Financial frictions and optimal monetary policy in an open economy*

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March 10, 2012

Abstract

A growing number of papers have studied positive and normative implications of financial frictions in DSGE models. We contribute to this literature by studying the welfare-based monetary policy in a two-country model characterized by financial frictions, alongside a number of key features, like capital accumulation, non-traded goods and foreign-currency debt denomination. We compare the co-operative Ramsey monetary policy with standard policy benchmarks (e.g. PPI stability) as well as with the optimal Ramsey policy in a currency area. We show that the two-country perspective offers new insights on the trade-offs faced by the monetary authority. Our main results are the following. First, strict PPI targeting (nearly optimal in our model if credit frictions are absent) becomes excessively procyclical in response to productivity shocks in the presence of financial frictions. The related welfare losses are non-negligible, especially if financial imperfections interact with nontradable production. Second, (asymmetric) foreign currency debt denomination affects the optimal monetary policy and has important implications for exchange rate regimes. In particular, the larger the variance of domestic productivity shocks relative to foreign, the closer the PPI-stability policy is to the optimal policy and the farther is the currency union case. Third, we find that central banks should allow for deviations from price stability to offset the effects of balance sheet shocks. Finally, while financial frictions substantially decrease attractiveness of all price targeting regimes, they do not have a significant effect on the performance of a monetary union agreement.

Keywords: financial frictions, open economy, optimal monetary policy
JEL Codes: E52, E61, E44, F36, F41

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*We thank seminar participants at the 15th SMYE in Luxembourg, the 17th CEF conference in London, the 2010 EEA meeting in Glasgow, for helpful discussions and comments. We also thank Luca Dedola, Oreste Tristani, Fiorella De Fiore and an anonymous referee for their useful comments. The views presented in this paper are those of the authors and not necessarily of the ECB and NBP.

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1 Introduction

The standard New Keynesian model assumes that financial markets work perfectly so that the interest rate set by central banks uniquely determines the cost of credit for borrowers. The recent financial crisis has exposed the weakness of this simplifying assumption and revived interest in business cycle models with financial frictions.

A growing number of papers follow the trail set by seminal works developed in this field in the 1990s (see, among others, Bernanke and Gertler, 1995; Bernanke, Gertler, and Gilchrist, 1999; Carlstrom and Fuerst, 1997; Kiyotaki and Moore, 1997). For instance, Curdia and Woodford (2008) extend the basic New Keynesian monetary model to allow for a spread between interest rates faced by savers and borrowers. They show that if spreads are purely exogenous, the optimal policy conduct does not differ substantially from the frictionless case. Allowing for endogenous spreads (in a reduced-form way, i.e. by making them dependent on borrowers' debt) affects this conclusion only modestly. In particular, complete price stabilization is still very close to the optimal policy. Furthermore, adjusting the intercept in the Taylor rule by changes in credit spreads improves upon an unadjusted rule.

A more micro-founded contribution is offered by Carlstrom, Fuerst, and Paustian (2010), who incorporate agency costs into a standard New Keynesian model. Since agency costs manifest themselves as endogenous cost-push shocks, maintaining price stability is not optimal in response to productivity shocks. However, it is very close to optimal even if agency costs are quite severe. A similar conclusion is reached by Demirel (2009) and Fiore and Tristani (2009), who introduce costly state verification into a model with a direct credit channel à la Ravenna and Walsh (2006), in which firms need to borrow in advance to finance production.

Overall, this line of the literature suggests that if financial markets do not work perfectly, the central bank has an incentive to depart from full price stability in response to productivity shocks. However, the marginal welfare gain of neutralizing the credit friction distortion is rather low, so strict inflation targeting is not far from optimal.

The literature surveyed above focuses on simple, analytically tractable models. They abstract from endogenous capital formation, which is generally seen as crucial in describing the effects of financial frictions on the business cycle (e.g. Kiyotaki and Moore, 1997, Bernanke, Gertler, and Gilchrist, 1999 and Carlstrom and Fuerst, 1997). Furthermore, the open economy dimension has been generally neglected. On the other hand, there is a number of papers incorporating financial frictions into a more sophisticated framework. This literature looks at welfare-based comparisons of alternative simple policy regimes without discussing the optimal monetary policy.

For instance, building on Faia and Monacelli (2007), Faia (2010) considers a general class of Taylor rules, with strict inflation and exchange rate targeting as extremes, in a two-country sticky price model with financial accelerator as in Bernanke, Gertler, and Gilchrist (1999). Using the welfare rankings that ignore the effect of volatilities on mean welfare, she finds that the presence of credit frictions strengthens the case for floating exchange rate regimes in economies facing external shocks. She also finds that the currency denomination of debt does not change her results.[1] A related line of papers

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[1] Faia (2007a,b) studies the effects of financial frictions on the international business cycle, also in

consider a small open economy model with financial frictions and foreign denomination of debt. Gertler, Gilchrist, and Natalucci (2007) find that a fixed exchange regime exacerbates the contraction caused by an adverse risk premium shock. According to Devereux, Lane, and Xu (2006), financial frictions magnify volatility but do not affect the ranking of alternative policy rules. Finally, Elekdag and Tchakarov (2007) show that at a certain level of leverage the peg starts to dominate the float if shocks originate abroad.

The aim of this paper is to fill the gaps in the literature surveyed above. Our main contribution is providing a qualitative and quantitative characterization of the optimal monetary policy conduct in an open economy facing financial market distortions alongside other policy-relevant frictions, including those widely discussed in the open economy literature. To this end, we consider a medium-size two-country New Keynesian DSGE model with producer currency pricing, augmented by the financial accelerator mechanism (Bernanke, Gertler, and Gilchrist, 1999). Having defined the optimal policy as a Ramsey cooperative equilibrium, we discuss the main incentives faced by a benevolent central bank, show how they are affected by fixing the exchange rate and compare the optimal outcomes to those obtained for a set of standard simple targeting rules. Contrary to the existing literature, we discuss how financial market imperfections interact with such frictions as foreign debt denomination and the presence of nontradable goods. We argue that a richer model is a necessary step forward as the policy implications are sensitive to the types of frictions and shocks we consider in our paper.

To build intuition for the main results, we start with a simple New Keynesian framework with capital accumulation and then build it up, explaining the impact of each extension for the policy prescriptions. Our main results can be summarized as follows. First, we find that if credit markets do not work perfectly, strict PPI targeting (nearly optimal in our model if credit frictions are absent) becomes excessively procyclical in response to productivity shocks. This is because keeping producer prices unchanged after a positive (negative) technology shock requires monetary easing (tightening), which sparks the financial accelerator effect and leads to an inefficient drop (increase) in the external finance premium. An additional disadvantage of strict PPI targeting arises if debt contracts are nominal as asymmetric CPI movements open the gap between the two countries' credit premia. Importantly, and in contrast to the findings from simple closed-economy models, the related welfare losses are non-negligible, especially if financial imperfections interact with such frictions as nontradable production. Second, monetary policy should accommodate balance sheet shocks, thus allowing for deviations from price stability. In this respect, the policy prescriptions related to this type of disturbances resemble those found by the earlier literature for standard cost-push (e.g. markup) shocks. Third, (asymmetric) foreign currency debt denomination affects the optimal monetary policy as it opens up an additional channel that, depending on shocks and policy response, either dampens or amplifies the financial accelerator effects in the euroized economy. As a result, debt denomination has important implications for

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the case of a currency area. She finds that the more similar the financial systems the stronger the business cycle comovements.

exchange rate regimes. In particular, the larger the variance of domestic productivity shocks relative to foreign, the closer the PPI-stability policy is to the optimal policy and the farther is the currency union case. Fourth, in all model extensions we consider, financial frictions substantially decrease attractiveness not only of PPI targeting, but also of other price targeting regimes. In contrast, the presence of financial frictions does not have a significant effect on the performance of a monetary union agreement.

The paper proceeds as follows. Section 2 lays out the structure of our model. Section 3 discusses its calibration. The welfare-based framework for evaluating alternative policies is presented in section 4. The incentives faced by an optimizing policy maker are discussed in section 5. Section 6 presents our more detailed results. Section 7 concludes.

2 Structure of the model

There are two countries in the world: Home (H) and Foreign (F). Each is inhabited by a continuum of infinite-lived households, who consume a homogeneous consumption good and supply labor to a continuum of firms. A perfectly competitive sector of capital producers combines the existing capital with investment flows to produce the installed capital stock. Capital is managed and rented to firms by a continuum of entrepreneurs, who use their net worth and a bank loan to finance the capital expenditures. Productivity of each entrepreneur is subject to an idiosyncratic shock, not observed by the bank. This creates agency problems and so interest charged by the banking sector is subject to a premium over the risk-free rate paid by banks on households' deposits, as in Bernanke, Gertler, and Gilchrist (1999).

There are two types of firms in each economy, each using capital and labor as inputs. Nontradable goods producers sell their output only domestically, while tradable goods firms produce both for the local market and for exports. Prices are denominated in the producer currency and set in a monopolistically competitive fashion. Nontradable and tradable goods produced at home are combined with goods imported from abroad into final consumption and investment goods in a perfectly competitive environment.

International financial markets are complete. Fiscal authorities finance their expenditures on nontradable goods by collecting lump sum taxes from the households.

Since the general setup of the Foreign country is similar to that for the Home economy, in the following and more detailed exposition we focus on the latter. To the extent needed, variables and parameters referring to foreign agents are marked with an asterisk. Unless stated otherwise, all variables in the derivations below are expressed in per capita terms. Whenever aggregation across countries is needed, we make use of the normalization of the world population to one so that the size of Home is n and that of Foreign is $1-n$.

2.1 Households

Households in a given country are assumed to be homogeneous, i.e. they have the same preferences and endowments and do not face any idiosyncratic shocks nor frictions.

Hence, we can focus on the optimization problem of a representative household.

A typical household maximizes the following lifetime utility function:

$$U_t = E_t \left\{ \sum_{k=0}^{\infty} \beta^k \left[\frac{\varepsilon_{d,t+k}}{1-\sigma} C_{t+k}^{1-\sigma} - \frac{\kappa}{1+\varphi} L_{t+k}^{1+\varphi} \right] \right\} \tag{1}$$

where E_t is the expectation operator conditioning on information available at time t, β is the discount rate, σ is the inverse of the elasticity of intertemporal substitution, κ is the weight of leisure in utility and φ denotes the inverse of the Frisch elasticity of labor supply. The instantaneous utility is thus a function of a consumption bundle C_t, to be defined below, and labor effort L_t. The utility is also affected by a consumption preference shock $\varepsilon_{d,t}$, common to all households in a given country.

The maximization of (1) is subject to a sequence of intertemporal budget constraints of the form:

$$P_{C,t}C_t + R_t^{-1} D_{t+1} + E_t \left[\mathcal{Q}_{t+1} B_{t+1} \right] = W_t L_t + R_{K,t} K_t + Div_{H,t} + Div_{N,t} + T_t + Tr_{E,t} + D_t + B_t \tag{2}$$

where $P_{C,t}$ is the price of the consumption bundle C_t, W_t is the nominal wage rate, $R_{K,t}$ denotes households' income from renting a unit of capital K_t, $Div_{H,t}$ and $Div_{N,t}$ are dividends from tradable and nontradable goods producers, respectively, T_t stands for lump sum government transfers net of lump sum taxes, and $Tr_{E,t}$ denotes wealth received from exiting (net of transfers to surviving and entering) entrepreneurs. Households hold their financial wealth in form of bank deposits D_t, paying the risk-free (gross) rate R_t. As in Chari, Kehoe, and McGrattan (2002), we assume complete international markets for state-contingent claims. This means that households have also access to state-contingent bonds B_t, paying the stochastic return $\mathcal{Q}_t$.

The first order conditions to the representative consumer maximization problem imply the following conventional stochastic Euler equation:

$$\beta E_t \left\{ \mathcal{Q}_{t+1} \frac{R_t}{\Pi_{C,t+1}} \right\} = 1, \tag{3}$$

where $\mathcal{Q}_t = \frac{\Lambda_{C,t+1}}{\Lambda_{C,t}}$, $\Pi_{C,t}$ denotes consumer price inflation (CPI), expressed in gross terms, and $\Lambda_{C,t}$ is the marginal utility of consumption, defined as:

$$\Lambda_{C,t} = \varepsilon_{d,t} C_t^{-\sigma} \tag{4}$$

The consumption bundle C_t consists of final tradable goods $C_{T,t}$ and nontradable goods $C_{N,t}$, aggregated according to:

$$C_t = \frac{C_{T,t}^{\gamma_c} C_{N,t}^{1-\gamma_c}}{\gamma_c^{\gamma_c} (1-\gamma_c)^{1-\gamma_c}} \tag{5}$$

where γ_c is the share of tradable goods in total consumption.

The index of tradable goods is defined by:

$$C_{T,t} = \frac{C_{H,t}^{\alpha} C_{F,t}^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}} \tag{6}$$

where $C_{H,t}$ is the bundle of home-made tradable goods consumed at home, $C_{F,t}$ is the bundle of foreign-made tradable goods consumed at home and α denotes the share of home goods in the home basket of tradable goods.

The indices of nontradable and both types of tradable goods are in turn given by the following aggregators of individual varieties:

$$C_{N,t} = \left[\int_0^1 C_t(z_N)^{\frac{\phi_N-1}{\phi_N}} dz_N\right]^{\frac{\phi_N}{\phi_N-1}} \tag{7}$$

$$C_{H,t} = \left[\int_0^1 C_t(z_H)^{\frac{\phi_H-1}{\phi_H}} dz_H\right]^{\frac{\phi_H}{\phi_H-1}} \tag{8}$$

$$C_{F,t} = \left[\int_0^1 C_t(z_F)^{\frac{\phi_F-1}{\phi_F}} dz_F\right]^{\frac{\phi_F}{\phi_F-1}} \tag{9}$$

where ϕ_N, ϕ_H, and ϕ_F are the elasticities of substitution across varieties of a given type.

The sequence of intratemporal optimization problems implies the following demand functions for each variety of goods:

$$C_t(z_N) = (1-\gamma_c)\left(\frac{P_t(z_N)}{P_{N,t}}\right)^{-\phi_N}\left(\frac{P_{N,t}}{P_{C,t}}\right)^{-1} C_t \tag{10}$$

$$C_t(z_H) = \gamma_c \alpha \left(\frac{P_t(z_H)}{P_{H,t}}\right)^{-\phi_H}\left(\frac{P_{H,t}}{P_{T,t}}\right)^{-1}\left(\frac{P_{T,t}}{P_{C,t}}\right)^{-1} C_t \tag{11}$$

$$C_t(z_F) = \gamma_c(1-\alpha)\left(\frac{P_t(z_F)}{P_{F,t}}\right)^{-\phi_F}\left(\frac{P_{F,t}}{P_{T,t}}\right)^{-1}\left(\frac{P_{T,t}}{P_{C,t}}\right)^{-1} C_t \tag{12}$$

where $P_t(z_j)$ is the price of variety z_j, while the composite price indexes are defined as follows:

$$P_{N,t} = \left[\int_0^1 P_t(z_N)^{1-\phi_N} dz_N\right]^{\frac{1}{1-\phi_N}} \tag{13}$$

$$P_{H,t} = \left[\int_0^1 P_t(z_H)^{1-\phi_H} dz_H\right]^{\frac{1}{1-\phi_H}} \tag{14}$$

$$P_{F,t} = \left[\int_0^1 P_t(z_F)^{1-\phi_F} dz_F\right]^{\frac{1}{1-\phi_F}} \tag{15}$$

$$P_{T,t} = P_{H,t}^{\alpha} P_{F,t}^{1-\alpha} \tag{16}$$

$$P_{C,t} = P_{T,t}^{\gamma_c} P_{N,t}^{1-\gamma_c} \tag{17}$$

We assume that labor markets are competitive and wages are fully flexible, so real wage is equal to the marginal rate of substitution between consumption and labor:

$$\frac{W_t}{P_{C,t}} = \kappa \frac{L_t^{\varphi}}{\Lambda_{C,t}} \tag{18}$$

2.2 Capital producers

There is a continuum of perfectly competitive capital producers, owned by households. At the end of each period, they buy capital from entrepreneurs and combine it with investment goods to produce new installed capital, which is then sold to entrepreneurs.

Consistently with the market clearing on the capital market, the total amount of capital purchased by capital producers must be equal to total undepreciated capital stock in the economy. Hence, the economy-wide capital available for production K_t evolves according to the formula:

$$K_{t+1} = (1-\tau)K_t + \varepsilon_{i,t}\left(1 - \Gamma_{I,t}\right) I_t \tag{19}$$

where I_t is investment and τ is the depreciation rate. As in Christiano, Eichenbaum, and Evans (2005), capital accumulation is subject to investment-specific technological progress $\varepsilon_{i,t}$ and adjustment cost represented by a function $\Gamma_{I,t}$, defined as:

$$\Gamma_{I,t} = \frac{\varsigma_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \tag{20}$$

The optimization problem of a representative capital producer is to maximize the present discounted value of future profits:

$$E_t\left\{\sum_{k=0}^{\infty}\beta^k \frac{\Lambda_{C,t+k}}{P_{C,t+k}}\left[Q_{T,t+k}P_{C,t+k}\left((1-\tau)K_{t+k} + \varepsilon_{i,t+k}\left(1-\Gamma_{I,t+k}\right)I_{t+k} - K_{t+k}\right) - P_{I,t+k}I_{t+k}\right]\right\} \tag{21}$$

where $P_{I,t}$ is the price of investment goods I_t and $Q_{T,t}$ is the real price of installed capital (Tobin's Q).

The first order condition to this optimization problem yields the following investment demand equation:

$$\frac{P_{I,t}}{P_{C,t}} = \varepsilon_{i,t}\left(1 - \Gamma_{I,t} - I_t\Gamma'_{I,t}\right)Q_{T,t} + \beta E_t\left\{\frac{\Lambda_{C,t+1}}{\Lambda_{C,t}}\varepsilon_{i,t+1}\frac{I_{t+1}^2}{I_t}\Gamma'_{I,t+1}Q_{T,t+1}\right\} \tag{22}$$

The final investment good is produced in a similar fashion as the final consumption good, which implies the following definitions:

$$I_t = \frac{I_{T,t}^{\gamma_i} I_{N,t}^{1-\gamma_i}}{\gamma_i^{\gamma_i}(1-\gamma_i)^{1-\gamma_i}} \tag{23}$$

$$I_{T,t} = \frac{I_{H,t}^{\alpha} I_{F,t}^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}} \tag{24}$$

$$P_{I,t} = P_{T,t}^{\gamma_i} P_{N,t}^{1-\gamma_i} \tag{25}$$

Hence, while we allow for differences in the tradable-nontradable composition between the final consumption basket and the investment basket (i.e. γ_c need not be equal to γ_i), we assume for simplicity that the structure of the purely tradable component is identical for both types of goods.

2.3 Entrepreneurs and banks

Capital services to firms are supplied by a continuum of risk-neutral entrepreneurs, indexed by z_E. At the end of period t, each entrepreneur purchases installed capital $K_{t+1}(z_E)$ from capital producers, partly using its own financial wealth $N_{t+1}(z_E)$ and financing the remainder by a bank loan $B_{E,t+1}(z_E)$:

$$B_{E,t+1}(z_E) = Q_{T,t} P_{C,t} K_{t+1}(z_E) - N_{t+1}(z_E) \geq 0 \tag{26}$$

After the purchase, each entrepreneur experiences an idiosyncratic productivity shock, which converts its capital to $a_E(z_E)K_{t+1}(z_E)$, where a_E is a random variable, distributed independently over time and across entrepreneurs, with a cumulative density function $F(a_E)$ and a unit mean. Following Christiano, Motto, and Rostagno (2003), we assume that this distribution is log normal, with a time-varying standard deviation of $\log a_E$ equal to $\varepsilon_{e,t}\sigma_E$, known to entrepreneurs before their capital decisions.

Next, each entrepreneur rents out capital services, treating the rental rate $R_{K,t+1}$ as given. Since the mean of an idiosyncratic shock is equal to one, the average rate of return on capital earned by entrepreneurs can be written as:

$$R_{E,t+1} = \frac{R_{K,t+1} + (1-\tau) Q_{T,t+1} P_{C,t+1}}{Q_{T,t} P_{C,t}} \tag{27}$$

and the rate of return earned by an individual entrepreneur is $a_E(z_E)R_{E,t+1}$.

Idiosyncratic shocks are observed by entrepreneurs but not by banks, so lending involves agency costs, reflected in a debt contract between these two parties. The contract specifies the size of the loan $B_{E,t+1}(z_E)$ and the gross non-default interest rate $R_{B,t+1}(z_E)$ charged by the bank. The solvency criterion can also be defined in terms of a cut-off value of idiosyncratic productivity, denoted as $\tilde{a}_{E,t+1}(z_E)$, such that the entrepreneur has just enough resources to repay the loan:[2]

$$\tilde{a}_{E,t+1} R_{E,t+1} Q_{T,t} P_{C,t} K_{t+1}(z_E) = R_{B,t+1} B_{E,t+1}(z_E) \tag{28}$$

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[2] In order to save on notation, in what follows we use the result established later on, according to which the cutoff productivity $\tilde{a}_E(z_E)$ and the non-default interest paid on a bank loan $R_{B,t+1}(z_E)$ are the same for all entrepreneurs.

Entrepreneurs with a_E below the threshold level go bankrupt. Their all resources are taken over by banks, after they pay proportional and nontradable monitoring costs μ.

Banks finance their loans by issuing time deposits to households at the risk-free interest rate R_t. The banking sector is assumed to be perfectly competitive and owned by risk-averse households. This together with risk-neutrality of entrepreneurs implies a financial contract insulating the lender from any aggregate risk.[3] Hence, interest paid on a bank loan by entrepreneurs is state contingent and guarantees that banks break even in every period. The aggregate zero profit condition for the banking sector can be written as:

$$\left(1 - F_{1,t+1}\right) R_{B,t+1} B_{E,t+1} + \left(1 - \mu\right) F_{2,t+1} R_{E,t+1} Q_{T,t} P_{C,t} K_{t+1} = R_t B_{E,t+1} \tag{29}$$

or equivalently (using (28)):

$$R_{E,t+1} Q_{T,t} P_{C,t} K_{t+1} \left[\tilde{a}_{E,t+1}(1 - F_{1,t+1}) + \left(1 - \mu\right) F_{2,t+1}\right] = R_t B_{E,t+1} \tag{30}$$

where

$$F_{1,t} = \int_0^{\tilde{a}_{E,t}} dF\left(a_E\right) \tag{31}$$

$$F_{2,t} = \int_0^{\tilde{a}_{E,t}} a_E dF\left(a_E\right) \tag{32}$$

and the analytical formulas for $F_{1,t}$ and $F_{2,t}$, making use of the log-normal assumption for $F(a_E)$, are given in the Appendix.

The equilibrium debt contract maximizes welfare of each individual entrepreneur. We define it in terms of expected end-of-contract net worth relative to the risk-free alternative, which is holding a domestic bond:

$$E_t \left\{ \frac{\int_{\tilde{a}_{E,t}}^{\infty} \left(R_{E,t+1} Q_{T,t} P_{C,t} K_{t+1}(z_E) a_E(z_E) - R_{B,t+1} B_{E,t+1}(z_E)\right) dF(a_E(z_E))}{R_t N_{t+1}(z_E)} \right\} \tag{33}$$

The first-order condition to this optimization problem can be written as:

$$E_t \left\{ \begin{array}{c} \frac{R_{E,t+1}}{R_t}\left[1 - \tilde{a}_{E,t+1}(1 - F_{1,t+1}) - F_{2,t+1}\right] + \\ + \frac{1 - F_{1,t+1}}{1 - F_{1,t+1} - \mu \tilde{a}_{E,t+1} F'_{1,t+1}} \left(\frac{R_{E,t+1}}{R_t}\left[\tilde{a}_{E,t+1}(1 - F_{1,t+1}) + \left(1 - \mu\right) F_{2,t+1}\right] - 1 \right) \end{array} \right\} = 0 \tag{34}$$

As can be seen from (34), the ex ante external financing premium, defined as[4]

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[3] Given the infinite number of entrepreneurs, the risk arising from idiosyncratic shocks is fully diversifiable.

[4] See e.g. Gertler, Gilchrist, and Natalucci (2007) for a reduced-form representation of the financial accelerator.

$$\chi_t = \frac{E_t R_{E,t+1}}{R_t} \tag{35}$$

arises because of monitoring costs. If μ is set to zero, the expected rate of return on capital is equal to the risk-free interest rate and so the financial markets are frictionless.

Equation (34), together with the bank zero profit constraint (30), defines the optimal debt contract in terms of the cutoff value of the idiosyncratic shock $\tilde{a}_{E,t+1}$ and the leverage ratio ϱ_t, defined as:

$$\varrho_t = \frac{Q_{T,t} P_{C,t} K_{t+1}}{N_{t+1}} \tag{36}$$

It is easy to verify that these two contract parameters are identical across entrepreneurs. There are two important implications of this result, facilitating aggregation. First, the loan amount taken by each entrepreneur is proportional to his net worth. Second, the rate of interest paid to the bank is the same for each non-defaulting entrepreneur:

$$R_{B,t+1} = \frac{\tilde{a}_{E,t+1} R_{E,t+1} \varrho_t}{\varrho_t - 1} \tag{37}$$

We will refer to the difference between this rate and the risk-free rate R_t as the credit spread. Finally, it is easy to show that

$$\chi_t = \chi\left(\varrho_t, \mu\right) \tag{38}$$

where $\chi(\varrho_t, 0) = 1$, $\chi_{\varrho_t}\left(\varrho_t, \mu\right) > 0$ and $\chi_{\mu}\left(\varrho_t, \mu\right) > 0$.

Proceeds from selling capital, net of interest paid to banks, constitute end of period net worth. To capture the phenomenon of ongoing entries and exits of firms and to ensure that entrepreneurs do not accumulate enough wealth to become fully self-financing, we assume that each period a randomly selected and time-varying fraction $1 - \varepsilon_{\nu,t}\upsilon$ of them go out of business, in which case all their financial wealth is rebated to the households. At the same time, an equal number of new entrepreneurs enters, so that the total number of entrepreneurs is constant. Those who survive and enter receive a transfer T_E from households. This ensures that both entrants and surviving bankrupt entrepreneurs have at least a small but positive amount of wealth, without which they would not be able to buy any capital.

Aggregating across all entrepreneurs and using (30) yields the following law of motion for net worth in the economy:

$$N_{t+1} = \varepsilon_{\nu,t}\upsilon \left[R_{E,t} Q_{T,t-1} P_{C,t-1} K_t - \left(R_{t-1} + \frac{\mu F_{2,t} R_{E,t} Q_{T,t-1} P_{C,t-1} K_t}{B_{E,t}} \right) B_{E,t} \right] + T_E \tag{39}$$

The term in the square brackets represents the total revenue from renting and selling capital net of interest paid on bank loans, averaged over both bankrupt and non-bankrupt entrepreneurs.

While discussing our results, we also consider a situation in which bank loans taken by entrepreneurs in the home country are denominated in foreign rather than domestic currency. The modifications needed to implement this variant are presented in the Appendix.

2.4 Firms

2.4.1 Production technology

There exist a continuum of identically monopolistic competitive firms in each of the nontradable and tradable sectors, owned by households and indexed by z_N and z_H, respectively. The production technology is homogenous with respect to labor and capital inputs:

$$Y_t(z_N) = \varepsilon_{n,t} L_t(z_N)^{1-\eta_N} K_t(z_N)^{\eta_N} \tag{40}$$

$$Y_t(z_H) = \varepsilon_{t,t} L_t(z_H)^{1-\eta_H} K_t(z_H)^{\eta_H} \tag{41}$$

where η_N and η_H are sector-specific capital shares, while $\varepsilon_{n,t}$ and $\varepsilon_{t,t}$ are sector-specific productivity parameters. The output indexes are given by the Dixit-Stiglitz aggregators:

$$Y_{N,t} = \left[\int_0^1 Y_t(z_N)^{\frac{\phi_N - 1}{\phi_N}} dz_N \right]^{\frac{\phi_N}{\phi_N - 1}} \tag{42}$$

$$Y_{H,t} = \left[\int_0^1 Y_t(z_H)^{\frac{\phi_H - 1}{\phi_H}} dz_H \right]^{\frac{\phi_H}{\phi_H - 1}} \tag{43}$$

Since all firms in a given sector operate technologies with the same relative intensity of productive factors and face the same prices for labor and capital inputs (factor markets are homogeneous), cost minimization implies the following sector-specific capital-labor relationships:

$$\frac{W_t L_{N,t}}{R_{K,t} K_{N,t}} = \frac{1-\eta_N}{\eta_N} \qquad \frac{W_t L_{H,t}}{R_{K,t} K_{H,t}} = \frac{1-\eta_H}{\eta_H} \tag{44}$$

2.4.2 Price setting

Firms producing nontradable goods set their prices according to the Calvo (1983) staggering mechanism. Only a fraction $1-\theta_N$ of them set their prices in a forward-looking manner, while the prices of firms that do not receive a price signal are fully indexed to the steady-state inflation in the nontradable sector $\bar{\Pi}_N$.

Firms that are allowed to reoptimize realize that they may not be allowed to do so for some time, hence their price-setting problem is to maximize the expected present discounted value of future profits:

$$E_t\left\{\sum_{k=0}^{\infty}\theta_N^k\beta^k\frac{\Lambda_{C,t+k}}{P_{C,t+k}}Y_{t+k}(z_N)\left[P_t(z_N)\bar{\Pi}_N^k-P_{N,t+k}MC_{N,t+k}\right]\right\} \tag{45}$$

subject to the sequence of demand constraints:

$$Y_{t+k}(z_N)=\left[\frac{P_t(z_N)}{P_{N,t+k}}\bar{\Pi}_N^k\right]^{-\phi_N}Y_{N,t+k} \tag{46}$$

where $MC_{N,t}$ is the real marginal cost (identical across nontradable goods firms) defined as:

$$MC_{N,t}=\frac{1}{P_{N,t}\varepsilon_{n,t}}\left(\frac{W_t}{1-\eta_N}\right)^{1-\eta_N}\left(\frac{R_{K,t}}{\eta_N}\right)^{\eta_N} \tag{47}$$

The first-order condition associated with the profit-maximization problem faced by reoptimizing firms can be written as:

$$E_t\left\{\sum_{k=0}^{\infty}\theta_N^k\beta^k\frac{\Lambda_{C,t+k}}{P_{C,t+k}}Y_{t+k}(z_N)\left[P_t(z_N)\bar{\Pi}_N^k-\frac{\phi_N}{\phi_N-1}P_{N,t+k}MC_{N,t+k}\right]=0\right\} \tag{48}$$

There are no firm-specific shocks in the model, so all firms that are allowed to reset their price in a forward-looking manner select the same optimal price $\tilde{P}_{N,t}$, which implies the following recursive representation of the first-order condition (48):

$$\frac{\tilde{P}_{N,t}}{P_{N,t}}=\frac{\phi_N}{\phi_N-1}\frac{\Phi_{N,t}}{\Psi_{N,t}} \tag{49}$$

where

$$\Phi_{N,t}=\frac{\Lambda_{C,t}}{P_{C,t}}MC_{N,t}P_{N,t}Y_{N,t}+\beta\theta_N E_t\left\{\left(\frac{\Pi_{N,t+1}}{\bar{\Pi}_N}\right)^{\phi_N}\Phi_{N,t+1}\right\} \tag{50}$$

$$\Psi_{N,t}=\frac{\Lambda_{C,t}}{P_{C,t}}P_{N,t}Y_{N,t}+\beta\theta_N E_t\left\{\left(\frac{\Pi_{N,t+1}}{\bar{\Pi}_N}\right)^{\phi_N-1}\Psi_{N,t+1}\right\} \tag{51}$$

The expression for the evolution of the home nontradable goods price index can be written as follows:

$$P_{N,t}=\left[\theta_N\left(P_{N,t-1}\bar{\Pi}_N\right)^{1-\phi_N}+(1-\theta_N)\tilde{P}_{N,t}^{1-\phi_N}\right]^{\frac{1}{1-\phi_N}} \tag{52}$$

The price-setting problem solved by firms producing tradable goods is similar and leads to first-order conditions and price indices analogous to equation (48) and (52), respectively. We assume that prices are set in the producer currency and that the international law of one price holds for each tradable variety. Therefore, the prices of home goods sold abroad and those of foreign goods sold domestically are given by:

$$P_t^*(z_H) = S_t^{-1} P_t(z_H) \qquad P_t(z_F) = S_t P_t^*(z_F) \tag{53}$$

where S_t is the nominal exchange rate expressed as units of domestic currency per one unit of foreign currency.

2.5 Exchange rate dynamics

The perfect risk sharing condition implies (see Chari, Kehoe, and McGrattan, 2002):

$$\frac{\Lambda_{C,t}^*}{\Lambda_{C,t}} = \kappa Q_t \tag{54}$$

where Q_t is the real exchange rate defined as:

$$Q_t = \frac{S_t P_{C,t}^*}{P_{C,t}}, \tag{55}$$

and where κ is a constant depending on initial wealth distribution and therefore is equal to 1 in our model.

Perfect risk sharing combined with the consumption Euler equation (3) and its foreign counterpart implies the following uncovered interest rate parity (UIP) condition:

$$E_t \left\{ \frac{\Lambda_{C,t+1}}{\Lambda_{C,t}} \left(\frac{\beta R_t}{\Pi_{C,t+1}} - \frac{\beta^* R_t^*}{\Pi_{C,t+1}^*} \frac{Q_{t+1}}{Q_t} \right) \right\} = 0 \tag{56}$$

The real exchange rate is allowed to deviate from the purchasing power parity (PPP) due to changes in relative prices of nontradable goods in both countries and changes in terms-of-trade, as long as there is some home bias in preferences ($\alpha \neq \alpha^*$). This can be demonstrated using the price indices derived above and the law of one price conditions for tradable goods:

$$Q_t = TOT_t^{\alpha - \alpha^*} \frac{X_t^{*1-\gamma_c^*}}{X_t^{1-\gamma_c}} \tag{57}$$

where the terms-of-trade TOT_t is defined as home import prices relative to home export prices:

$$TOT_t = \frac{S_t P_{F,t}^*}{P_{H,t}} \tag{58}$$

and the relative prices of nontradable goods X_t and X_t^* are defined as:

$$X_t = \frac{P_{N,t}}{P_{T,t}} \qquad X_t^* = \frac{P_{N,t}^*}{P_{T,t}^*} \tag{59}$$

2.6 Monetary and fiscal authorities

We consider several variants of monetary policy regimes, including the Ramsey optimal policy. For calibration, we assume that the monetary authority responds to the economic conditions through the following interest rate feedback rule:

$$R_t = R_{t-1}^{\rho} \left[\bar{R} \left(\frac{\Pi_{C,t}}{\bar{\Pi}_C} \right)^{\phi_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\phi_{dy}} \left(\frac{\Pi_{C,t}}{\Pi_{C,t-1}} \right)^{\phi_{d\pi}} \right]^{1-\rho} \varepsilon_{m,t} \tag{60}$$

where Y_t is total output, $\bar{R}$ is the steady state interest rate and $\varepsilon_{m,t}$ is a monetary policy shock.

The fiscal authority is modeled in a very simplistic fashion: government expenditures and transfers to the households are fully financed by lump sum taxes, so that the government's budget is balanced each period. The government spending is fully directed at nontradable goods and is modeled as a stochastic process $\varepsilon_{g,t}$.

2.7 Market clearing conditions

2.7.1 Goods markets

The model is closed by imposing the following market clearing conditions. Output of each firm producing nontradable goods is either consumed domestically, spent on investment, purchased by the government or used by banks to cover monitoring costs. Similarly, all tradable goods are consumed or invested, either domestically or abroad. Using these conditions, the demand functions (10), (11) and (12), together with their analogs for investment and government goods, the output indexes given by (42) and (43), and taking into account the size of both countries, one can write aggregate output in the two sectors at home as:

$$\begin{aligned} Y_{N,t} &= (1-\gamma_c)\frac{P_{C,t}}{P_{N,t}}C_t + (1-\gamma_i)\frac{P_{I,t}}{P_{N,t}}I_t + G_t + \\ &\quad +\mu F_{2,t} R_{E,t} Q_{T,t-1} P_{C,t-1} K_t P_{N,t}^{-1} \end{aligned} \tag{61}$$

$$\begin{aligned} Y_{H,t} &= \alpha\gamma_c \frac{P_{C,t}}{P_{H,t}}C_t + \frac{1-n}{n}\alpha^*\gamma_c^* \frac{P_{C,t}^*}{P_{H,t}^*}C_t^* + \\ &\quad +\alpha\gamma_i \frac{P_{I,t}}{P_{H,t}}I_t + \frac{1-n}{n}\alpha^*\gamma_i^* \frac{P_{I,t}^*}{P_{H,t}^*}I_t^* \end{aligned} \tag{62}$$

Total output Y_t is the sum of output produced in the nontradable and tradable sectors:

$$P_t Y_t = P_{N,t} Y_{N,t} + P_{H,t} Y_{H,t} \tag{63}$$

where P_t is the implicit total output deflator, which defines the producer price inflation (PPI).

2.7.2 Factor markets

Equilibrium in factor markets requires:

$$L_t = \int_0^1 L_t(z_N)dz_N + \int_0^1 L_t(z_H)dz_H \tag{64}$$

$$K_t = \int_0^1 K_t(z_N)dz_N + \int_0^1 K_t(z_H)dz_H \tag{65}$$

which can be rewritten using (40), (41), (44) and the demand sequences like in (46) as:

$$L_t = \left(\frac{1-\eta_N}{\eta_N}\right)^{\eta_N} \left(\frac{R_{K,t}}{W_t}\right)^{\eta_N} \frac{Y_{N,t}}{\varepsilon_{n,t}}\Delta_{N,t} + \left(\frac{1-\eta_H}{\eta_H}\right)^{\eta_H} \left(\frac{R_{K,t}}{W_t}\right)^{\eta_H} \frac{Y_{H,t}}{\varepsilon_{t,t}}\Delta_{H,t} \tag{66}$$

$$K_t = \left(\frac{\eta_N}{1-\eta_N}\right)^{1-\eta_N} \left(\frac{W_t}{R_{K,t}}\right)^{1-\eta_N} \frac{Y_{N,t}}{\varepsilon_{n,t}}\Delta_{N,t} + \left(\frac{\eta_H}{1-\eta_H}\right)^{1-\eta_H} \left(\frac{W_t}{R_{K,t}}\right)^{1-\eta_H} \frac{Y_{H,t}}{\varepsilon_{t,t}}\Delta_{H,t} \tag{67}$$

where $\Delta_{N,t}$ and $\Delta_{H,t}$ are the measures of price dispersion in the nontradable and tradable sector:

$$\Delta_{N,t} = \int_0^1 \left(\frac{P_{N,t}(z_N)}{P_{N,t}}\right)^{-\phi_N} dz_N \qquad \Delta_{H,t} = \int_0^1 \left(\frac{P_{H,t}(z_H)}{P_{H,t}}\right)^{-\phi_H} dz_H \tag{68}$$

The following laws of motion for the two dispersion indexes can be derived using (52):

$$\Delta_{N,t} = (1-\theta_N)\left(\frac{\tilde{P}_{N,t}}{P_{N,t}}\right)^{-\phi_N} + \theta_N\left(\frac{\bar{\Pi}_N}{\Pi_{N,t}}\right)^{-\phi_N} \Delta_{N,t-1} \tag{69}$$

$$\Delta_{H,t} = (1-\theta_H)\left(\frac{\tilde{P}_{H,t}}{P_{H,t}}\right)^{-\phi_H} + \theta_H\left(\frac{\bar{\Pi}_H}{\Pi_{H,t}}\right)^{-\phi_H} \Delta_{H,t-1} \tag{70}$$

As shown in Benigno and Woodford (2004), these laws of motion can be written, to second order, as proportional to the square of sector-specific inflation.

2.7.3 Financial markets

Finally, in equilibrium, household deposits at banks must be equal to total funds lent to entrepreneurs:

$$D_t = B_{E,t} \tag{71}$$

2.8 Exogenous shocks

The source of exogenous disturbances is key in determining the welfare costs of the business cycle and, in particular, the costs of alternative monetary policies. In order to give quantitative predictions of the welfare costs that are empirically relevant we consider a set of shocks that is representative of the source of exogenous disturbances discussed in the related literature. In particular we consider eight stochastic disturbances per country. These concern: productivity in the tradable sector, productivity in the nontradable sector, consumption preferences, government spending, investment-specific technology, survival of entrepreneurs, idiosyncratic riskiness and the monetary policy. The log of each shock follows a linear first-order autoregressive process, except for the monetary policy shock, which is assumed to be white noise.[5]

3 Calibration

We calibrate our model to the euro area economy, setting its size in our two-country world to 0.25. The parameters for the rest of the world are assumed to be identical to those in the euro area. Our calibration proceeds in two steps. We first match the key steady-state ratios of the euro area and set the other structural parameters so that they are consistent with the estimated version of the New Area-Wide Model (NAWM), documented in Christoffel, Coenen, and Warne (2008). While parameterizing the financial frictions block, we draw on Bernanke, Gertler, and Gilchrist (1999) and Christiano, Motto, and Rostagno (2010). In particular, we set the financial sector parameters such that half of capital is financed by debt. In the next step, the inertia and volatility of stochastic disturbances are chosen to match the moments of a standard set of euro area macroaggregates and two financial variables. These are the debt of the enterprise sector and the spread between interest charged on loans to firms and the short-term yield on government bonds. The results of the calibration exercise are reported in Tables 1 to 4 and the resulting variance decomposition is shown in Table 5.

Tables 1 to 5 about here

Our model replicates the standard deviations of GDP and its main components. It significantly underestimates the volatility of the short-term interest rate and roughly captures that of inflation. As regards our two financial variables, there is some trade-off in matching the standard deviation of entrepreneurs' debt and that of credit spreads. In principle, a better fit could be obtained by increasing the volatility of the survival shock at the expense of the riskiness shock, but would require significant deviations from the econometric estimates obtained by Christiano, Motto, and Rostagno (2010).

Turning to other moment matching results, our model gets the persistence and cyclical behaviour of most of the variables of interest more or less right, although the fit for investment can be seen as disappointing, given the model's focus on frictions

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[5] See for example Stockman and Tesar (1995), Dotsey and Duarte (2008), Gilchrist, Ortiz, and Zakrajšek (2009), Christiano, Motto, and Rostagno (2010) and Coenen, Lombardo, Smets, and Straub (2009).

in financing capital expenditures. It is also worth noting that while our model makes the premium less countercyclical than in the data, it somewhat exaggerates its negative correlation with investment. Clearly, a better fit in this dimension would require allowing for financial frictions also in the household sector.

4 Welfare-based evaluation of alternative policies

Our model features monopolistic competition on the goods markets, so the decentralized equilibrium is not efficient even in the non-stochastic steady state. Financial frictions are yet another distortion, acting like a tax on the gross rate of return on capital (see equation (35)). In principle, the first best allocation could be achieved, at least in the steady state, using appropriately designed subsidies. We assume that such instruments are not available and focus instead on the problem faced by a benevolent monetary policy maker striving to achieve the second best allocation, i.e. the constrained Ramsey cooperative equilibrium.

The Ramsey cooperative equilibrium can be thought of as an arrangement in which both central banks agree to implement policies that maximize the weighted average of a representative household's welfare of the two regions, with the weights given by the population size.[6] As in Woodford (2003), we consider policies under commitment in a timeless perspective. Under these restrictions, the cooperative equilibrium benchmark generates the second best allocation in our two-region world. In principle, there is no guarantee that this policy maximizes welfare of a representative consumer in each region. Coenen, Lombardo, Smets, and Straub (2009) show that the Nash equilibrium, in which each central bank maximizes welfare of its own country taking as given the other central bank's action, might yield higher welfare from an individual country's perspective so that the gains from cooperation are negative, unless appropriate wealth transfers are allowed. We leave this more complex analysis of non-cooperative policies for future research and will refer henceforth to the cooperative equilibrium as optimal.[7]

In order to build intuition for the optimal policy outcomes, we compare them to those obtained under simple policy variants. These include various forms of strict inflation targeting. We also consider the case of a full monetary integration, defined as the same benchmark cooperative equilibrium, except that the exchange rate between the two regions is fixed.

We assess the welfare implications of the alternative monetary policy strategies by taking a second-order approximation of all model equations, including the first-order conditions of the welfare maximization problem of the policy maker.[8] Such a numerical approach yields a correct ranking of alternative policies and has been used in many analyses of optimal policy (see e.g. Schmitt-Grohe and Uribe, 2006; Coenen, Lombardo,

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[6] The first order conditions of the welfare maximization problem of the policy maker(s) are computed using G. Lombardo's lq_solution routine (see also Coenen, Lombardo, Smets, and Straub, 2009).

[7] Another problematic feature of the Nash equilibrium is that it depends on the choice of instrument defining the policy game and on the concept of equilibrium (open loop vs. closed loop).

[8] The calculations are performed in Dynare 4, which can be downloaded from http://www.cepremap.cnrs.fr/dynare.

Smets, and Straub, 2009).[9]

We evaluate each policy by calculating the welfare loss, expressed in terms of the proportion of each period's consumption that a typical household in the home economy would need to give up in a deterministic world so that its welfare is equal to the expected conditional utility in the stochastic world. More precisely, we calculate Ω that satisfies the following equation:

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\varepsilon_{d,t+k}}{1-\sigma} C_{t+k}^{1-\sigma} - \frac{\kappa}{1+\varphi} L_{t+k}^{1+\varphi} \right) = \frac{1}{1-\beta} \left(\frac{1}{1-\sigma} \left[\left(1 - \frac{\Omega}{100} \right) C \right]^{1-\sigma} - \frac{\kappa}{1+\varphi} L^{1+\varphi} \right) \tag{72}$$

where variables without time subscripts denote their respective steady state values and the starting point for the left hand side of (72) is the ergodic mean of the cooperative equilibrium.

5 Incentives of cooperative policymakers

We have already noted that the external finance premium is inefficient, so, absent other frictions, if a specific subsidy was available to the policymaker, she would eliminate the financial frictions completely by ensuring that the expected rate of return on capital is equal to the risk free rate at all times. To understand the policymaker's incentives in a second best world, and absent such a subsidy, it is instructive to first consider a simplified version of our model, in which we abstract from the presence of nontradable goods, home bias or government purchases, so that it becomes a standard two-country New Keynesian model with capital accumulation and financial frictions.

The first column in Table 6 shows the mean and standard deviation of the external finance premium under optimal policy and flexible prices. It is clear that the cooperative policymaker does not bring the mean of the premium below its steady state value, even if shocks are only to productivity. This result is similar to the related well-known outcome for a simple Calvo model with perfect financial markets, according to which inflating the economy to achieve a reduction in the mean markup is suboptimal (see e.g. King and Wolman, 1999, Woodford, 2003 and Benigno and Woodford, 2006). Furthermore, although the optimizing policymaker limits fluctuations in the premium, she does not find it optimal to eliminate them completely. To see why, one needs to note that, from equation (35), complete stabilization of the premium requires constant leverage. In other words, avoiding fluctuations in the premium implies constraining capital expenditures to move only in proportion to entrepreneurs' net worth, which is a state variable. Thus, the dependence of the premium on the leverage creates a trade-off that the policymaker might want to resolve by allowing some fluctuations in

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[9] An alternative would be to use a linear-quadratic approximation described in Benigno and Woodford (2005), which is a generalization to Rotemberg and Woodford (1998). As discussed by Benigno and Woodford (2006), a clear advantage of this analytical approach is that it helps to gain insight into fully optimal policy. However, given the size and complexity of our model, following this way is of little use, so we opt for a more practical method.

the former.[10]

Table 6 about here

Another important feature of allocations under *optimal* policy in the flexible price case is cross-country premia equalization following asymmetric productivity shocks. This finding is related to the international real business cycle literature (e.g. Baxter and Crucini, 1993), according to which an efficient allocation in a frictionless world implies equalization of the ex ante rates of return on capital (corrected for the exchange rate movements) across countries. If financial markets are imperfect and households equally patient in both economies, the UIP condition (56), the external finance premium definition (35) and its foreign counterpart imply the following relationship between home and foreign rates of return on capital:

$$E_t\left\{\frac{\Lambda_{C,t+1}}{\Lambda_{C,t}}\left(\frac{E_tR_{E,t+1}}{\chi_t\Pi_{C,t+1}}-\frac{E_tR^*_{E,t+1}}{\chi^*_t\Pi^*_{C,t+1}}\frac{Q_{t+1}}{Q_t}\right)\right\}=0. \tag{73}$$

Other things equal, and to first order, the cooperative policymaker would have the incentive to generate perfect correlation of the premia (or perfect stabilization). By doing so, the cross-country allocation of capital would coincide to that of a frictionless international real business cycle model. In the face of other frictions, though, this incentive will be traded off with other efficiency margins, and, in general, full stabilization (or perfect comovement) will not be achieved.

Now we can discuss the consequences of allowing for stickiness in price setting. In a simple open economy New Keynesian model with producer currency pricing and perfect financial markets, PPI targeting eliminates price dispersion and so replicates optimal policy outcomes.[11] Introducing financial frictions creates a trade-off between eliminating price dispersion and following the incentives discussed above. As can be seen from the second column in Table 6, the optimal policy solves this trade-off by departing somewhat from PPI stabilization, allowing more fluctuations in the premia and breaking their cross-country comovement.

In particular, the premia equalization incentive is in conflict with the expenditure switching motive known from the earlier literature (see e.g. Engel, 2003). Price rigidity calls for nominal exchange rate adjustments in response to shocks. These adjustments, though, have an asymmetric effect on CPI in the two countries. As entrepreneurial debt is nominal, asymmetric inflation dynamics will imply asymmetric effects on its real value, and hence on the external finance premium. Therefore, this open-economy channel brings about a new trade-off for the policymaker. For example, this would be

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[10] To have a better understanding of this trade-off, it is instructive to look at the optimal responses of the economy in which monitoring costs are zero so that changes in leverage do not create any frictions. Clearly, leverage is not constant in such an environment as it would hamper an optimal response of the capital stock to macroeconomic shocks.

[11] As shown by Benigno and Benigno (2006), the equivalence of PPI targeting and optimal policy is exact if either the steady state is efficient or output is equal to consumption. This is not the case in the simplified version of our model discussed in this section as it includes steady-state distortions and investment. However, as we show in the next section, the departures turn out to be negligible, so we can treat PPI targeting as nearly optimal.

the case for all those shocks that exert a downward (upward) pressure on the home external finance premium that is stronger than that exerted on the foreign premium and that, at the same time, requires a depreciation (appreciation) of the exchange rate. The induced relative change in inflation, in this case, would widen the gap between the external finance premia, bringing the economy further away from the financial-frictionless equilibrium.

The introduction of nontradable goods makes the job of the central bank even harder. Now a sectoral productivity shock cannot be fully neutralized by an adjustment of the exchange rate. For example, an exchange rate depreciation engineered to absorb a domestic tradable productivity shock will generate a misalignment of the relative price between domestic nontradables and foreign tradables. Now the optimal policy will have to trade off relative price adjustments, changes in external finance premia and relative adjustments of the latter.

6 Main results

6.1 Optimal policy in a simple model with capital accumulation

Our main objective is to demonstrate and quantitatively evaluate how the presence of financial frictions changes the optimal policy responses to macroeconomic shocks. To make our exposition transparent, we start with a standard symmetric two-country New Keynesian model considered in the previous section, with capital accumulation and producer currency pricing. In particular, we abstract for now from the presence of nontradable goods, home bias or government purchases.

Before we move on to the results, one remark is in order. Remember that we calibrate all parameters (and shock volatilities in particular) using the fully-fledged version of our model. This means that its simple variants do not necessarily retain a solid empirical basis if all parameters are kept unchanged. Therefore, in order to facilitate comparisons across models, we normalize all welfare losses and other moments presented below by the ratio of the output variance in a given version (under the Taylor rule) to output variance in the full version of our model.[12]

Table 7 present the welfare losses (of the home country relative to the optimal cooperative policy) for a set of simple policies in our benchmark model with perfect or imperfect financial markets. Our results confirm that in the former case PPI targeting nearly replicates the optimal policy outcomes and so can serve as a useful benchmark. The losses associated with keeping consumer prices or the exchange rate stable are non-negligible but do not exceed 0.08% of steady-state consumption. These losses are

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[12] This is motivated by the fact that welfare losses, as well as means and variances of the main variables of interest, are approximately proportional to the variance of stochastic disturbances. Therefore, our normalization can be thought of as a proportional correction of all shock volatilities so that the volatility of output in all model versions matches that observed in the data. Since losses and moments are corrected by the same factor for all regimes of a given model, the normalization leaves the policy rankings unaffected.

almost entirely due to technology disturbances, while the contribution of other shocks (preference and investment-specific in this simple model version) is very close to zero.

Table 7 about here

We have already discussed that if financial markets are imperfect, PPI targeting is no longer optimal. The welfare loss associated with this policy amounts to around 0.05% of steady-state consumption. While this number is about half of the loss of following a strict CPI-stability policy in the frictionless case, it might still appear rather small. However, as Table 8 reveals, the consequences of introducing financial frictions turn out to be an order of magnitude larger than those related to other frictions emphasized in the literature as sources of welfare losses, e.g. home bias (Faia and Monacelli, 2008), habits (Leith, Moldovan, and Rossi, 2009), nontradable goods (Duarte and Obstfeld, 2008) or government expenditures (Benigno and Woodford, 2005). Interestingly, the presence of financial frictions makes the monetary union (under optimal policy) relatively more attractive, while the opposite holds true for CPI targeting.[13]

Table 8 about here

To shed more light on the results presented above, we compare the impulse responses under the cooperative regime to those implied by PPI targeting and the monetary union. Figure 1 depicts the dynamic responses to a positive productivity shock in the home economy. The optimal policy clearly deviates from strict stabilization of producer price inflation. As discussed in the previous section, this is for two reasons. The first one is related to an inefficient drop in the external finance premia in both countries. This comes about since keeping PPI unchanged after a positive technology shock requires monetary easing (i.e. a decrease in real interest rates), sparking the financial accelerator effect and amplifying the economic expansion. The second reason is related to asymmetric responses of the premia across the two economies. As discussed in the literature stressing expenditure switching effects of the exchange rates in the presence of nominal rigidities and producer-currency pricing, the home currency needs to depreciate for producer prices to remain stable (see e.g. Engel (2003), Devereux and Engel (2007) and Sutherland (2006)). This means that, under PPP (i.e. constant real exchange rate), CPI has to jump at home and go down abroad. Since financial contracts are nominal, real value of debt decreases at home and increases abroad, which opens the gap between the external finance premia of the two countries. Overall, the cooperative policy maker trades off costly price adjustments with these inefficient changes in the financial premium. As a result, it is optimal to actually tighten the policy on impact (i.e. design an increase in real interest rates) and limit the exchange rate movements. It has to be noted, however, that some depreciation is needed for the premia to be equalized. As can be seen from the responses under the union regime, fixing the exchange rate results in a premium gap of the opposite sign: there is a drop in the premium abroad and a slight increase at home. In the union case and with flexible

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[13] Strict CPI stability and the monetary union imply a constant nominal exchange rate, when PPP holds. Foregoing exchange rate volatility, therefore, does not put the policymaker in the monetary union at a disadvantage relative to the strict CPI-stability case.

prices, premia would be identical across countries under the optimal policy. In this way, the international allocation of capital would be consistent with that predicted by the real business cycle model, as implied by equation (73). When prices are sticky and the exchange rate is fixed, the policymaker needs to implement a monetary expansion to limit the fall in domestic prices. This policy generates a fall in the real marginal return of home factors of production and an increase in the marginal return of foreign factors (and of foreign PPI). Consistently with equation (73) these adjustments generate the asymmetric response of the premia shown in the Figure.

Figure 1 about here

As in the frictionless case, the welfare implications of other shocks (preference and investment-specific shocks, as well as two shocks related to entrepreneurs, i.e. survival and riskiness) lumped together are much smaller than those of productivity shocks. It is interesting to note, however, that in this case the fixed exchange rate regime performs better than strict PPI targeting. This observation applies for any of these shocks considered individually.[14]

We take a closer look at a negative survival rate shock. This shock can be interpreted as an exogenous destruction in entrepreneurs' net worth, which decreases their ability to borrow. While its welfare implications are not large under our calibration, they may become very significant at times of severe financial distress. The dynamic responses are shown in Figure 2. By raising the external financing premium, this shock acts like a cost-push shock, so keeping prices stable requires monetary tightening (see the PPI case). The optimal response tries to strike a balance between the negative effects of price dispersion and an excessive increase in the external financing premium.[15] As a result, a benevolent central bank tries to offset some of net worth destruction resulting from the shock with an initial easing of the monetary policy, which allows to dampen the response in the premium at the expense of a rise in inflation and large swings in the nominal exchange rate. If both countries agree to fix their exchange rate, they come closer to the optimum than under PPI targeting. The reason is that the union case allows for some increase in inflation and a short-run expansion in output, which helps to limit an increase in the premium.

Figure 2 about here

While the general prescriptions for the optimal policy facing financial frictions and net worth shocks developed above are broadly consistent with the analysis of Carlstrom, Fuerst, and Paustian (2010) in a model without capital accumulation, one remark is in order. In their model, optimal policy is expansionary in response to a negative net worth shock in terms of cumulative real rates, but they actually increase on impact only to decline below levels implied by price stability, so the initial rise of the risk premium

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[14] To see this, consider the difference between the last two rows of Table 7.

[15] Even if prices were flexible, the optimizing policy maker would not try to stabilize the premium completely as it would require her to generate inflation decreasing the real value of entrepreneurs' debt, but also of households' deposits. However, the optimal increase of the premium in the flexible price case is smaller than that in the presence of nominal rigidities.

is higher under optimal policy. This results in a rather counter-intuitive conclusion that introducing risk premia will lead the central bank to magnify their movements compared to the strict inflation targeting regime. The authors conjecture that a more elaborate model, featuring demand-side effects via endogenous capital accumulation, would preserve this result. In contrast, our model implies that the initial response of optimizing policy makers to net worth destruction will be expansionary. Arguably a more realistic result.

6.2 Debt denomination

In the simple model considered so far, the two economies were perfectly symmetric. In this section we revisit the case when the home country's entrepreneurial debt is denominated in the foreign country's currency. We will refer to this case as debt euroization. We start by noting that debt denomination is inconsequential for allocations under optimal policy if prices are fully flexible. This is because the central banks can still achieve the desired redistribution of wealth between households and entrepreneurs by affecting inflation in both economies at no cost in terms of price dispersion. In particular, the optimal response to asymmetric productivity shocks will imply cross-country equalization of the external finance premia. In contrast, debt euroization modifies the policy trade-offs if prices are sticky.

The welfare implications of foreign currency denomination under sticky prices are summarized in Table 9. The most striking result is that, if domestic entrepreneurs' debt is denominated in the foreign currency, PPI targeting nearly replicates the optimal response to home productivity shocks, while the other regimes somewhat lose in attractiveness. In contrast, strict producer price inflation stabilization performs significantly worse than CPI targeting, and even more so compared to the union case, if productivity shocks originate abroad. Therefore, if productivity shocks abroad are on average sufficiently larger than at home, then the euroized economy may find itself better-off having the exchange rate fixed rather than pursuing strict PPI targeting. On balance, if productivity volatility is equal in both economies, the welfare ranking of alternative regimes remains intact compared to the non-euroized case.

Table 9 about here

These results can be explained as follows. If home entrepreneurs' debt is denominated in the foreign currency, exchange rate movements affect directly their balance sheets. Depending on shocks and the policy response, this additional channel either dampens or amplifies the financial accelerator effect in the euroized economy, and hence affects the actions taken by the optimizing central bank. This is confirmed by the impulse responses to a home productivity shock presented in Figure 3, where we also replicate the union case, identical to that presented in Figure 1, for convenience. Remember that in the non-euroized case the policy maker deviated from perfect PPI stabilization, finding it optimal to tighten on impact and dampen the response of the exchange rate. If debt is euroized, however, the exchange rate depreciation actually helps to achieve the central bank objectives, which is preventing excessive and asymmetric movements in the external finance premia. This is because a deterioration in home entrepreneurs' balance sheets dampens the financial accelerator effect, and much more so at home than abroad. As a result, the optimal policy no longer needs to tighten but rather lets the real interest rates fall, like under PPI targeting. The achieved drop in the premium at home is about four times smaller than in the non-euroized case and differs very little from that abroad. By construct, this channel does not operate if the exchange rate is fixed, so the responses under monetary union are the same in the euroized and non-euroized cases. As they imply initial tightening rather than easing, the allocations under this regime are now further away from the optimum.

Figure 3 about here

An analogous reasoning can be used to analyze the optimal policy when debt is denominated in the foreign currency and productivity shocks originate abroad (see Figure 4). In this case, keeping PPI stable implies appreciation of the exchange rate, which amplifies the financial accelerator effect at home. To prevent an excessive drop in both countries' premium, the monetary policy now needs to be tightened much more than in the non-euroized case. This implies a substantial deviation from PPI targeting. With our parametrization, this effect is strong enough to make the fixed exchange rate a relatively more attractive option.

Figure 4 about here

More generally, the policy ranking obtained in the euroized case for foreign productivity shocks depends on the extent of financial market imperfections and the size of leverage. If financial frictions are substantial and entrepreneurs run sufficiently high debt denominated in the foreign currency, the balance sheet effects related to exchange rate movements are important and the fixed exchange rate regime yields higher welfare than PPI targeting. If on the other hand financial markets are close to perfect and leverage is small, stabilizing PPI inflation may be preferred.

6.3 Nontradable production

In this section we study the interaction between financial frictions and nontradable goods. The presence of nontradable-good production provides a further challenge to the optimal conduct of monetary policy, in the presence of non-trivial trade-offs and sectoral shocks.[16] Furthermore, a large literature has emphasized the importance of nontradables in improving the empirical fit of the model (e.g. Stockman and Tesar, 1995, Burstein, Neves, and Rebelo, 2003, Burstein, Eichenbaum, and Rebelo, 2006 and Dotsey and Duarte, 2008) suggesting that they might be important for quantitative welfare assessments. To this effect, we extend the model to include non-traded goods in consumption and investment (see the baseline calibration).

It is important to realize first that in such an environment the cooperative policy maker will not always find it optimal to design cross-country equalization of the external finance premia in response to productivity shocks, even if prices are fully flexible. To

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[16] Optimal policy in the presence of non-tradable goods is studied, among others, by Duarte and Obstfeld (2008), Faia and Monacelli (2008) and Lombardo and Ravenna (2010).

see why, it is instructive to examine the link between the relative price of nontradable goods and the real exchange rate. Let us consider an improvement in nontradable sector productivity, for which an efficient switch in demand requires the relative price of tradables to go up. However, as it is clear from equation (57), if the shock is asymmetric, the real exchange rate has to adjust. This amplifies the boom in the country hit, driving the premia apart. It turns out that the incentive to equalize the premia is far weaker than the incentive to allow for efficient movements in the real exchange rate: the optimal policy allows only marginally smaller real exchange rate volatility compared to perfect PPI stabilization.[17] In contrast, the motive to dampen the overall premia movements remains important also after allowing for nontradable production.

Now we revert to the sticky price environment. As before, we start with discussing the welfare implications of alternative monetary regimes, among which we also include nontradable PPI targeting. The results are reported in Table 10.

Table 10 about here

Our findings for a model with perfect capital markets are consistent with the previous literature. In particular, PPI targeting no longer replicates the optimal policy, even though the losses are small in practice.[18] Also, in line with Duarte and Obstfeld (2008), the presence of nontradable goods clearly strengthens the case for exchange rate flexibility.

Adding financial frictions makes the losses from PPI targeting non-negligible. This effect is substantially stronger than in a model where all goods are tradable. Taking a closer look at the decomposition of welfare losses by shocks when entrepreneurs' debt is denominated in the domestic currency, at least one observation warrants a comment. Contrary to the model without nontradables, PPI targeting performs slightly worse than CPI targeting and substantially worse than the monetary union in response to productivity shocks originating in the domestic tradable sector. However, in this very case, it is actually targeting PPI in the nontradable sector that comes closest to the optimal policy.

To shed some light on why the policy ranking changes if we allow for nontradable production, we use the impulse response analysis. Figure 5 shows the dynamic responses to a home tradable sector productivity shock under various regimes. The outcomes under optimal policy are qualitatively very similar to those obtained in the fully tradable version of our model presented in Figure 1. The optimal cooperative policy tries to dampen the boom fueled by the financial accelerator mechanism, as compared to strict PPI targeting. Importantly, however, the difference between these two policies is now more pronounced in relative terms. In particular, the optimal policy designs nearly twice lower depreciation and a three times lower decrease in the external finance premium

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[17] With symmetric preferences, the relative price of nontradables in both economies change by the same proportion under the optimal policy and tradable sector shocks. As a result, the real exchange rate is constant and the external finance premia equalization is satisfied.

[18] Interestingly, if productivity shocks originate abroad, PPI targeting yields marginally higher welfare for the home economy than the cooperative equilibrium. This means that implementing the cooperative policy might be problematic in practice, as it would require cross-country transfers.

than perfect PPI stabilization. The reason why PPI targeting overexpands relatively more than we have seen in our simple model with tradable goods only is that the presence of a nontradable sector makes stabilizing the overall producer price inflation more difficult. This is because nontradable goods prices are less flexible, which follows from our calibration (see Table 1), but mainly from the fact that they are insulated from direct effects of exchange rate movements.[19] As a result, keeping PPI constant now requires more policy easing (in relative terms, i.e. after correcting for the fact that an increase in productivity affects only one sector of the economy), the side effect of which is an excessive decrease in the external financing premia.

As in the fully tradable case, if the exchange rate is not allowed to depreciate, the economic expansion is too weak at home and excessive abroad. However, as the presence of nontradables makes the expenditure switching effect of nominal exchange rate movements less important, the union regime now deviates from the optimal policy by less than PPI targeting and hence ranks better. Finally, the simple rule that comes closest to optimal is targeting nontradable goods prices. It completely eliminates price dispersion in the nontradable sector and lets the average level of producer prices drop. Hence, it does not require as much easing as PPI targeting and so leads to a boom that is only slightly excessive. Naturally, the ranking of regimes established above remains valid in the model with nontradable production as long as the share of the latter in output is sufficiently large. As our experiments show, however, the union case dominates PPI targeting in response to domestic tradable productivity shocks already when the share of nontradables is around 10%, so our finding about the change in the policy ranking can be treated as robust.

Figure 5 about here

As one can see from Table 10, if some goods are nontradable and domestic entrepreneurs' debt is denominated in the foreign currency, our results are qualitatively similar to those obtained for the fully tradable and euroized case presented in Table 9. In particular, PPI targeting performs closest to optimal in response to domestic tradable sector productivity shocks. This means that the presence of nontradables is not enough to offset the stabilizing effect of euroized liabilities discussed in the previous section. In principle, this result depends on the size of the nontradable sector. We find, however, that the fixed exchange rate regime yields higher welfare than PPI targeting in response to domestic tradable sector productivity disturbances in a euroized economy only if the share of nontradable production in total output is at least 80%, which is more than observed in the data (Lombardo and Ravenna, 2010)

Finally, we note that, as in the model with tradables only, if shocks originate in the tradable sector abroad, PPI targeting performs worse than CPI targeting and the union. However, these two rules are beaten by nontradable goods inflation stabilization. More generally, while targeting nontradable sector prices seems to be an attractive alternative to stabilizing the weighted average of inflation in both sectors whenever the

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[19] If the Calvo probabilities in the tradable and nontradable sectors are equal, monetary union still generates higher welfare in response to a home tradable sector productivity shock than PPI targeting. Naturally, the difference between the performance of these two regimes is then much smaller.

latter policy performs worse than the union case, it is not so in general. Taking all shocks into account, targeting PPI in the nontradable sector is inferior to total PPI targeting.

7 Conclusions

In this paper, we have analyzed and quantified how frictions in financing capital expenditures affect the optimal monetary policy conduct in a two-country DSGE setup. Consistently with the earlier literature using more simple and closed-economy models, we find that financial market imperfections generate a trade-off between inflation and external financing premium stabilization. By extending the analysis to the open economy, we are able to show that the policy trade-off is crucially affected by exchange rate adjustments. In an open economy, the optimal cooperative policy aims at equalizing expected returns on capital across countries. Exchange rate adjustments tend to introduce a wedge between the external cost of finance across countries and, hence, they make return equalization a more difficult task.

We show that the welfare implications of these trade-offs are non-negligible. In particular, financial frictions substantially magnify the incentives to deviate from price stability if we allow for nontradable goods.

In contrast, financial market imperfections considered in our paper do not have a significant effect on the performance of the monetary union. This means that the presence of financial frictions strengthens the case for such an arrangement if cooperation between countries under flexible exchange rate regimes is difficult to implement.

There is a number of potentially fruitful future research directions, of which we will name only two. First, it might be interesting to revisit the literature on international monetary policy cooperation. According to our preliminary (and not reported) calculations, gains from cooperation after introducing financial frictions remain small, especially if mark-up shocks are absent. However, this may change if one allows for international financial market integration, where firm balance sheets depend on foreign assets, as in Dedola and Lombardo (2009). Second, some of the issues addressed in our paper, like debt euroization and monetary integration, may be particularly relevant for small open economies. A more realistic investigation of such cases would call for an asymmetric setup, especially while constructing monetary policy games. We leave these interesting extensions for future research.

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Tables and figures

Table 1. Structural parameters

Parameter	Value	Description
Households		
β	0.994	discount rate
σ	2.0	inverse of intertemporal elasticity of substitution
κ	160	weight on disutility of labor
φ	2.0	inverse of Frisch elasticity of labor supply
γ_c	0.3	share of tradables in consumption
α	0.6	home bias (consumption and investment goods)
Capital production and financial frictions		
τ	0.025	depreciation rate
ς_i	5.2	investment adjustment costs
γ_i	0.6	share of tradables in investment
μ	0.1	monitoring costs
ν	0.977	survival rate for entrepreneurs
σ_E	0.27	steady-state standard deviation of idiosyncratic productivity
Intermediate goods firms		
η_N	0.38	capital share in nontradable production
η_H	0.38	capital share in tradable production
ϕ_N	3.50	elasticity of substitution between intermediate nontradable varieties
ϕ_H	5.76	elasticity of substitution between intermediate tradable varieties
θ_N	0.9	Calvo probability for nontradables
θ_H	0.75	Calvo probability for tradables
Monetary authority		
ρ	0.85	interest rate smoothing
ϕ_π	2.00	long-run response to inflation
$\phi_{\Delta y}$	0.15	response to output growth
$\phi_{\Delta \pi}$	0.19	response to change in inflation

Table 2. Stochastic processes

Parameter	Value	Description
Autoregressive coefficients		
ρ_t	0.85	productivity shock in tradable sector
ρ_n	0.85	productivity shock in nontradable sector
ρ_d	0.80	consumption preference shock
ρ_g	0.96	government spending shock
ρ_i	0.75	investment-specific technology shock
ρ_ν	0.50	financial wealth shock
ρ_e	0.75	riskiness shock
Standard deviations		
σ_t	0.024	productivity shock in tradable sector
σ_n	0.019	productivity shock in nontradable sector
σ_d	0.005	consumption preference shock
σ_g	0.0045	government spending shock
σ_i	0.016	investment-specific technology shock
σ_ν	0.012	financial wealth shock
σ_e	0.04	riskiness shock
σ_m	0.001	monetary policy shock

Table 3. Steady-state ratios

Variable	Value
Consumption share in GDP	58.5
Government expenditures share in GDP	21.0
Investment share in GDP	20.5
Exports share in GDP	12.0
Net exports share in GDP	0.0
Net worth share in capital	50.0
External finance premium ($R_E - R$, annualized)	1.64
Bankruptcy rate (per quarter)	0.73
Bankruptcy costs share in output	0.27
Share of transfers to entrepreneurs in output	4.1

Table 4. Moment matching for the euro area

Variable	model	data
Standard deviations		
GDP	0.48	0.48
Consumption	0.48	0.48
Investment	1.31	1.31
Government spending	1.61	1.60
Inflation	0.36	0.36
Short-term interest rate	1.16	2.81
Entrepreneurs' debt	1.41	1.53
Credit spread	0.54	0.43
Autocorrelations		
GDP	0.31	0.24
Consumption	0.07	0.06
Investment	0.73	0.16
Government spending	0.96	0.96
Inflation	0.59	0.70
Short-term interest rate	0.93	0.98
Entrepreneurs' debt	0.51	0.18
Credit spread	0.91	0.81
Correlations with GDP		
Consumption	0.70	0.65
Investment	0.34	0.80
Government spending	0.01	-0.21
Inflation	-0.44	-0.04
Short-term interest rate	-0.05	-0.04
Entrepreneurs' debt	0.13	0.26
Credit spread	-0.11	-0.22
Other correlations		
Credit spread-investment	-0.21	-0.12

Notes: GDP components and entrepreneurs' debt are expressed in log differences.

Table 5. Variance decomposition

Shock	GDP	Consump.	Investment	Inflation	Interest rate	Entrepr. debt	Credit spread
Prod. (T)	26.4	6.8	4.1	24.3	4.5	1.7	3.8
Prod. (NT)	46.9	34.9	1.7	37.9	26.1	5.6	8.8
Preference	5.0	26.6	0.0	0.4	1.5	0.1	0.0
Gov. spending	0.9	0.9	0.0	0.2	0.8	0.0	0.0
Inv. specific	2.8	0.7	28.4	2.0	11.0	1.8	1.4
Monetary	11.3	8.7	6.0	14.2	1.9	0.4	2.9
Ent. survival	4.0	3.5	46.1	3.4	29.3	89.9	58.8
Ent. riskiness	0.6	0.0	2.1	0.0	0.2	0.1	23.9
Foreign	2.0	17.9	11.6	17.6	24.6	0.4	0.3

Notes: GDP components and entrepreneurs' debt are expressed in log differences.

Table 6. Wedges under optimal policy: simple model with financial frictions

	Flexible prices	Sticky prices
All shocks		
mean premium	0.3	1.7
stdev premium	23.4	51.4
stdev PPI	0.8	0.1
Home productivity		
mean premium	0.0	1.5
stdev premium	2.5	20.9
stdev PPI	0.7	0.1
Foreign productivity		
mean premium	0.0	0.0
stdev premium	2.5	6.4
stdev PPI	0.0	0.0

Notes: The numbers are in basis points (premium) and percentage points (inflation). The mean of the premium is relative to its steady-state level. The normalization factors for the means are 12.2 (flexible prices) and 4.2 (sticky prices), while those for the standard deviations are 3.5 and 2.0, respectively.

Table 7. Welfare costs: simple model

	PPI targ.	CPI targ.	Mon. union
No financial frictions			
All shocks	0.000	0.077	0.077
Productivity shocks	0.000	0.076	0.077
Financial frictions			
All shocks	0.051	0.101	0.066
Productivity shocks	0.042	0.092	0.064

Notes: All numbers are relative to the cooperative equilibrium. Welfare losses are expressed in percent of steady-state consumption. The normalization factors (variance of output relative to the fully-fledged version of the model) are 4.1 (no financial frictions) and 4.2 (financial frictions).

Table 8. Welfare costs of PPI targeting: various frictions

	Welfare losses
Baseline	0.0000
Home bias	0.0000
Consumption habits	0.0007
Nontradable goods	0.0034
Government	0.0001
Financial frictions	0.0509

Notes: All numbers are relative to the cooperative equilibrium. Welfare losses are expressed in percent of steady-state consumption. Baseline refers to the simple New Keynesian model. Other rows show the consequences of augmenting the baseline with various frictions (one at a time). The normalization factors (variance of output relative to the fully-fledged version of the model) are: 4.1 (baseline), 4.8 (home bias), 3.3 (consumption habits, with persistence 0.57), 1.1 (nontradable goods), 2.5 (government spending) and 4.2 (financial frictions).

Table 9. Welfare costs: the role of debt denomination

	PPI targ.	CPI targ.	Mon. union
Domestic currency debt denomination			
All shocks	0.051	0.101	0.066
Productivity (H)	0.025	0.044	0.031
Productivity (F)	0.018	0.048	0.033
Foreign currency debt denomination			
All shocks	0.061	0.105	0.071
Productivity (H)	0.000	0.055	0.041
Productivity (F)	0.055	0.044	0.029

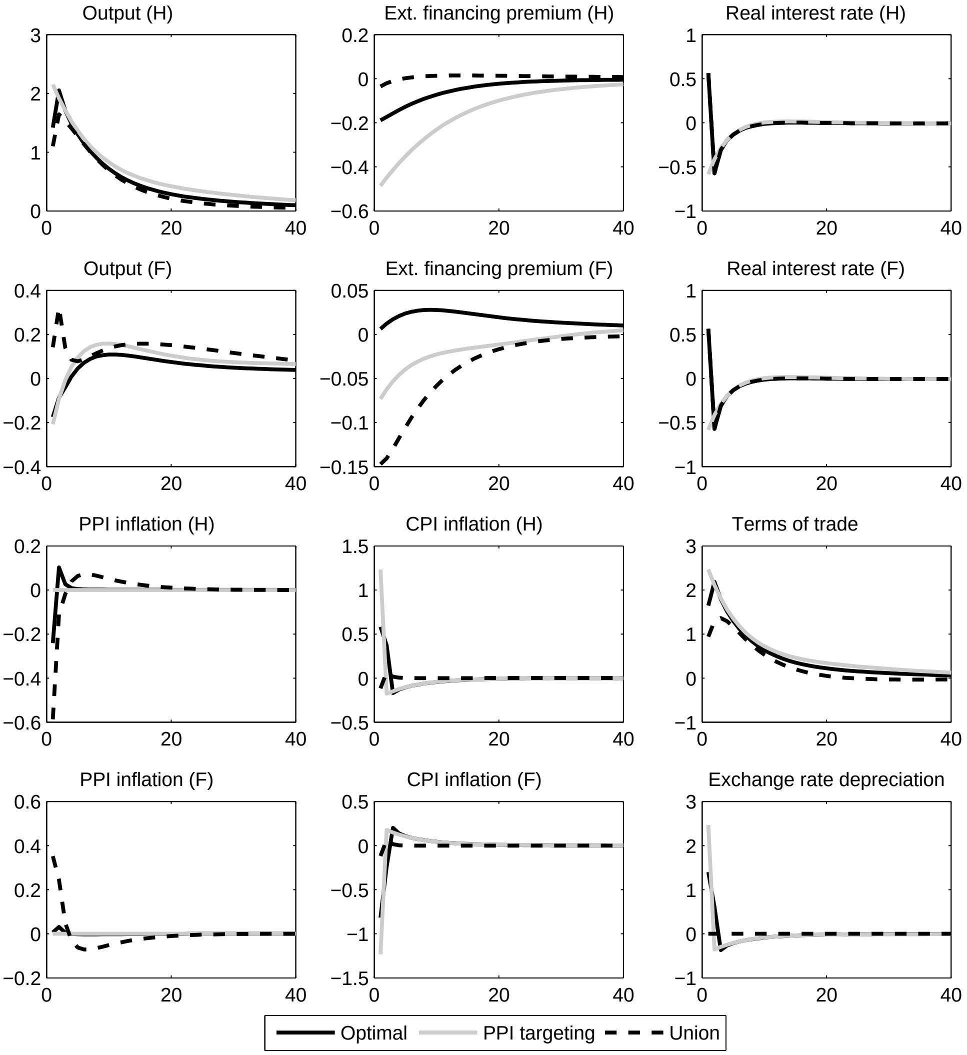
Notes: All numbers are relative to the cooperative equilibrium. Welfare losses are expressed in percent of steady-state consumption. The normalization factor is 4.2 (both for domestic and foreign currency denomination).

Table 10. Welfare costs: the role of nontradables

	PPI targ.	CPI targ.	Mon. union	ntPPI targ.
No financial frictions				
All shocks	0.003	0.068	0.124	0.042
Trad. productivity (H)	0.004	0.012	0.017	0.007
Nontrad. productivity (H)	0.003	0.019	0.044	0.004
Trad. productivity (F)	-0.002	0.030	0.037	0.020
Nontrad. productivity (F)	-0.001	0.006	0.025	0.012
Domestic currency debt denomination				
All shocks	0.095	0.131	0.141	0.130
Trad. productivity (H)	0.042	0.018	0.015	0.008
Nontrad. productivity (H)	0.008	0.018	0.048	0.044
Trad. productivity (F)	0.005	0.039	0.032	0.013
Nontrad. productivity (F)	0.004	0.019	0.031	0.029
Foreign currency debt denomination				
All shocks	0.117	0.130	0.131	0.158
Trad. productivity (H)	0.003	0.021	0.019	0.008
Nontrad. productivity (H)	0.005	0.021	0.052	0.003
Trad. productivity (F)	0.047	0.040	0.030	0.022
Nontrad. productivity (F)	0.036	0.023	0.025	0.101

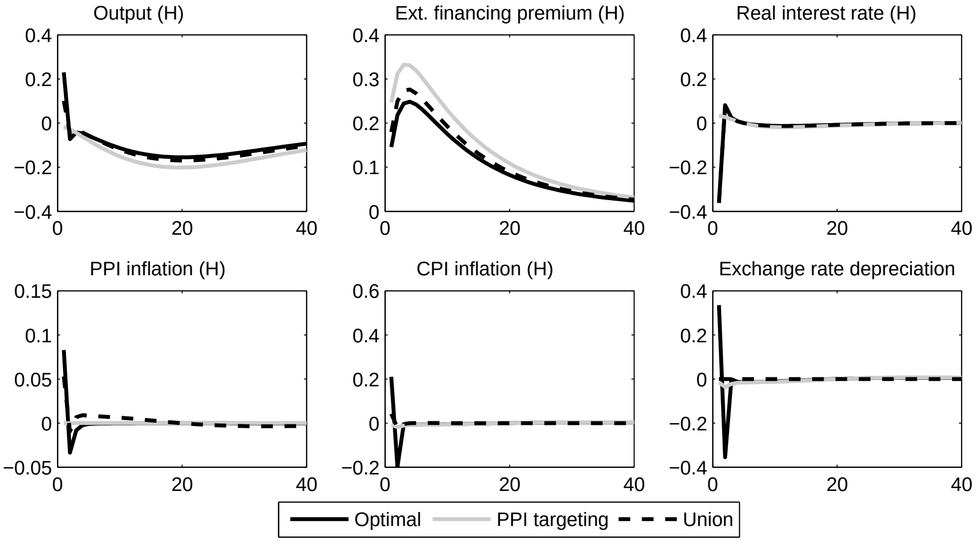
Notes: All numbers are relative to the cooperative equilibrium. Welfare losses are expressed in percent of steady-state consumption. The normalization factor is 1.1 for all model variants.

Figure 1. Home productivity shock - simple model



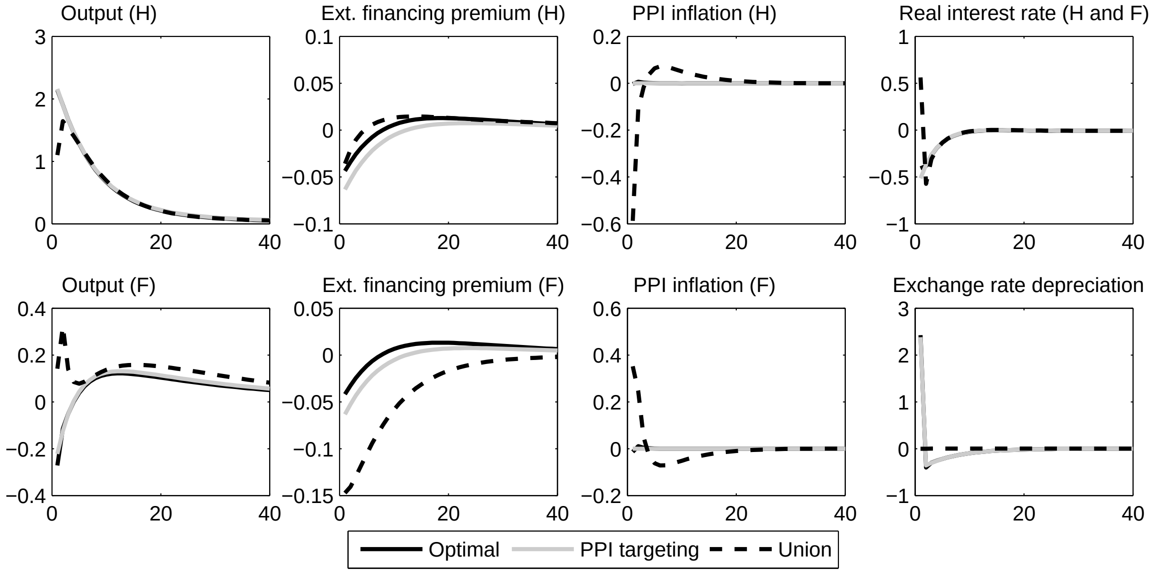
Note: The external financing premium, inflation and the interest rate are expressed as percentage point deviations from their steady-state levels. All remaining variables are reported as percentage deviations.

Figure 2. Negative home net worth shock - simple model



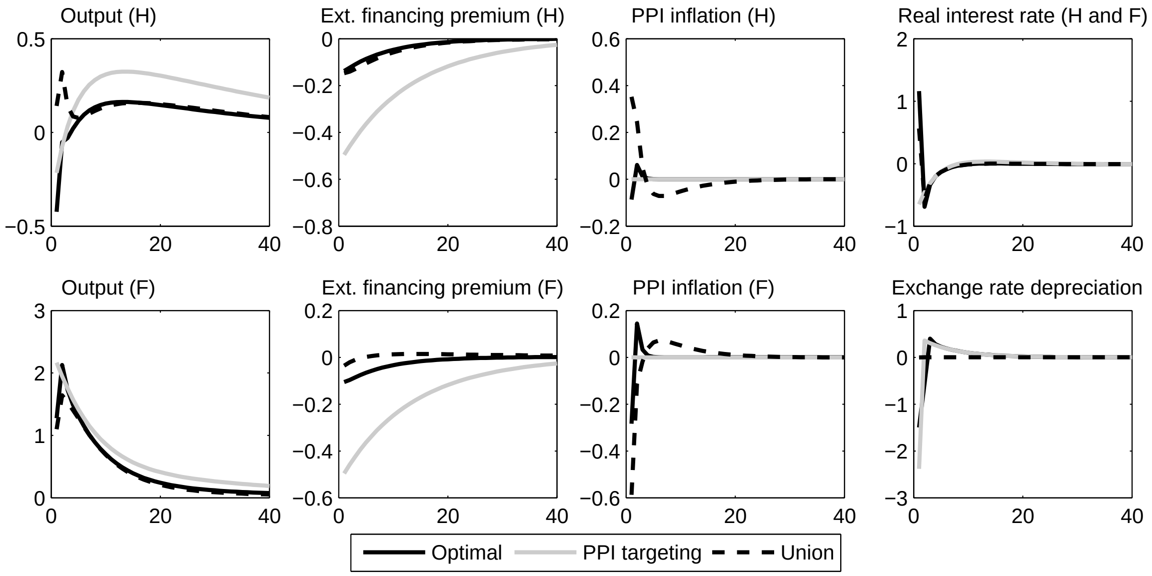
Note: The external financing premium, inflation and the interest rate are expressed as percentage point deviations from their steady-state levels. All remaining variables are reported as percentage deviations.

Figure 3. Home productivity shock - euroized debt



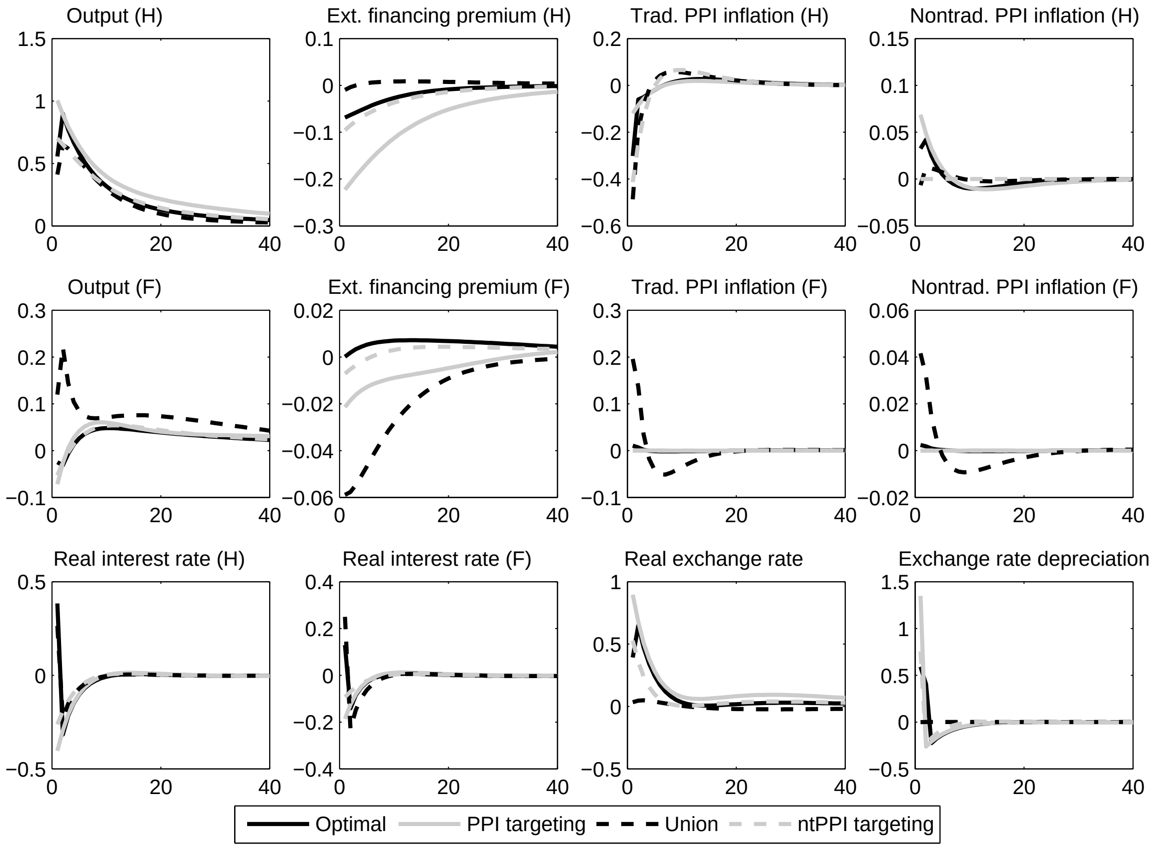
Note: The external financing premium, inflation and the interest rate are expressed as percentage point deviations from their steady-state levels. All remaining variables are reported as percentage deviations.

Figure 4. Foreign productivity shock - euroized debt



Note: The external financing premium, inflation and the interest rate are expressed as percentage point deviations from their steady-state levels. All remaining variables are reported as percentage deviations.

Figure 5. Home tradable sector productivity shock



Note: The external financing premium, inflation and the interest rate are expressed as percentage point deviations from their steady-state levels. All remaining variables are reported as percentage deviations.

Appendix

A.1 Foreign currency denomination of entrepreneurs' debt

If loans taken by entrepreneurs are denominated in the foreign currency, the amount borrowed in the domestic currency can be written as $B_{E,t+1}S_t$. The principal due, however, is equal to $B_{E,t+1}S_{t+1}$, so that entrepreneurs are exposed to exchange rate risk. The zero profit condition (30) thus becomes:

$$R_{E,t+1}Q_{T,t}P_{C,t}K_{t+1}\left[\tilde{a}_{E,t+1}(1-F_{1,t+1})+(1-\mu)\,F_{2,t+1}\right]=R_t^*B_{E,t+1}S_{t+1} \tag{A.1}$$

Similarly, the first order condition defining the optimal debt contract (34) is now given by:

$$E_t\left\{\begin{array}{c}\frac{R_{E,t+1}}{R_t^*\frac{S_{t+1}}{S_t}}\left[1-\tilde{a}_{E,t+1}(1-F_{1,t+1})-F_{2,t+1}\right]+\\ +\frac{1-F_{1,t+1}}{1-F_{1,t+1}-\mu\tilde{a}_{E,t+1}F'_{1,t+1}}\left(\frac{R_{E,t+1}}{R_t^*\frac{S_{t+1}}{S_t}}\left[\tilde{a}_{E,t+1}(1-F_{1,t+1})+(1-\mu)\,F_{2,t+1}\right]-1\right)\end{array}\right\}=0 \tag{A.2}$$

Finally, the law of motion for aggregate net worth (39) can be rewritten as:

$$N_{t+1}=\varepsilon_{n,t}\upsilon\left[\begin{array}{c}R_{E,t}Q_{T,t-1}P_{C,t-1}K_t-\\ -\left(R_{t-1}^*\frac{S_t}{S_{t-1}}+\frac{\mu F_{2,t}R_{E,t}Q_{T,t-1}P_{C,t-1}K_t}{B_{E,t}S_{t-1}}\right)B_{E,t}S_{t-1}\end{array}\right]+T_{E,t} \tag{A.3}$$

A.2 Probability distributions

In this section we show the analytical formulas for functions of entrepreneurs' idiosyncratic productivity distribution.

If a_E has a log normal distribution F with mean equal to 1, then $\log a_E$ has a normal distribution with mean equal to $-\frac{\sigma_E^2}{2}$, where σ_E^2 is the variance of $\log a_E$. This observation leads to the following formulas, which we use in the derivations presented in section 2:

$$F_{1,t}=\int_0^{\tilde{a}_{E,t}}dF\left(a_E\right)=cdf\left(\frac{\log\tilde{a}_{E,t}+\frac{1}{2}\sigma_E^2}{\sigma_E}\right) \tag{A.4}$$

$$F_{2,t}=\int_0^{\tilde{a}_{E,t}}a_E dF\left(a_E\right)=cdf\left(\frac{\log\tilde{a}_{E,t}+\frac{1}{2}\sigma_E^2}{\sigma_E}-\sigma_E\right) \tag{A.5}$$

$$F'_{1,t}=\frac{1}{\tilde{a}_{E,t}\sigma_E}pdf\left(\frac{\log\tilde{a}_{E,t}+\frac{1}{2}\sigma_E^2}{\sigma_E}\right) \tag{A.6}$$

where *pdf* (*cdf*) is probability density function (cumulative distribution function) of a standard normal distribution.