumulation more attractive. Increases in $\widehat{R}_t$ and $\widehat{\tau}_t^i$ lead to higher costs of obtaining funds and thus lower earnings while raising the incentive to accumulate more net worth. Since the former effect outweighs the latter, the net impact on net worth accumulation is negative.

The last relationship we need is a dynamic equation for the evolution of the leverage ratios. We can obtain this relationship by combining (18), (28), (29), and (27):

$$\begin{aligned}\widehat{\phi}_t^H &= \phi^H\Delta^H\widehat{\Delta}_t^H - \left[1+\phi^H(\Delta^H-1)\right]\widehat{\epsilon}_{\lambda,t}^H - \beta(\phi^H-1)\widehat{\tau}_t^H \\ &\quad +\theta\left[1+\phi^H(\Delta^H-1)\right]^2 E_t\left(\widehat{\epsilon}_{\lambda,t+1}^H + \widehat{\phi}_{t+1}^H\right), \quad (45)\\ \widehat{\phi}_t^F &= \phi^F\Delta^F\widehat{\Delta}_t^F - \left[1+\phi^F(\Delta^F-1)\right]\widehat{\epsilon}_{\lambda,t}^F - \beta(\phi^F-1)\widehat{\tau}_t^F \\ &\quad +\theta\left[1+\phi^F(\Delta^F-1)\right]^2 E_t\left(\widehat{\epsilon}_{\lambda,t+1}^F + \widehat{\phi}_{t+1}^F\right). \quad (46)\end{aligned}$$

Equations (45)-(46) describe the Home and Foreign forward-looking conditions for the evolution of the leverage ratios. Expectations about the future ratio (and also about the shocks $\widehat{\epsilon}_{\lambda,t+1}^i$) play an important role for the actual leverage ratio. A rise in the credit spread leads to a higher leverage ratio since banks' franchise value increases, whereas a positive shock to (current) $\widehat{\epsilon}_{\lambda,t}^i$ leads to a decrease in leverage. Here, we follow Dedola et al. (2013) and interpret this financial shock as a loss of confidence in the banking sector. Households believe that there is an increase in banks' incentive to divert funds: the leverage ratio that depositors accept decreases. Thus, banks have to deleverage which results in a sharp contraction in deposits and loans, i.e. a credit crunch, that triggers a recession. Macroprudential policy changes the optimal composition of banks' balance sheets and can therefore dampen the effects described above.

Equations (34)-(36), (39)-(46), together with the shock processes of $\widehat{\epsilon}^{i}_{d,t}$, $\widehat{\epsilon}^{i}_{\pi,t}$, and $\widehat{\epsilon}^{i}_{\lambda,t}$ show the dynamics of the model that is finally closed by a description of monetary and macroprudential policy.

3 Framing the Policy Problem

In this section we describe the nature of optimal discretionary policy and optimal commitment policy by the monetary and macroprudential authority. The central bank is responsible for both types of policies and chooses jointly the union-wide nominal interest rate $\widehat{R}_t$ and the (national) macroprudential tool $\widehat{\tau}^i_t$ to maximize the utility of the representative household given by (1). This case of a centralized single policymaker corresponds to that of full coordination of monetary and supervisory authorities.

3.1 Welfare Objective

We obtain the objective function of the single policymaker from a second-order Taylor expansion of (1) around the deterministic steady state (see Appendix for details):

$$-E_0\left\{\sum_{t=0}^{\infty}\beta^t\frac{1}{2}\Psi_t\right\}+t.i.p., \tag{47}$$

where $t.i.p.$ stands for terms independent of policy. The per-period quadratic deadweight loss function Ψ_t is given by

$$\begin{aligned}\Psi_t \;=\;& (\sigma+\varphi)(\widehat{y}^W_t)^2+\gamma\frac{\varepsilon}{\kappa^H}(\pi^H_t)^2+(1-\gamma)\frac{\varepsilon}{\kappa^F}(\pi^F_t)^2+\gamma(1-\gamma)(1+\varphi)(\widehat{Q}_t)^2\\ &+\gamma\frac{\alpha(1-\alpha)}{1+\varphi}(\widehat{R}_t+\widehat{\Delta}^H_t)^2+(1-\gamma)\frac{\alpha(1-\alpha)}{1+\varphi}(\widehat{R}_t+\widehat{\Delta}^F_t)^2. \end{aligned} \tag{48}$$

The advantage using a second-order Taylor expansion of the utility function is that we obtain a microfounded objective function, where the weights of the respective variables are all functions of deep model parameters. The variables in the upper line of the loss function (48) are the standard target variables and weights for a two-country currency union (see for example Benigno, 2004, or Beetsma and Jensen, 2005). The variables $(\widehat{R}_t+\widehat{\Delta}^i_t)$ in the bottom line are new to the baseline New Keynesian model (see De Paoli and Paustian, 2013, for a closed-economy version of our model). The effective interest rate $\widehat{R}^i_{s,t}$, as sum of the nominal interest rate $\widehat{R}_t$ and the credit spread $\widehat{\Delta}^i_t$, is part of the loss function due to the existence of the cost channel and the credit channel, i.e. the tightness of the leverage constraint. Movements in the effective interest rate induce inefficient factor allocations. The central bank tries to stabilize the business cycle by choosing the nominal interest rate and the (country-specific) macroprudential tool, $\widehat{R}_t$ and $\widehat{\tau}^i_t$. However, as changes in $\widehat{\tau}^i_t$ lead to fluctuations in $\widehat{\Delta}^i_t$, the use of the instruments is not for free and causes a welfare loss per se. Varying the interest rate will cause an inefficient distribution between both input factors.[9] Macroprudential policy has a similar cost-push effect as the credit spreads are directly affected. Setting $\alpha = 0$ or $\alpha = 1$, the objective reduces to the standard two-country currency union loss function. If all output is produced by the unconstrained input factor ($\alpha = 0$), the effective interest rate drops out of the target criterion since there is no need for borrowing. If all output is produced by the constrained labor input ($\alpha = 1$), the term $(\widehat{R}_t + \widehat{\Delta}^i_t)$ drops out as there is no inefficient allocation between both input factors.

If the duration of price contracts is identical across countries, $\kappa^H = \kappa^F = \kappa$, the per-period loss function (48) can be rewritten in area and relative terms as

$$\begin{aligned}\Psi_t &= (\sigma+\varphi)(\widehat{y}^W_t)^2 + \frac{\varepsilon}{\kappa}\left[(\pi^W_t)^2 + \gamma(1-\gamma)(\pi^R_t)^2\right] + \gamma(1-\gamma)(1+\varphi)(\widehat{Q}_t)^2 \\ &\quad + \frac{\alpha(1-\alpha)}{1+\varphi}\left[(\widehat{R}_t + \widehat{\Delta}^W_t)^2 + \gamma(1-\gamma)(\widehat{\Delta}^R_t)^2\right]. \end{aligned} \tag{49}$$

Regarding the case of having merely a union-wide macroprudential tool, the policy-maker has only two aggregate tools ($\widehat{R}_t$ and $\widehat{\tau}^W_t$) with which the central bank cannot affect differentials. The objective further simplifies to $\Psi_t = (\sigma+\varphi)(\widehat{y}^W_t)^2 + \frac{\varepsilon}{\kappa}(\pi^W_t)^2 + \frac{\alpha(1-\alpha)}{1+\varphi}(\widehat{R}_t + \widehat{\Delta}^W_t)^2$, equivalent to the loss function in De Paoli and Paustian (2013). Fluctuations in relative variables still create losses but the central bank ignores them.

3.2 Calibration

Let us outline the parametrization for the quantitative policy analysis. The model is calibrated to a quarterly frequency. We use standard preference and technology parameters: the discount factor β is set equal to 0.99, so that the steady-state real interest rate is 4% p.a. By calibrating the elasticity of substitution between goods ε to

[9]The costly use of instruments is already known in the literature regarding optimal fiscal policy where varying government spendings creates a welfare loss (see e.g. Beetsma and Jensen, 2005, or Gali and Monacelli, 2008). Note that in most of the literature regarding the cost channel (e.g. Ravenna and Walsh, 2006), there are no direct welfare losses when varying the interest rate. This is because these models include only one unconstrained labor input.

a value of 7.66, we follow Benigno (2004) and assume that the steady-state mark-up of prices over marginal costs is around 15%, which is a reasonable value for the European economies. The price rigidity is assumed to be equal in both countries. Therefore the Calvo parameter ζ^i is set equal to a standard value of 0.75, implying an average duration of price contracts of four quarters. We divide the monetary union into two equal-sized groups, so that $\gamma = 0.5$. As in Carlstrom et al. (2010), the share of constrained labor (α) is set equal to 0.5. Following Woodford (2003) the inverse of the Frisch elasticity of labor supply (φ) and the inverse of the intertemporal elasticity of substitution (σ) are set equal to 0.47 and 0.16 respectively. Key financial parameters are chosen to match common values used in banking frameworks à la Gertler and Karadi (2011) and are assumed to be equal in both countries. Banks' survival probability (θ) is set to a value of 0.972, implying an average horizon of 8 years. In order to hit an annual steady-state credit spread spread ($R_s^i - R$) of 100 basis points, i.e. $\Delta^i = 1+\beta(R_s^i - R)$, and a steady-state leverage ratio (ϕ^i) of 4, the values of λ^i and ξ are set equal to 0.385 and 0.002. Moreover, we adopt a degree of persistence in the shocks of 0.8, i.e. $\rho_d = \rho_\pi = \rho_\lambda = 0.8$.

4 Dynamics

The objective of this section is to analyze the dynamic response of the relevant endogenous variables to different kinds of shocks, i.e. demand shocks, financial shocks and markup shocks. We distinguish between aggregate and idiosyncratic shocks and focus on the latter. In order to avoid (too) many case differentiations, the presentation focuses on optimal discretionary policy. Moreover, Lim et al. (2011) show that some macroprudential instruments need to be adjusted discretionarily.

4.1 Aggregate Shocks

In this subsection we briefly discuss the optimal policy mix in the case of different kind of aggregate shocks. Since both countries are symmetrical, the analysis is isomorphic to the case of a closed economy.

Proposition 1 *Optimal monetary and macroprudential policy fully absorbs aggregate demand and financial shocks.*

Proof. The nominal interest rate is set according to $\widehat{R}_t = (1-\rho_d)\widehat{\epsilon}_{d,t}^W$ and the macroprudential tool $\widehat{\tau}_t^W$ is set according to (45) and (46) so that $\widehat{y}_t^W = \pi_t^W = \widehat{R}_{s,t}^W = 0$, ensuring efficiency $\Psi_t = 0$ (see (49)) in every period. ■

We start by considering a positive aggregate demand (preference) shock, i.e. $\widehat{\epsilon}_{d,0}^{W} = \widehat{\epsilon}_{d,0}^{H} = \widehat{\epsilon}_{d,0}^{F} = 0.01$. Without a dynamic macroprudential tool ($\widehat{\tau}_t^i = 0$)[10], optimal policy consists only of an increase in the interest rate. Because of the cost channel and the credit channel, monetary policy cannot perfectly absorb the shock. The rise of the interest rate pushes $\widehat{R}_{s,t}^{W}$ and inflation up via the supply side of the economy. Moreover there is an inefficient allocation between labor inputs creating a welfare loss. Allowing macroprudential policy to act dynamically changes the picture. Now both instruments are used to correct the inflationary boom. The interest rate is varied in order to perfectly absorb fluctuations in output ($\widehat{R}_t = (1-\rho_d)\widehat{\epsilon}_{d,t}^{W}$). Distortions caused by variations in the interest rate are perfectly offset by the macroprudential instrument, so that $\widehat{R}_t = -\widehat{\Delta}_t^W$ and $\widehat{R}_{s,t}^{W} = \pi_t^W = 0$. Hence, in accordance to the Tinbergen principle, both policies are not perfect substitutes, i.e. they are independent. Since there are no relative distortions between Home and Foreign, it is obvious that there is no advantage of having country-specific macroprudential tools.

Following a negative aggregate financial shock ($\widehat{\epsilon}_{\lambda,0}^{W} = \widehat{\epsilon}_{\lambda,0}^{H} = \widehat{\epsilon}_{\lambda,0}^{F} = 0.01$), the incentive constraint (16) is tightened and banks start a deleveraging process by cutting down loans and deposits. Hence, $\widehat{\Delta}_t^W$, marginal costs and thus inflation increase. Without macroprudential policy, tightening monetary policy reduces the positive inflation gap but the output gap becomes negative. The first best outcome is only feasible when the macroprudential tool is available as a policy instrument: loosening macroprudential policy perfectly offsets fluctuations in $\widehat{\phi}_t^W$. There is no need to adjust credit spreads. As a result, the interest rate is kept constant ($\widehat{R}_t = 0$).

Proposition 2 *Consider an aggregate markup shock. a) For $\alpha = 1$, optimal monetary and macroprudential policy fully eliminates economic distortions. b) For $\alpha \neq 1$, full stabilization of aggregate output and inflation is possible but not optimal.*

Proof. a) The instruments are set such that $\widehat{R}_t = 0$ and $\widehat{\tau}_t^W = -\frac{\phi^i \Delta^i}{\beta(\phi^i - 1)}\epsilon_{\pi,t}^W$ (see (43)-(46)) so that $\widehat{\Delta}_t^W = -\widehat{\epsilon}_{\pi,t}^W$ and thus $\widehat{y}_t^W = \pi_t^W = 0$, ensuring efficiency $\Psi_t = 0$ (see (49)) in every period, as there is no inefficient labor allocation. b) Due to the fact that there is an inefficient labor allocation as the financing of production factors differs, varying instruments is costly per se and causes additional losses according to (49). ■

A positive markup shock ($\widehat{\epsilon}_{\pi,0}^{W} = \widehat{\epsilon}_{\pi,0}^{H} = \widehat{\epsilon}_{\pi,0}^{F} = 0.01$) drives a wedge between the inflation and output target and cannot be offset if there is no macroprudential tool. The central bank mitigates the inflationary cost-push effect by increasing the interest

[10] Note that $\widehat{\tau}_t^i = 0$ also implies the case of a macroprudential regulation that is in place but cannot be dynamically used to smoothen the business cycle.

rate, though there will not be full accommodation. In presence of the macroprudential tool, the markup shock can be fully absorbed if $\alpha = 1$, i.e. all output is produced by the constrained labor input only. In this case, the macroprudential tool is a perfect supply-side instrument, since it does not produce any inefficient input factor allocations. Hence, monetary policy remains inactive ($\widehat{R}_t = 0$) while macroprudential policy affects the credit spreads ($\widehat{\Delta}_t^W = -\widehat{\epsilon}_{\pi,t}^W$) in order to offset the markup shock. This no longer holds true if $\alpha \neq 1$ as fluctuations in the credit spreads (by using the macroprudential tool) are costly per se. The outcome $\widehat{y}_t^W = \pi_t^W = 0$ is possible but not optimal. Following the shock, there will be a positive inflation gap and a negative output gap. In this case, it is optimal to increase the nominal interest rate (in order to reduce inflation) and to decrease the macroprudential tool (in order to reduce credit spreads). The interest rate hike, the inflation and the output gap are significantly lower compared to the case without macroprudential policy.

4.2 Idiosyncratic Shocks

Let our focus now turn to the case of idiosyncratic shocks. In the following we will consider a demand shock, a financial shock and a markup shock in the Home country. In all cases we are interested in the change in the inflation and output dynamics when the instrument set of the central bank is enhanced by adding macroprudential policy (tools). Even though both countries are symmetrical, there will be relative distortions following a shock in only one of the countries. It is well known that monetary policy is not able to affect differences across countries in a monetary union as the nominal interest rate is a union-wide instrument only. When country-specific macroprudential policy is available, the central bank has a (relative) instrument in order to mitigate relative fluctuations across countries.

4.2.1 Demand Shock

Proposition 3 *Consider an idiosyncratic demand shock. a) In the case that there is only a union-wide macroprudential tool, optimal monetary and macroprudential policy fully absorbs aggregate fluctuations, but a welfare loss due to variations in relative variables remains. b) In the case that there are country-specific macroprudential tools and $\alpha = 1$, optimal monetary and macroprudential policy fully eliminates fluctuations in aggregate and relative target variables. c) In the case that there are country-specific macroprudential tools and $\alpha \neq 1$, full stabilization of relative output and inflation is possible but not optimal.*

Proof. a) The optimal policy mix implies $\widehat{R}_t = (1 - \rho_d)\gamma\epsilon_{d,t}^H$ and that $\widehat{\tau}_t^W$ is set according to (45) and (46) so that aggregate distortions are eliminated, i.e. $\widehat{R}_t = -\widehat{\Delta}_t^W$

and $\widehat{y}_t^W = \pi_t^W = 0$. Since the policymaker ignores differentials there is still a welfare loss arising from fluctuations in π_t^R, $\widehat{Q}_t$, and $\widehat{\Delta}_t^R$. b) The instruments $\widehat{R}_t$ and $\widehat{\tau}_t^W$ are set according to a) and $\widehat{\tau}_t^R$ is set consistent with (43)-(46) so that $\widehat{y}_t^W = \pi_t^W = \pi_t^R = \widehat{Q}_t = 0$ which insures efficiency $\Psi_t = 0$ (see (49)) in every period. Due to the fact that there is no difference in the financing of production factors, there is no inefficient input factor allocation ($\alpha = 1$) and varying instruments is not costly per se. Hence, $\widehat{\tau}_t^R$ can be used to eliminate fluctuations ($\widehat{\Delta}_t^R = -(\sigma + \varphi)\widehat{y}_t^R = -\frac{(\sigma+\varphi)}{\sigma}(1 - \rho_d)\epsilon_{d,t}^H$) in relative marginal costs $\widehat{p}_t^R = (\sigma + \varphi)\widehat{y}_t^R + (1 - \sigma)\widehat{Q}_t + \widehat{\Delta}_t^R$ (see (37)) to stabilize $\pi_t^R = \beta E_t \pi_{t+1}^R + \kappa \widehat{p}_t^R$ and $\widehat{Q}_t$ (36) which ultimately results in the first best outcome. c) The inefficient input factor allocation implies that varying instruments is costly per se and causes additional losses according to (49). ■

Figure (1) displays the impulse responses to a positive Home demand shock for the benchmark calibration. Without a macroprudential tool (blue line), the shock cannot be absorbed due to the cost channel and the credit channel which lead to an inefficient labor allocation. Due to these distortions, monetary policy becomes more aggressive than in a world without these frictions (see Michaelis and Palek, 2016) where the central bank could stabilize the economy by setting the nominal interest rate according to $\widehat{R}_t = (1 - \rho_d)\gamma\epsilon_{d,t}^H$. In presence of macroprudential policy (red and green line), all aggregate fluctuations are eliminated as monetary policy absorbs the shock ($\widehat{R}_t = (1 - \rho_d)\gamma\epsilon_{d,t}^H$) while macroprudential policy offsets the distortions caused by using the nominal interest rate ($\widehat{R}_t = -\widehat{\Delta}_t^W$). Nevertheless, there is still a welfare loss due to fluctuations in relative inflation, the terms of trade and relative credit spread.

In the case that there are country-specific macroprudential tools, optimal monetary and macroprudential policy fully absorb idiosyncratic demand shocks if $\alpha = 1$. In this case varying instruments is not costly per se anymore. Country-specific macroprudential policy is used to offset all fluctuations in relative variables. More precisely, $\widehat{\tau}_t^R$ is used to lower the Home credit spread while $\widehat{\Delta}_t^F$ increases. This stabilizes relative marginal costs which implies that relative inflation and the terms of trade do not move ($\pi_t^R = \widehat{Q}_t = 0$). Fluctuations in $\widehat{y}_t^R$ remain but cause no welfare loss.

If $\alpha \neq 1$, reaching the first-best outcome is not possible anymore as it implies an inefficient input factor allocation. So it is not optimal to fully stabilize relative marginal costs since the use of $\widehat{\tau}_t^R$ and thus changes in $\widehat{\Delta}_t^R$ are costly. Therefore there are fluctuations in relative inflation, the terms of trade and the relative output gap. Having country-specific macroprudential tools improves welfare compared to one union macroprudential tool since the gaps in relative inflation, the relative credit spread and the terms of trade become smaller (see green line).

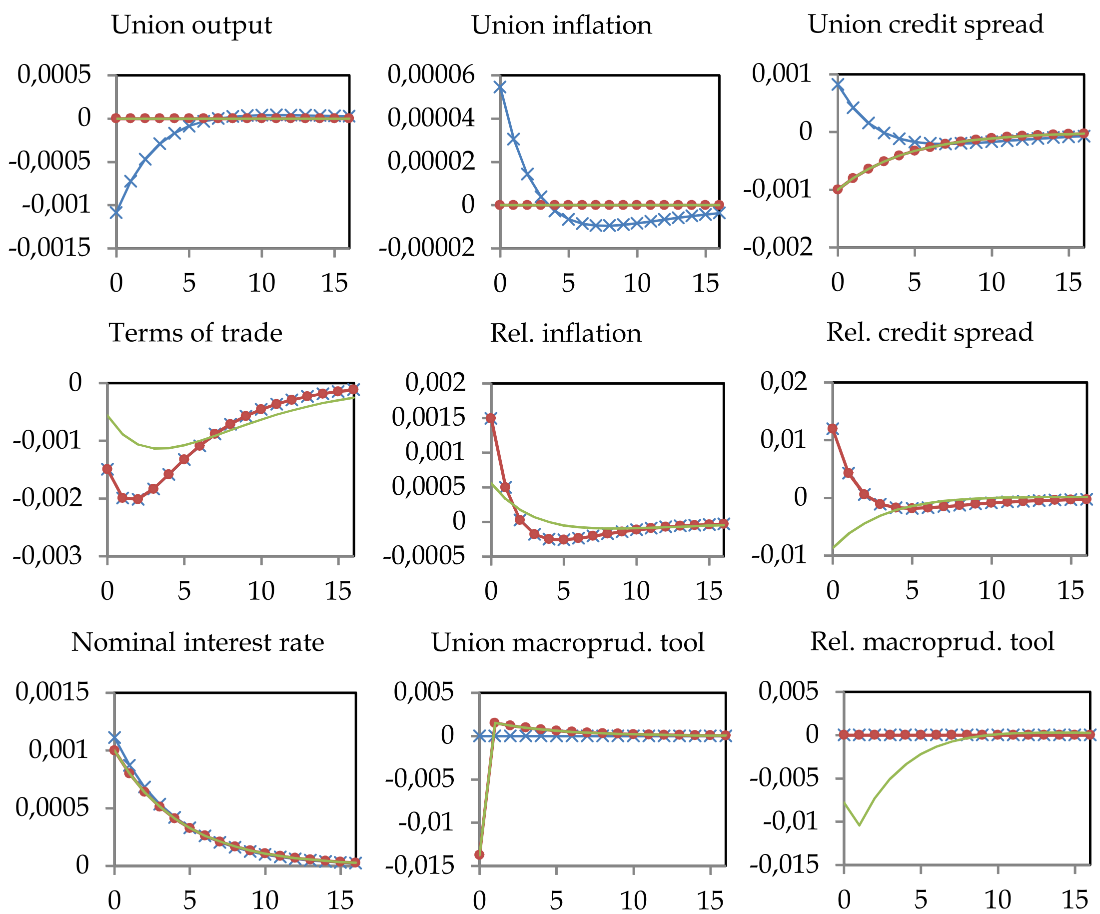

Figure 1: Impulse responses to a Home demand shock. No macroprudential tool (blue line), union macroprudential tool (red line), national macroprudential tools (green line)

4.2.2 Financial Shock

Proposition 4 *Consider an idiosyncratic financial shock. a) In the case that there is only a union-wide macroprudential tool, optimal macroprudential policy fully absorbs aggregate fluctuations, but a welfare loss due to fluctuations in relative variables remains. b) In the case that there are country-specific macroprudential tools, optimal macroprudential policy fully eliminates economic distortions.*

Proof. a) Macroprudential policy is superior to monetary policy, $\widehat{R}_t = 0$, and only $\widehat{\tau}_t^W$ is set according to (45) and (46) in order to eliminate aggregate distortions, $\widehat{y}_t^W = \pi_t^W = \widehat{\Delta}_t^W = 0$. Since the policymakers ignore differentials there is still a welfare loss arising from fluctuations in π_t^R, $\widehat{Q}_t$, and $\widehat{\Delta}_t^R$. b) Macroprudential policy remains superior to monetary policy which implies $\widehat{y}_t^W = \pi_t^W = 0$. Furthermore, setting both macroprudential tools $(\widehat{\tau}_t^R)$ according to (45) and (46) eliminates relative distortions $\pi_t^R = \widehat{Q}_t = \widehat{\Delta}_t^R = 0$ which insures efficiency $\Psi_t = 0$ (see (49)) in every period. ■

Following a negative Home financial shock (see Figure (2)), the union and relative credit spread rises and therefore union and relative inflation increases. Without macroprudential policy (blue line), the central bank acts exactly as in the case of an aggregate financial shock by increasing the interest rate in order to mitigate the effects on the union target variables. But contrary to the aggregate shock, there are additional

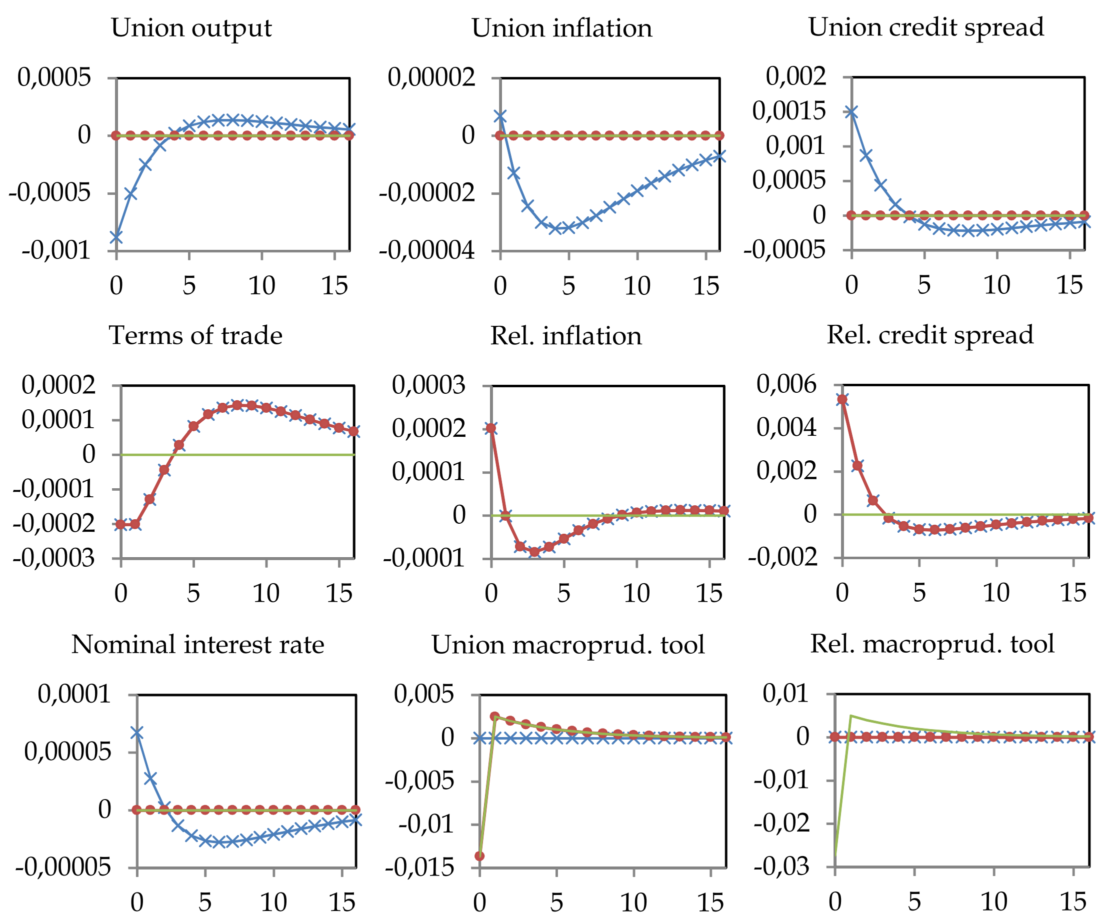

Figure 2: Impulse responses to a Home financial shock. No macroprudential tool (blue line), union macroprudential tool (red line), national macroprudential tools (green line)

welfare losses due to fluctuations in the relative variables which cannot be affected by monetary policy. With a union-wide macroprudential tool at hand (red line) the shock can be fully absorbed at the union but not on the relative level. Macroprudential policy stabilize $\widehat{\Delta}_t^W$ and therefore $\widehat{y}_t^W = \pi_t^W = 0$. Welfare losses arise due to fluctuations in π_t^R, $\widehat{Q}_t$, and $\widehat{\Delta}_t^R$. Country-specific macroprudential tools (green line) are able to eliminate these distortions by decreasing the relative macroprudential instrument such that $\widehat{\Delta}_t^R = \pi_t^R = \widehat{Q}_t = 0$. Hence, there are no welfare losses irrespective of the value of α.

4.2.3 Markup Shock

Proposition 5 *Consider an idiosyncratic markup shock. a) In the case that there is only a union-wide macroprudential tool and for $\alpha = 1$, optimal monetary and macroprudential policy fully absorbs aggregate fluctuations, but a welfare loss due to fluctuations in relative variables remains. b) In the case that there is only a union-wide macroprudential tool and for $\alpha \neq 1$, full stabilization of aggregate output and inflation is possible but not optimal. Hence, losses arise from variations in aggregate and relative variables. c) In the case that there are country-specific macroprudential tools and for $\alpha = 1$, optimal monetary and macroprudential policy fully eliminates economic distortions. d) In the case that there are country-specific macroprudential tools and for $\alpha \neq 1$, full stabilization of aggregate and relative output and inflation is possible but not optimal.*

Proof. a) Macroprudential policy is superior to monetary policy, hence $\widehat{R}_t = 0$. The macroprudential tool is set according to $\widehat{\tau}_t^W = -\frac{\phi^i \Delta^i}{\beta(\phi^i - 1)} \gamma \epsilon_{\pi,t}^H$ (see (43)-(46)) so that $\widehat{\Delta}_t^W = -\gamma \widehat{\epsilon}_{\pi,t}^H$ which eliminates aggregate distortions, $\widehat{y}_t^W = \pi_t^W = 0$. Since the policymaker ignores differentials there is still a welfare loss arising from fluctuations in π_t^R and $\widehat{Q}_t$. b) The inefficient input factor allocation implies that varying instruments causes additional losses according to (49). c) As in a), macroprudential policy remains superior to monetary policy which implies $\widehat{y}_t^W = \pi_t^W = 0$. Furthermore, the country-specific tools are set such that $\widehat{\tau}_t^R = -\frac{\phi^i \Delta^i}{\beta(\phi^i - 1)} \epsilon_{\pi,t}^H$ (see (43)-(46)) so that $\widehat{\Delta}_t^R = -\widehat{\epsilon}_{\pi,t}^H$ which eliminates relative distortions, $\pi_t^R = \widehat{Q}_t = 0$ (see (39),(40),(36)), and insures efficiency $\Psi_t = 0$ (see (49)) in every period since there are no sectoral distortions. d) Due to the fact that the financing of production factors differs, there is an inefficient input factor allocation and varying instruments is costly per se and causes additional losses according to (49). ■

A positive Home markup shock raises union and relative inflation. Figure (3) displays the impulse responses for the benchmark specification. The positive inflation differential lets the Home terms of trade deteriorate and the relative output gap becomes negative due to the decline in relative demand. In absence of macroprudential

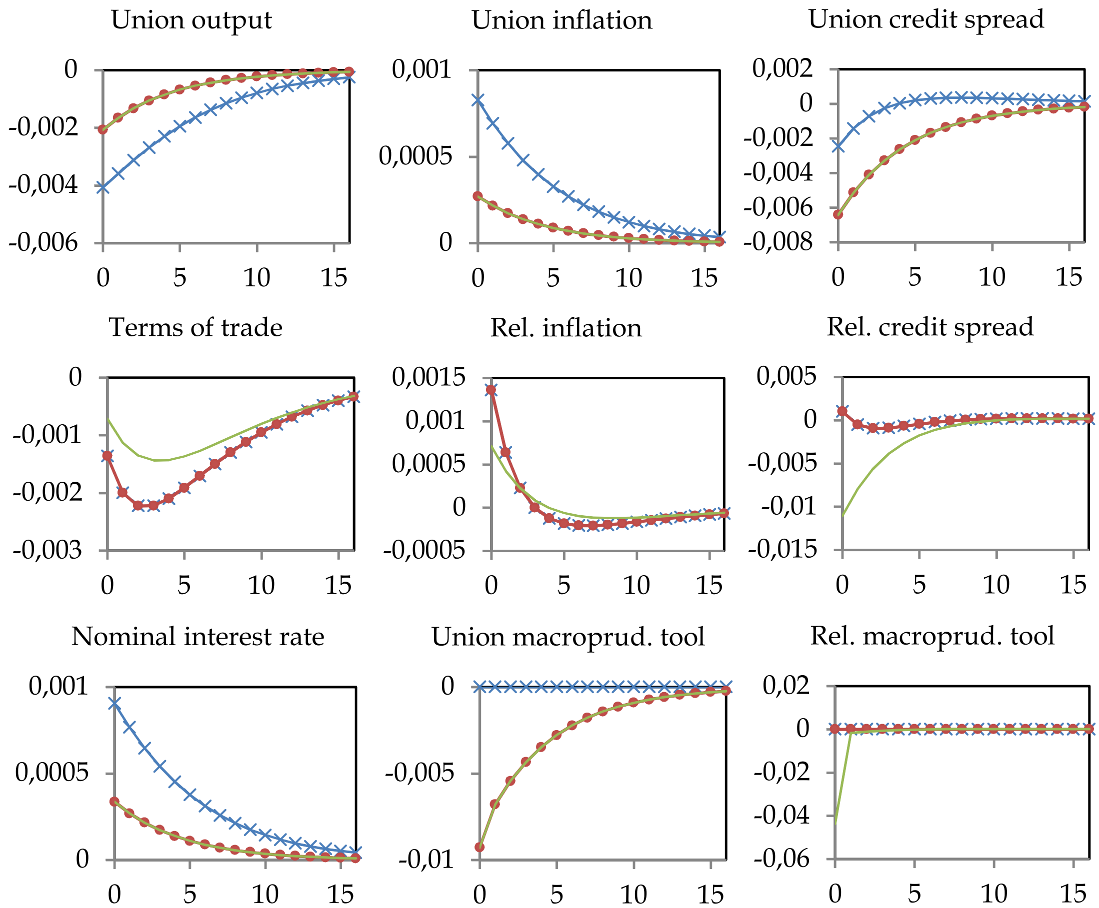

Figure 3: Impulse responses to a Home markup shock. No macroprudential tool (blue line), union macroprudential tool (red line), national macroprudential tools (green line)

policy (blue line), the optimal interest rate hike only diminishes union-wide fluctuations. Without sectoral distortions ($\alpha = 1$), the nominal interest rate is kept constant ($\widehat{R}_t = 0$) as the union-wide macroprudential tool is able to stabilize the economies on the aggregate level ($\widehat{y}_t^W = \pi_t^W = 0$). Variations in all relative target variables remain as they cannot be addresses with aggregate instruments. Again, country-specific macroprudential tools are able to manipulate relative credit spreads ($\widehat{\Delta}_t^R = -\widehat{\epsilon}_{\pi,t}^H$) and eliminate relative distortions so that $\pi_t^R = \widehat{Q}_t = 0$ which implies no welfare losses.

When there are different input factors ($\alpha \neq 1$), using policy instruments is costly per se so that the first-best outcome is not feasible anymore. Hence, a policy mix is required. In the case of a union-wide macroprudential tool (red line), it is optimal to increase the nominal interest rate (in order to reduce union inflation) and to decrease the macroprudential tool (in order to lower the union credit spread) which reduces aggregate marginal costs and union inflation. The availability of a dynamic macroprudential policy tool makes the optimal interest hike, the union inflation and the union output gap significantly lower compared to the case where only monetary policy serves as shock stabilizer.

With country-specific macroprudential tools (green line), the level of the union-wide instruments remains the same but the composition of $\widehat{\tau}_t^W$ changes such that $\widehat{\tau}_t^R$ decreases. Lowering the relative macroprudential tool decreases relative marginal costs and thus the inflation differential by reducing the relative credit spreads.

5 Welfare Analysis

The objective of this section is twofold. First, we will show the size of welfare gain of having macroprudential policy at disposition. Second, we will assess the performance of different policy regimes that follows simple rules.

Table (1) displays the welfare losses of various types of shocks when optimal policy is conducted under discretion or commitment. For each shock type, Table (1) shows the losses for a different kind of macroprudential instrument set, expressed as a fraction of steady-state consumption that must be given up to equate welfare in the stochastic economy to that in a deterministic steady state. Throughout all types of shocks there are (significant) welfare improvements by introducing a union-wide macroprudential tool.[11] When macroprudential policy is available, the additional gain from having country-specific tools is modest (except for the idiosyncratic demand shock in the baseline specification). Compared to commitment, this additional welfare gain is lower under discretion. These results are robust to a large set of alternative parametrizations.

So far we have (derived and) discussed the optimal policy mix under discretion and commitment. However, almost all of the research on macroprudential policy assumes that the design of the policy follows (optimal) simple rules (see, for instance, Loisel, 2014). It is obvious that even optimal simple rules will lead to higher welfare losses compared to the Ramsey policy. However, we are interested in the welfare implication of implementing macroprudential policy under different policy regimes/lacks of commitment. In order to not rely on specific weights for each target variable and to show the

[11] Note that markup shocks create large welfare losses due to high deviations of the inflation gap since microfounded welfare functions attach a weight to inflation that can be over ten or twenty times higher than the one attached to the output term (see Woodford, 2003, Ch.6). For many macroeconomists this sounds counterintuitive. Either the intuition is wrong or the model does not capture important cost drivers of the output gap. For a pragmatic view - conduct a robustness check by varying the weights - see Wren-Lewis (2011) and Kirsanova et al. (2013).

Macroprud. instruments	Demand shock Aggre-gate	Demand shock Idio-syncratic	Financial shock Aggre-gate	Financial shock Idio-syncratic	Markup shock Aggre-gate	Markup shock Idio-syncratic
Discretion						
No tool	0.00057	0.00407	0.00043	0.00026	0.04775	0.01551
Tool	0	0.00392	0	0.00015	0.00861	0.00573
Tools	0	0.00111	0	0	0.00861	0.00394
Commitment						
No tool	0.00053	0.00406	0.00032	0.00023	0.01242	0.00668
Tool	0	0.00392	0	0.00015	0.00550	0.00495
Tools	0	0.00087	0	0	0.00550	0.00278

Table 1: Welfare losses under different macroprudential policy instrument sets

best possible outcome, we apply the optimal simple rule approach. We (still) restrict our analysis to the case of perfect cooperation (between different authorities).

Regarding monetary policy we differentiate between a Taylor Rule and an augmented Taylor Rule. In the first case, the nominal interest rate evolves according to $\widehat{R}_t = k_1 \cdot \widehat{R}_{t-1} + (1-k_1)\left(k_2 \cdot \pi_t^W + k_3 \cdot \widehat{y}_t^W\right)$, where k_i reflects the optimized weight of the corresponding variable. As already mentioned, the literature has emphasized a wide range of tangible indicators measuring "financial stability". According to our welfare criterion (49), we augment the Taylor Rule by adding credit spreads. In line with large parts of the literature (see, among others, Ueda and Valencia, 2014), we also add leverage ratios as additional target variables.[12] In this (second) case, the interest rate is set according to $\widehat{R}_t = k_1 \cdot \widehat{R}_{t-1} + (1-k_1)\left(k_2 \cdot \pi_t^W + k_3 \cdot \widehat{y}_t^W + k_4 \cdot \widehat{\Delta}_t^W + k_5 \cdot \widehat{\phi}_t^W\right)$. When macroprudential policy is available, monetary policy follows the (first) Taylor Rule, while macroprudential policy addresses "financial stability" measured by credit spreads and leverage ratios. The union-wide macroprudential instrument is set according to $\widehat{\tau}_t^W = k_6 \cdot \widehat{\tau}_{t-1}^W + (1-k_6)\left(k_7 \cdot \widehat{\Delta}_t^W + k_8 \cdot \widehat{\phi}_t^W\right)$, while the country-specific tools follow $\widehat{\tau}_t^R = k_9 \cdot \widehat{\tau}_{t-1}^R + (1-k_9)\left(k_{10} \cdot \widehat{\Delta}_t^W + k_{11} \cdot \widehat{\phi}_t^W\right)$.

Table (2) depicts the welfare losses under different policy regimes for various kinds of shocks. Several comments are in order. First, all rules produces welfare outcomes that are relatively close to the optimal (Ramsey) policy. Thus, the specification of the rules seems to be appropriate. Second, except for the demand shock, the augmented Taylor Rule leads to no significant welfare improvements. It is not sufficient to augment the

[12] We have also incorporated other indicators (credit aggregates, loan-to-GDP), which leads to similar results.

	Demand shock		Financial shock		Markup shock	
Optimal simple rule	Aggre-gate	Idio-syncratic	Aggre-gate	Idio-syncratic	Aggre-gate	Idio-syncratic
Taylor Rule	0.00087	0.00447	0.00033	0.00024	0.01288	0.00687
Aug. TR	0.00065	0.00408	0.00033	0.00024	0.01256	0.00678
TR + tool	0.00065	0.00409	0.00019	0.00020	0.00585	0.00520
TR + tools	0.00065	0.00252	0.00019	0.00012	0.00585	0.00513

Table 2: Welfare losses under different optimal simple rules

interest rate rule in order to address credit spreads as additional target. The instrument set has to be expanded as well. Third, there are (significant) welfare improvements by introducing a union-wide macroprudential policy rule. When macroprudential policy is available, the additional gain from having country-specific macroprudential tools is relatively low, similar to the cases of discretion and commitment. Fourth, compared to discretion and commitment, this additional gain from country-specific macroprudential policy is scarce (except for the idiosyncratic demand shock in the baseline specification). Against this background, it seems plausible that the ECB increasingly focuses on the implementation of macroprudential policy at a union level. This argument gets further strengthened by considering (game-theoretical) interactions between authorities and policy failures (see, for instance, De Paoli and Paustian, 2013).

The main results are summarized in the following:

Proposition 6 *a) There are significant welfare improvements by introducing a union-wide macroprudential tool. b) The additional welfare gain from varying the relative macroprudential tool is modest c) The additional welfare gain from having country-specific macroprudential policy vanishes as the ability of the central bank to commit decreases.*

6 Conclusions

This paper investigates the optimal monetary and macroprudential policy mix in a currency union in presence of aggregate and idiosyncratic demand, financial and markup shocks. We incorporate an elaborated financial sector à la Gertler and Karadi (2011) into the standard New Keynesian model, which leads to credit frictions when firms need external finance. Given our assumptions on nominal rigidities and financial frictions trade-offs arise between stabilizing inflation, output, the credit spread as well as the terms of trade. As the interest rate is too blunt of an instrument there is a rationale for the use of macroprudential policy as a stabilization tool. In particular, the presence of idiosyncratic shocks calls for actions in country-specific macroprudential policy.

In our analysis, the monetary and macroprudential instruments are modelled as independent tools. By introducing macroprudential policy, fluctuations on the union level can be fully absorbed for a large set of different scenarios. Welfare losses due to variations on the relative level remain even when country-specific macroprudential tools are available as long as the financing of production factors differs. Introducing a union-wide macroprudential tool therefore improves welfare significantly. The additional welfare gain from varying the relative macroprudential tool is small though. The setup of our model allows us to study welfare-based (optimal) monetary and macroprudential policy in a currency union which is the main difference to other studies who assume a(n) (optimal) simple rules policy design. Therefore, we compare Ramsey policy with optimal macroprudential and monetary simple rules. Evaluating the performance of these policy regimes with a microfounded welfare criterion shows that the implementation of a union-wide macroprudential tool leads to significant welfare improvements, whereas additional welfare gains from having country-specific macroprudential policy vanish as the ability of the central bank to commit decreases. Against this background, macroprudential policy should be at least implemented at a union level, as does by the ECB with the introduction of the SSM.

Our analysis can be extended in several directions: Introducing financial interdependence by financial integration in loan and deposit markets (as in Dedola et al., 2013, for example), or modelling the strategic interaction between the central bank and regulatory authorities in the sense of De Paoli and Paustian (2013) are important issues for future research.

Appendix: Union's Welfare Loss

The central bank's loss function is given by

$$\psi_t = \gamma U(C_t^H, L_t^H, u_t^H, \epsilon_{d,t}^H) + (1-\gamma) U(C_t^F, L_t^F, u_t^F, \epsilon_{d,t}^F). \quad \text{(A.1)}$$

We take a second-order approximation of the Home utility function $U(C_t^H, L_t^H, u_t^H, \epsilon_{d,t}^H)$ (see (1)) and $U(C_t^F, L_t^F, u_t^F, \epsilon_{d,t}^F)$ around the steady-state $U(C, L^H, u^H), U(C, L^F, u^F)$:

$$\begin{aligned}
\psi_t - \psi &= \gamma C^{1-\sigma}[\widehat{C}_t^H(1+\widehat{\epsilon}_{d,t}^H) + \frac{1-\sigma}{2}(\widehat{C}_t^H)^2] \\
&\quad +(1-\gamma)C^{1-\sigma}[\widehat{C}_t^F(1+\widehat{\epsilon}_{d,t}^F) + \frac{1-\sigma}{2}(\widehat{C}_t^F)^2] \\
&\quad -\gamma(L^H)^{1+\varphi}[\widehat{L}_t^H(1+\widehat{\epsilon}_{d,t}^H) + \frac{1+\varphi}{2}(\widehat{L}_t^H)^2] \\
&\quad -(1-\gamma)(L^F)^{1+\varphi}[\widehat{L}_t^F(1+\widehat{\epsilon}_{d,t}^F) + \frac{1+\varphi}{2}(\widehat{L}_t^F)^2] \\
&\quad -\gamma(u^H)^{1+\varphi}[\widehat{u}_t^H(1+\widehat{\epsilon}_{d,t}^H) + \frac{1+\varphi}{2}(\widehat{u}_t^H)^2] \\
&\quad -(1-\gamma)(u^F)^{1+\varphi}[\widehat{u}_t^F(1+\widehat{\epsilon}_{d,t}^F) + \frac{1+\varphi}{2}(\widehat{u}_t^F)^2] + t.i.p., \quad \text{(A.2)}
\end{aligned}$$

where $t.i.p.$ captures all terms independent of policy and $C^H = C^F = C$ due to perfect risk sharing. Terms of third or higher order are dropped.

Assuming that the steady-state employment subsidies are used to offset all distortions, i.e. for country $i, i = \{H, F\}$, $\omega_w^i = (R_S^i - p^i)/p^i$ and $\omega_r^i = (1-p^i)/p^i$ lead to an efficient steady state, we can obtain the following relations

$$(L^i)^{1+\varphi} = \alpha C^{1-\sigma}, \quad \text{(A.3)}$$

$$(u^i)^{1+\varphi} = (1-\alpha) C^{1-\sigma}. \quad \text{(A.4)}$$

By combining the production function with the total demand function for h and similarly for f, it can be shown (see Gali, 2015, chap. 4) that

$$\begin{aligned}
\alpha\widehat{L}_t^H + (1-\alpha)\widehat{u}_t^H &= \widehat{y}_t^H + \ln\int_0^1 \left(\frac{P_t(h)}{P_{H,t}}\right)^{-\varepsilon} \\
\alpha\widehat{L}_t^H + (1-\alpha)\widehat{u}_t^H &= \widehat{y}_t^H + \frac{\varepsilon}{2} var_h \widehat{P}_t(h), \qquad \text{(A.5)} \\
\alpha\widehat{L}_t^F + (1-\alpha)\widehat{u}_t^F &= \widehat{y}_t^F + \ln\int_0^1 \left(\frac{P_t(f)}{P_{F,t}}\right)^{-\varepsilon} \\
\alpha\widehat{L}_t^F + (1-\alpha)\widehat{u}_t^F &= \widehat{y}_t^F + \frac{\varepsilon}{2} var_f \widehat{P}_t(f). \qquad \text{(A.6)}
\end{aligned}$$

Inserting (A.3), (A.4), (A.5), (A.6), and the aggregate demand functions (33) into (A.2) and ignoring terms of order three or higher yields

$$\begin{aligned}
\frac{\psi_t - \psi}{C^{1-\sigma}} &= \frac{1-\sigma}{2}(\widehat{C}_t^W)^2 - \gamma\frac{\varepsilon}{2} var_h \widehat{P}_t(h) - (1-\gamma)\frac{\varepsilon}{2} var_f \widehat{P}_t(f) \\
&\quad -\gamma\frac{1+\varphi}{2}[\alpha(\widehat{L}_t^H)^2 + (1-\alpha)(\widehat{u}_t^H)^2] \\
&\quad -(1-\gamma)\frac{1+\varphi}{2}[\alpha(\widehat{L}_t^F)^2 + (1-\alpha)(\widehat{u}_t^F)^2] + t.i.p., \qquad \text{(A.7)}
\end{aligned}$$

which can be rearranged:

$$\begin{aligned}
\frac{\psi_t - \psi}{U_C C} &= \frac{1-\sigma}{2}(\widehat{C}_t^W)^2 - \gamma\frac{\varepsilon}{2} var_h \widehat{P}_t(h) - (1-\gamma)\frac{\varepsilon}{2} var_f \widehat{P}_t(f) \\
&\quad -\gamma\frac{1+\varphi}{2}[\alpha(1-\alpha)(\widehat{u}_t^H - \widehat{L}_t^H)^2 + (\widehat{y}_t^H)^2] \\
&\quad -(1-\gamma)\frac{1+\varphi}{2}[\alpha(1-\alpha)(\widehat{u}_t^F - \widehat{L}_t^F)^2 + (\widehat{y}_t^F)^2] + t.i.p. \qquad \text{(A.8)}
\end{aligned}$$

Now, we combine households' factor supply (see (5) and (6)) and firms' factor demand (see (9) and (10)) to get an expression for the input factor choice

$$\frac{1-\alpha}{\alpha} R_{s,t}^i = \frac{(1+\omega_w^i)(u_t^i)^{1+\varphi}}{(1+\omega_r^i)(L_t^i)^{1+\varphi}}. \qquad \text{(A.9)}$$

In terms of log deviations from an efficient steady state

$$\widehat{R}_{s,t}^i = (1+\varphi)(\widehat{u}_t^i - \widehat{L}_t^i). \qquad \text{(A.10)}$$

Next, we take a second-order approximation of aggregate demands

$$\begin{aligned}
\widehat{y}_t^H + \frac{1}{2}\left(\widehat{y}_t^H\right)^2 &= (1-\gamma)\widehat{Q}_t + \widehat{C}_t^W + \frac{1}{2}(1-\gamma)^2\widehat{Q}_t^2 \\
&\quad + \frac{1}{2}(\widehat{C}_t^W)^2 + (1-\gamma)\widehat{Q}_t\widehat{C}_t^W, \qquad \text{(A.11)} \\
\widehat{y}_t^F + \frac{1}{2}\left(\widehat{y}_t^F\right)^2 &= -\gamma\widehat{Q}_t + \widehat{C}_t^W + \frac{1}{2}\gamma_t^2\widehat{Q}_t^2 \\
&\quad + \frac{1}{2}(\widehat{C}_t^W)^2 - \gamma\widehat{Q}_t\widehat{C}_t^W. \qquad \text{(A.12)}
\end{aligned}$$

By inserting (A.10), (A.11), and (A.12), we can simplify (A.8) as

$$\begin{aligned}
\frac{\psi_t - \psi}{U_C C} &= -\frac{\sigma+\varphi}{2}(\widehat{y}_t^W)^2 - \gamma\frac{\varepsilon}{2}var_h\widehat{P}_t(h) - (1-\gamma)\frac{\varepsilon}{2}var_f\widehat{P}_t(f) \\
&\quad - \frac{1}{2}\gamma(1-\gamma)(1+\varphi)(\widehat{Q}_t)^2 - \frac{1}{2}\gamma\frac{\alpha(1-\alpha)}{1+\varphi}(\widehat{R}_{s,t}^H)^2 \\
&\quad - \frac{1}{2}(1-\gamma)\frac{\alpha(1-\alpha)}{1+\varphi}(\widehat{R}_{s,t}^F)^2 + t.i.p. \qquad \text{(A.13)}
\end{aligned}$$

Finally, it can be shown (see Woodford, 2003, chap. 6) that

$$\sum_{t=0}^{\infty}\beta^t var_i p_t(i) = \frac{\zeta^i}{(1-\zeta^i)(1-\beta\zeta^i)}\sum_{t=0}^{\infty}\beta^t(\pi_t^i)^2. \qquad \text{(A.14)}$$

Using this expression, the union's welfare function can be written as

$$W = E_0\left\{\sum_{t=0}^{\infty}\beta^t\frac{\psi_t-\psi}{U_C C}\right\} = -E_0\left\{\sum_{t=0}^{\infty}\beta^t\frac{1}{2}\Psi_t\right\} + t.i.p., \qquad \text{(A.15)}$$

where

$$\begin{aligned}
\Psi_t &= (\sigma+\varphi)(\widehat{y}_t^W)^2 + \gamma\frac{\varepsilon}{\kappa^H}(\pi_t^H)^2 + (1-\gamma)\frac{\varepsilon}{\kappa^F}(\pi_t^F)^2 + \gamma(1-\gamma)(1+\varphi)(\widehat{Q}_t)^2 \\
&\quad + \gamma\frac{\alpha(1-\alpha)}{1+\varphi}(\widehat{R}_{s,t}^H)^2 + (1-\gamma)\frac{\alpha(1-\alpha)}{1+\varphi}(\widehat{R}_{s,t}^F)^2. \qquad \text{(A.16)}
\end{aligned}$$

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