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# Optimal Monetary Policy in a Currency Union: Implications of a Country-specific Cost Channel\*

Jochen Michaelis<sup>†</sup> and Jakob Palek<sup>‡</sup>

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## Abstract

There is growing empirical evidence that the strength of the cost channel of monetary policy differs across countries. Using a New Keynesian model of a two-country monetary union, we show how the introduction of a cost channel (differential) alters the optimal monetary responses to union-wide and national shocks. The cost channel makes monetary policy less effective in combating inflation, but it is shown that the optimal response to the decline in effectiveness is a stronger use of the instrument. On the other hand, the larger the cost channel differential, the less aggressive will the optimal monetary policy be. For almost all parameter constellations, our welfare analysis suggests a clear-cut ranking of policy regimes: commitment outperforms the Taylor rule, the Taylor rule outperforms strict inflation targeting, and strict inflation targeting outperforms discretion.

JEL-Classification: E 31, E 52, F 41

Keywords: cost channel; optimal monetary policy; monetary union; open economy macroeconomics

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# 1 Introduction

The creation of the European Monetary Union has triggered a lively academic discussion on the question how monetary policy should be conducted in a currency area. The main challenge was quickly identified: the heterogeneity across member states. Given the differences in economic structures and/or shocks, just one policy instrument, e.g. the union-wide interest rate, seldom fits all. Differences in the degree of price stickiness (Benigno, 2004), the degree of product market competition (Lombardo, 2006), the degree of a pricing-to-market policy by firms (Michaelis, 2006) or trade openness with the rest of the world (de Paoli, 2009) cause a country-specific pass-through of union-wide (aggregate) shocks and, similarly, a country-specific pass-through of the interest rate policy. The optimal monetary response to shocks minimizes the welfare losses arising from these and other structural characteristics of the economies.

This paper focuses on heterogeneity across member states in the strength of the cost channel of monetary policy (Ravenna and Walsh, 2006). We show how the optimal monetary policy depends on the country-specific strength of the cost channel. We emphasize the cost channel, since growing empirical evidence suggests that the nominal interest rate directly enters into the marginal costs of production (see, among others, Barth and Ramey, 2001; Ravenna and Walsh, 2006; Chowdhury et al., 2006; Tillmann, 2008, 2009a). A changing interest rate matters for the pricing decision of firms and thus for inflation and output dynamics. And, equally important for our analysis, all these studies suggest that the strength of the cost channel differs across countries. Take, for instance, the empirical analysis of Chowdhury et al. (2006). They find that the firms' marginal costs raise by more than one for one with changes in the monetary policy rate in Italy. On the other hand, they cannot establish a significant cost channel in Germany. For France, the cost channel coefficient lies between these polar countries. Our conclusion from the empirical literature: Ignoring the cost channel (differentials) skews the real picture of the monetary transmission process and distorts the guidelines for the design of the optimal policy.

To address the issues of interest, we integrate a country-specific cost channel into an otherwise standard New Keynesian model of a two-country monetary union. A single central bank sets the union-wide interest rate. There are no stabilization policies at the national level. We analyze how the introduction of the cost channel alters the optimal monetary responses to aggregate, asymmetric and/or idiosyncratic demand and supply shocks. Our focus will be on the optimal policy under discretion. However, we also carry out a welfare analysis, where we compare the optimal policy under discretion with the optimal policy under commitment. In order to get some intuition on how optimal real world monetary policies are, we compare these solutions with two simple rules, strict inflation targeting and a Taylor rule.

The conduct of monetary stabilization policy in the presence of a cost channel has not received much research attention. This is surprising, since the design of optimal monetary policy in a currency union has been studied extensively. Lane (2000) shows that the optimal response to perfectly asymmetric shocks is to "do nothing". Benigno (2004) studies the implications of different degrees of price stickiness among member countries for the optimal target of inflation. Only if the member countries share the same degree of nominal rigidity, it is optimal to stabilize the price level for the union as a whole. Lombardo (2006) emphasizes the importance of country-specific degrees of product market competition for the design of optimal monetary policy. If the currency union has a trade linkage with the rest of the world, the strict inflation stabilization is no longer the first best policy and a partial stabilization of the exchange rate is desirable (de Paoli, 2009). Gali and Monacelli (2008) and Beetsma and Jensen (2005) focus on the optimal mix of monetary and fiscal policy. From the viewpoint of the union the optimal policy plan requires that union inflation is stabilized by the single central bank, whereas fiscal policy, implemented at the country-level, should stabilize idiosyncratic shocks. Ferrero (2009) moves one step further by introducing a government budget constraint. He shows that a balanced budget rule generates first-order welfare losses, allowing for variations in government debt is superior.

In a seminal paper, Ravenna and Walsh (2006) investigate the role of the cost channel for the design of optimal monetary policy. They show that, under optimal monetary policy, the output gap and inflation are allowed to fluctuate in response to both productivity and demand shocks. However, they restrict their analysis to the case of a closed economy and ignore all international linkages. Tillmann (2009b) introduces uncertainty about the true size of the cost channel into the model of Ravenna and Walsh. Since an uncertain monetary authority tends to overestimate the price effect of an interest rate hike, the interest rate response to inflation is smaller, uncertainty makes the central bank less aggressive. Lam (2010) as well as Demirel (2013) show that the value of monetary policy commitment to a low inflation target is increasing in the strength of the cost channel.

The cost channel makes monetary policy less effective in combating inflation. In this paper, we show that the optimal response to the decline in effectiveness is a stronger use of the instrument. In the presence of a cost channel, policymakers are generally more aggressive. On the other hand, our analysis suggests that in the presence of a cost channel differential (the strength of the cost channel differs across countries), the optimal monetary policy will generally be less aggressive. Compared to the case of identical cost channels across countries, heterogeneity always lowers welfare. The welfare loss is increasing in the size of the cost channel differential. Our welfare analysis encompasses four regimes: commitment, discretion, strict inflation targeting and a Taylor (1993) rule. For almost all parameter constellations and shocks we get the following ranking

in terms of welfare: commitment outperforms the Taylor rule, the Taylor rule outperforms strict inflation targeting, and strict inflation targeting outperforms discretion.

The remainder of the paper is structured as follows. Section 2 develops the basic structure of the model, the building blocks are the IS relation and the Phillips curve. Section 3 discusses the setup of the policy analysis, while Section 4 presents and discusses the inflation and output dynamics of various shocks. Section 5 compares the welfare losses associated with shocks under different kind of policy regimes. Section 6 concludes.

## 2 Basic Structure of the Model

We consider a world of two countries, (H)ome and (F)oreign. The countries form a monetary union with a single central bank. Countries produce differentiated commodities, all goods are traded. Labor and product markets are imperfectly competitive, and firms set prices subject to a Calvo (1983) scheme of staggered price adjustments. Labor serves as the only input. Based on Barth and Ramey (2001), Christiano et al. (2005), and Ravenna and Walsh (2006), we introduce country-specific cost channels by assuming that (a fraction of) firms have to pay their wage bill before they sell their product. Firms borrow at the riskless nominal interest rate set by the central bank.

### 2.1 The IS Relation

The population of the union is a continuum of households on the interval  $[0, 1]$ . The population of the segment  $[0, n)$  belongs to Home, while the population of  $[n, 1]$  belongs to Foreign. All households have identical preferences defined over consumption  $C_t$  and total hours worked  $L_t$ . The utility of a representative household  $j$  is given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{(C_t^j)^{1-\sigma}}{1-\sigma} - \frac{(L_t^j)^{1+\eta}}{1+\eta} \right], \quad (1)$$

where  $\beta \in [0, 1]$  is the discount factor,  $\sigma$  is the inverse of the intertemporal elasticity of substitution, and  $\eta$  is the inverse Frisch elasticity of labor supply. The consumption index  $C_t^j$  is defined as

$$C_t^j \equiv \left( \frac{C_{H,t}^j}{n} \right)^n \left( \frac{C_{F,t}^j}{1-n} \right)^{1-n}, \quad (2)$$

where  $C_{H,t}^j$  and  $C_{F,t}^j$  are the consumption baskets of Home and Foreign goods, respectively. These baskets are themselves CES aggregates across Home and Foreign brands. The elasticity of substitution between the two bundles of goods - the "macro" Armington elasticity - is restricted to unity.<sup>1</sup>

Let us introduce some notation before we proceed. Variables written in lower case letters denote the log of the corresponding variable (i.e.,  $x_t \equiv \ln X_t$ ), while a "hat" symbol (e.g.  $\hat{x}_t \equiv \ln(X_t/\bar{X})$ ) is used to denote the percentage deviation of  $X_t$  from its steady state value  $\bar{X}$ . Moreover, an aggregate (union) variable  $x_t^w$  is defined as weighted average of the national variables,  $x_t^w \equiv nx_t^H + (1-n)x_t^F$ , while the relative variable  $x_t^R$  is defined as  $x_t^R \equiv x_t^H - x_t^F$ .

There are no impediments to trade, 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  $p_t$  is identical across countries:  $p_t = np_t^H + (1-n)p_t^F$ , where  $p_t^H$  and  $p_t^F$  are the producer price indices of Home and Foreign goods, respectively. The Home and Foreign rates of producer price inflation, defined as  $\pi_t^i \equiv p_t^i - p_{t-1}^i$  with  $i = H, F$ , may differ across countries. Let  $q_t \equiv p_t^F - p_t^H$  represent the terms of trade. From this definition, we deduce that the terms of trade evolves according to<sup>2</sup>

$$q_t = q_{t-1} - (\pi_t^H - \pi_t^F). \quad (3)$$

The current period terms of trade is a function of its past value, thus the past level of the terms of trade is a state variable. As a consequence, neither the inflation rates (nor the output gaps, see below) jump to their new steady-state level after a shock, but converge gradually to the new equilibrium.

As shown in Appendix A, the demand side of the economies can be stated as

$$\hat{y}_t^H = (1-n)q_t + E_t \hat{y}_{t+1}^w - \sigma^{-1}(\hat{R}_t - E_t \pi_{t+1}^w) + u_t^H \quad (4)$$

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<sup>1</sup>Recent research on the magnitude of the Armington elasticity justifies the unitary assumption. We particularly refer to Feenstra et al. (2014). By using a nested CES preference structure, they show that the (micro) Armington elasticity between foreign varieties may be very different from the (macro) Armington elasticity between foreign and domestic goods. For U.S. data, the macro elasticity is not significantly different from unity. Feenstra et al. (2014) also discuss the reasons why their numbers are in contrast to the "elasticity optimism" result of Imbs and Méjean (2014), who estimate a macro elasticity of about 6 for the U.S. The main criticism: The data which Imbs and Méjean (2014) use in their estimation is for imports only, there is no matching with domestic production data. Hence, the aggregate elasticity they compute by taking a weighted average of sectoral elasticities is in fact still a micro Armington elasticity.

<sup>2</sup>It is straightforward to show that in our framework the steady-state terms of trade is equal to unity,  $\bar{Q} = 1$ . Hence we have  $\bar{q} = \log \bar{Q} = 0$ , and the terms of trade gap,  $\hat{q}_t = q_t - \bar{q}$ , coincides with the terms of trade  $q_t$ .

$$\widehat{y}_t^F = -nq_t + E_t \widehat{y}_{t+1}^w - \sigma^{-1}(\widehat{R}_t - E_t \pi_{t+1}^w) + u_t^F. \quad (5)$$

where  $\widehat{y}_t^H$  and  $\widehat{y}_t^F$  are real output gaps in Home and Foreign, respectively,  $\widehat{R}_t$  is the nominal interest rate gap, and  $E_t \pi_{t+1}^w$  is the expected consumer (and producer) price inflation in the union. Due to the well-known open economy expenditure-switching effect, the demand for Home (Foreign) goods is increasing (decreasing) in the terms of trade  $q_t$ . In (4) and (5), we have added a country-specific demand shock  $u_t^i$ , which is assumed to follow an AR(1) process

$$u_t^i = \rho_u u_{t-1}^i + \xi_{u,t}^i \quad (6)$$

where  $\xi_{u,t}^i$  is a zero mean white noise process, and  $\rho_u \in [0, 1]$ . From aggregation of (4) and (5), we obtain the union IS curve:

$$\widehat{y}_t^w = E_t \widehat{y}_{t+1}^w - \sigma^{-1}(\widehat{R}_t - E_t \pi_{t+1}^w) + u_t^w. \quad (7)$$

For the relative output gap, we get

$$\widehat{y}_t^R = q_t + u_t^R. \quad (8)$$

The interest rate gap vanishes, i.e. a change in  $\widehat{R}_t$  affects aggregate demand, but, on impact, it does not affect the split of demand between Home and Foreign. The opposite is true for the terms of trade (gap), a change in  $q_t$  affects the output gap differential but not the aggregate output gap.

## 2.2 The Phillips Curve

Monopolistically competitive firms aim to maximize the current value of profits. Each firm chooses the optimal price subject to three constraints: a downward sloped demand schedule for its product, a production function describing the technology, and a Calvo (1983) scheme of price adjustment where each firm producing in country  $i$  may reset its price with probability  $1 - \theta^i$  in any given period. Assuming that the steady state is characterized by zero inflation in both countries, the evolution of the producer inflation rate in region  $i$  is given by the marginal cost based (log-linearized) Phillips curve:

$$\pi_t^i = \beta E_t \pi_{t+1}^i + \lambda^i \cdot \widehat{m}c_t^i + e_t^i \quad (9)$$

where the composite parameter  $\lambda^i$  is given by  $\lambda^i \equiv \frac{(1-\theta^i)(1-\beta\theta^i)}{\theta^i}$  (see, e.g, Gali, 2008). In analogy to the assumption on the properties of the demand shock the exogenous supply shock,  $e_t^i$ , is assumed to be an AR(1) process

$$e_t^i = \rho_e e_{t-1}^i + \xi_{e,t}^i \quad (10)$$

where  $\xi_{e,t}^i$  is a zero mean white noise process, and  $\rho_e \in [0, 1]$ .

Firms produce output by means of labor according to

$$y_t^i = l_t^i. \quad (11)$$

Real marginal costs,  $mc_t^i$ , are linear in the real wage,

$$mc_t^i = w_t^i - p_t^i + z^i R_t \quad (12)$$

and, due to the cost channel, increasing in the nominal interest rate set by the central bank. Firms are assumed to face a liquidity constraint in the factor markets. Factors of production have to be paid before goods markets open and firms can sell their products. Here, labor is the only factor of production. Thus the wage bill is the maximum amount firms must borrow at the beginning of a period from financial intermediaries. Financial intermediaries receive deposits from households and supply loans to firms at the nominal interest rate  $R_t^l$ . For simplicity we can approximate the lending rate  $R_t^l$  by the policy-controlled risk-free interest rate  $R_t$ . Any wedge between these two interest rates will be captured by the parameter  $z^i \geq 0$ , which measures the strength of the country-specific cost channel. Note that it is the nominal interest rate, which enters into the firms' real marginal costs. The expected inflation rate does not matter, since loans are assumed to be supplied and repaid within a period. After goods have been produced and sold in the goods market, firms repay loans at the end of the period. There is no accumulation of debt.

What determines the importance of the cost channel? According to Rabanal (2007), the larger the fraction of firms facing a liquidity constraint, the higher  $z^i$  is. This line of reasoning rests on the assumption that only the interest rate on external funds raise the marginal costs of production. Barth and Ramey (2001), and Chowdhury et al. (2006), however, argue that all firms are affected by the cost channel. The concept of opportunity costs implies that the logic of the effects of interest rates on firms' costs also applies when firms are primarily financed by internal funds. A less controversial feature determining  $z^i$  is the degree of interest rate pass-through. In imperfect financial markets the change in the lending rate may even exceed the change in the central bank rate, i.e. financial market restrictions amplify the effects of the cost channel. The parameter  $z^i$  is thus not restricted to lie between zero and one (see de Bondt, 2005; Chowdhury et al., 2006; Ravenna and Walsh, 2006; Tillmann, 2009b). And finally, almost all the factors put forward in the literature on the balance-sheet channel and the financial accelerator substantiate the supply-side effects of monetary policy (see e.g.



Bernanke and Gertler, 1995; and Bernanke et al., 1999).

The strength of the cost channel varies across countries and over time. Ravenna and Walsh (2006) find a cost channel coefficient of 1.276 for the U.S. Tillmann (2008) provides supportive evidence for a significant cost channel for the Euro area. This result is confirmed by Henzel et al. (2009). The study of Chowdhury et al. (2006) suggests that the strength of the cost channel varies in accordance with differences in financial systems. For countries with a highly regulated financial sector such as Germany or Japan, they do not find a significant cost channel. However, for countries with a more market-based system such as in the UK or in the U.S., the authors estimate a coefficient of 1.3, which is very much in line with Ravenna and Walsh (2006). For France and Italy, they estimate a  $z$ -value of 0.2 and 1.5, respectively. Tillmann (2009a) argues that the coefficient for the U.S. follows a U-shaped pattern. The cost channel was most important in the pre-Volcker era and less important in the Volcker-Greenspan period. Recently, due to Tillmann, the cost channel regained quantitative importance. This in turn conflicts with Gabriel and Martins (2010), who claim that the cost channel is poorly identified for the U.S.

Let us turn back to the model. Nominal wages are set either by individual households (see e.g. Blanchard and Gali, 2010) or by non-atomistic trade unions (see Gnocchi, 2009). In all labor market settings the wage setting institution is interested in the real wage in terms of the consumer price index. We can thus proceed by assuming that the real consumer wage is a constant markup over the marginal rate of substitution between consumption and leisure. Observing the period utility function in (1) we get

$$w_t^i = p_t + \sigma c_t(i) + \eta l_t^i \quad (13)$$

where  $c_t(i)$  is the consumption of a household belonging to region  $i$ . Notice that the inverse of the Frisch elasticity of labor supply  $\eta$  turns out to be the employment elasticity of wages.

Given these ingredients, we can derive the Home Phillips curve (see Appendix B):

$$\pi_t^H = \beta E_t \pi_{t+1}^H + \lambda^H (1-n)(1-\sigma)q_t + \lambda^H (\sigma + \eta) \widehat{y}_t^H + \lambda^H z^H \widehat{R}_t + e_t^H. \quad (14)$$

The Foreign Phillips curve is given by

$$\pi_t^F = \beta E_t \pi_{t+1}^F - \lambda^F n(1-\sigma)q_t + \lambda^F (\sigma + \eta) \widehat{y}_t^F + \lambda^F z^F \widehat{R}_t + e_t^F. \quad (15)$$

An increase in the central bank interest rate above its steady-state value leads to a rise in real marginal costs and thus to a rise in the current inflation rate above its steady-state value. For  $\lambda^H z^H > \lambda^F z^F$ , the increase in  $\pi_t^H$  exceeds the increase in  $\pi_t^F$ , a positive inflation differential  $\pi_t^R \equiv \pi_t^H - \pi_t^F > 0$  emerges.

The demand effect of a higher interest rate - consumption, production, employment, wages, real marginal costs and thus prices decline - works in the opposite direction. Therefore, the overall effect of a higher interest rate on current inflation is a priori ambiguous.

### 3 Framing the Policy Problem

In this section, we describe the nature of the optimal discretionary policy and the optimal commitment policy by the monetary authority. Since we are interested in the welfare differences of a switch from some simple rules to optimal policies, we additionally analyze the performance of a strict inflation targeting and a Taylor rule.

#### 3.1 Welfare Objective

The common central bank chooses the union-wide nominal interest rate  $R_t$  to maximize the utility of the representative household given by (1). We obtain the objective function from a second-order Taylor expansion of (1) around the deterministic steady state (see Appendix C for details):<sup>3</sup>

$$-E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t \right\} + t.i.p. + o(\|\xi\|^3), \quad (16)$$

where *t.i.p.* stands for terms independent of policy and  $o(\|\xi\|^3)$  represents terms of order three and higher. The per-period deadweight loss function  $\mathcal{L}_t$  is given by

$$\mathcal{L}_t = \frac{1}{2}(\sigma + \eta) \cdot (\hat{y}_t^w)^2 + \frac{1}{2} \frac{\varepsilon}{\lambda^H} n \cdot (\pi_t^H)^2 + \frac{1}{2} \frac{\varepsilon}{\lambda^F} (1 - n) \cdot (\pi_t^F)^2 + \frac{1}{2} n(1 - n)(1 + \eta) \cdot (q_t)^2, \quad (17)$$

where  $\varepsilon > 1$  denotes the elasticity of substitution between any two brands (which turns out to be the price elasticity of product demand faced by each monopolistic firm). Stabilizing the output gap is desirable, because households are averse towards fluctuations in both consumption and hours worked. Stabilizing the union inflation rate  $\pi_t^w$ , however, is, in general, not a feature of the optimal policy. As first pointed out by Benigno (2004), the country with a higher degree of price stickiness comes up with a higher degree of price distortion and thus it is optimal to put a higher weight to

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<sup>3</sup>We follow (large parts of) the literature in assuming that steady state distortions arising from monopolistic competition and the presence of a cost channel are eliminated by appropriate subsidies. Thus, by assumption, the deterministic steady state and the flexible price equilibrium coincide.

the country with stickier prices. This result is replicated in (17) where the weights of the national inflation rates are increasing in the degree of price stickiness (decreasing in  $\lambda^i$ ). Only if the duration of price contracts is identical across countries, monetary policy should stabilize  $\pi_t^w$ .<sup>4</sup> The terms of trade gap is part of the loss function, such a gap causes output shifts between Home and Foreign and thus fluctuations in hours worked.

## 3.2 The Policy Regimes

In order to derive the performance of the different policy regimes, we assume the following sequence of events. First, the economy is in the deterministic steady state. Then, period  $t$  demand and/or supply shocks are revealed. Given the realizations of the shocks, the central bank sets the nominal interest rate. Next, wage setters decide on the wage, and firms decide on the product price and take up a loan to finance the wage bill. Employment is pinned down, and production takes place. After selling the products on the goods market firms repay the loan.

### *Discretion*

The central bank chooses the interest rate  $R_t$  to minimize the loss function (16) subject to the constraints (3), (7), (14) and (15). Under discretion the central bank does not make any promises on future actions, it thus cannot affect the expectations about future inflation and output. The monetary authority treats the policy problem as one of sequential optimization, it reoptimizes in each period and takes expectations as given (for the optimality conditions see Appendix D). The optimal discretionary policy is time-consistent, but the missing impact on expectations worsens the output gap/inflation tradeoff creating the Clarida et al. (1999) stabilization bias. The cost channel worsens the output gap/inflation tradeoff even more. As already pointed out by Lam (2010), the cost channel is thus an important driver of the stabilization bias. Moreover, the stabilization bias is no longer restricted to supply shocks but also arises from demand shocks, see Demirel (2013).

### *Commitment*

If the central bank is able to credibly commit itself to a policy plan, it is able to influence expectations. The optimal policy plan takes the expectation channel into account (see Appendix D). The central bank optimizes over an enhanced opportunity set, so that the commitment solution must be at least as good as the one under discretion, see Sauer (2010). The policymaker optimizes once and never reoptimizes. However, such a commitment to a history-dependent policy in the future is time inconsistent. In

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<sup>4</sup>For  $\lambda^H = \lambda^F$ , the inflation-specific terms of (17) collapse to  $\frac{1}{2} \frac{\varepsilon}{\lambda^H} [n \cdot (\pi_t^H)^2 + (1-n) \cdot (\pi_t^F)^2] = \frac{1}{2} \frac{\varepsilon}{\lambda^H} [(\pi_t^w)^2 + n(1-n) \cdot (\pi_t^R)^2]$ .

Parameter	Value	Description
$\beta$	0.99	Discount factor
$\varepsilon$	7.66	Elasticity of substitution between goods
$\sigma$	2	Inverse of intertemporal elasticity of substitution
$\eta$	3	Inverse of Frisch labor supply elasticity
$\theta^H$	0.75	Home degree of price stickiness
$\theta^F$	0.75	Foreign degree of price stickiness
$n$	0.5	Size of country H

Table 1: Benchmark calibration

any period  $t > 1$  the monetary authority has an incentive to exploit expectations and to apply the same optimization procedure again. To overcome this initial-period-problem, Woodford (1999) has proposed the concept of the timeless perspective. A timeless policymaker implements a policy conforming to a rule that would have been optimal to adopt in the distant past. Put differently, he promises not to exploit initial conditions. But the timeless perspective faces credibility problems too. If the economy is not close enough to its steady-state, a switch from discretion to the timeless perspective can be welfare decreasing; see Sauer (2010) and Dennis (2010). In our model, the timeless perspective and the commitment solution coincide, since the initial conditions coincide (the economy starts in the deterministic steady state).

*Two Simple Rules: Strict Inflation Targeting and Taylor Rule*

In order to get some intuition for the welfare difference of a switch from some simple rules to optimal policies, we have to evaluate the performance of these rules. The first is a strict inflation targeting rule (SIT) where  $\pi_t^w = 0$  for all  $t$ . The second is a Taylor rule given by  $\widehat{R}_t = (\sigma + \eta)\widehat{y}_t^w + \frac{\varepsilon}{\lambda^w}\pi_t^w$ , where the weights of the respective gaps are chosen such as to correspond to the weights in the objective function (17). Even though these rules are not microfounded, they are transparent and easy to commit.

### 3.3 Benchmark Parameter Combination

The model is calibrated to a quarterly frequency. Table 1 summarizes our choice of the benchmark specification.

The discount factor  $\beta$  is set equal to 0.99, so that the steady state real interest rate is 4% in annual terms. By calibrating the elasticity of substitution between goods  $\varepsilon$  to a value of 7.66, we assume that the steady state mark-up of prices over marginal costs is around 15% which is a reasonable value for the European economies according to Benigno (2004). Following Galí and Monacelli (2008), we assume the inverse of the

Frisch elasticity of labor supply  $\eta$  to be 3. The inverse of the intertemporal elasticity of substitution  $\sigma$  is set equal to 2 following the econometric estimate of Leith and Malley (2005). In the benchmark case, we assume the price rigidity to be equal in both countries. Therefore the Calvo parameter  $\theta^i$  is set equal to a standard value of 0.75 which implies an average duration of price contracts of four quarters. We follow Benigno (2004) and Beetsma and Jensen (2005) and divide the EMU countries in two groups with an approximate weight of 50% in GDP terms. Thus,  $n = 0.5$ . Moreover, the shocks are assumed to have a positive autocorrelation ( $\rho_u = \rho_e = 0.5$ ).

## 4 Policy Evaluation

The objective of this section is to analyze the dynamic response of the relevant endogenous variables to different kind of demand and supply shocks. We distinguish between aggregate, asymmetric and idiosyncratic shocks. In order to avoid (too) many case differentiations, the presentation focuses on the optimal discretionary policy. Note that our analysis disregards all problems arising from the zero lower bound on nominal interest rates. For a discussion of this issue, see, e.g., Adam and Billi (2007).

### 4.1 Discretionary Response to an Aggregate Demand Shock

Let us start with the case of identical cost channels across countries,  $z^H = z^F = z$ . Figure 1 displays the impulse responses to a positive one percent shock in aggregate demand  $u_t^w$ .

On impact, the demand shock creates inflation and a positive output gap. The optimal response of the central bank is an increase in the nominal interest rate. For  $z = 0$ , our model replicates the "divine coincidence"-result of Blanchard and Gali (2007):  $\hat{y}_t^w = \pi_t^w = 0$ . An aggregate demand shock will be offset perfectly by varying the interest rate. The interest rate necessary to bring back inflation to target is identical with the interest rate necessary to close the output gap. This solution, however, does not hold in the presence of a cost channel as it drives a wedge between the output and the inflation target. The rise of the interest rate pushes inflation up via the supply side of the economy. The cost channel makes monetary policy less effective in combating inflation, but the optimal response to the decline in effectiveness is a stronger use of the instrument. The central bank accepts an increase in union inflation, and the increase in the interest rate is strong enough to turn the union output gap into negative. Welfare losses associated with departures from price stability and a nonzero output gap result in consequence. These welfare losses are disproportionately increasing in the strength of the cost channel. We get small welfare losses (0.1674 percent of steady state

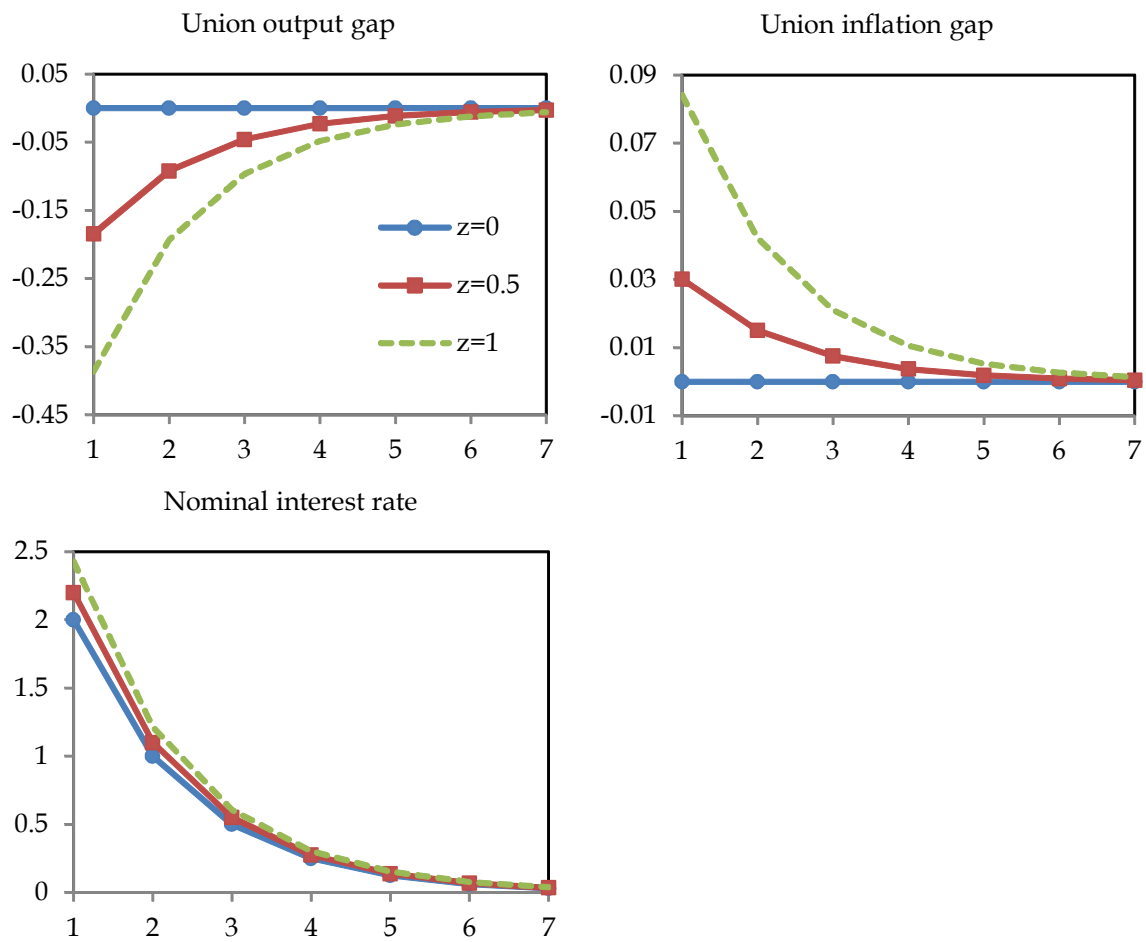


Figure 1: Aggregate demand shock with identical cost channels

consumption) in the case of  $z = 0.5$  but they become substantial when  $z$  is set to unity (0.9199 percent of steady state consumption).<sup>5</sup>

**Proposition 1** *Suppose identical cost channels across countries. a) The cost channel worsens the output gap/inflation tradeoff and impedes the perfect neutralization of aggregate demand shocks. b) Under discretion the optimal interest rate hike as response to an aggregate demand shock is increasing in the strength of the cost channel, the cost channel makes the optimal discretionary monetary policy more aggressive. c) The welfare loss arising from the cost channel increases disproportionately with the strength of the cost channel.*

Figure 2 depicts the impulse response functions to a positive aggregate demand shock for alternative values of the country-specific cost channels. In particular, the Home cost channel is turned off ( $z^H = 0$ ) and the Foreign cost channel varies from a relative small value ( $z^F = 0.3$ ) to a relative high value ( $z^F = 1$ ). The loss-minimizing response to the positive demand shock is an increase in the interest rate. As in the case of identical cost channels, the central bank tolerates an increase in union inflation, and, again, the rise in the interest rate is strong enough to generate a negative union output gap. The country-specific variables, however, evolve in a different manner. In the initial period, Home inflation is always lower than Foreign inflation. For  $z^H = 0$ , Home inflation is unambiguously negative. For  $z^F > z^H > 0$ , the cost channel differential  $z^F - z^H$  must exceed a threshold in order to generate negative Home inflation. In this case, with respect to Home inflation, the negative demand effect of the increase in the interest rate overcompensates both the initial positive demand shock and the price effect of the Home cost channel. If the differential is below the threshold, both Home and Foreign inflation will be positive.

A cost channel differential causes a terms of trade gap. For  $z^F > z^H$ , the Foreign price level exceeds the Home price level, Foreign faces a deterioration of its terms of trade,  $q_t \equiv p_t^F - p_t^H$  goes up. Demand switches from Foreign to Home magnifying the decline in Foreign output and mitigating the decline in Home output. As mentioned above, the past level of the terms of trade is a state variable, so that the demand switch in the initial period has long lasting effects. The stronger the cost channel differential, the stronger is the increase in  $q_t$ , and the more likely is the case that the initial negative Home output gap turns into positive in subsequent periods (see the time-path of Home output in Figure 2). Due to the demand switch, Home inflation goes up and Foreign inflation goes down in subsequent periods. In order to arrive at a new equilibrium for the terms of trade gap, Home inflation must exceed Foreign inflation during the adjustment process.

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<sup>5</sup>Welfare losses are expressed as fraction of steady-state consumption that much be given up to equate welfare in the stochastic economy to that in a deterministic steady-state.

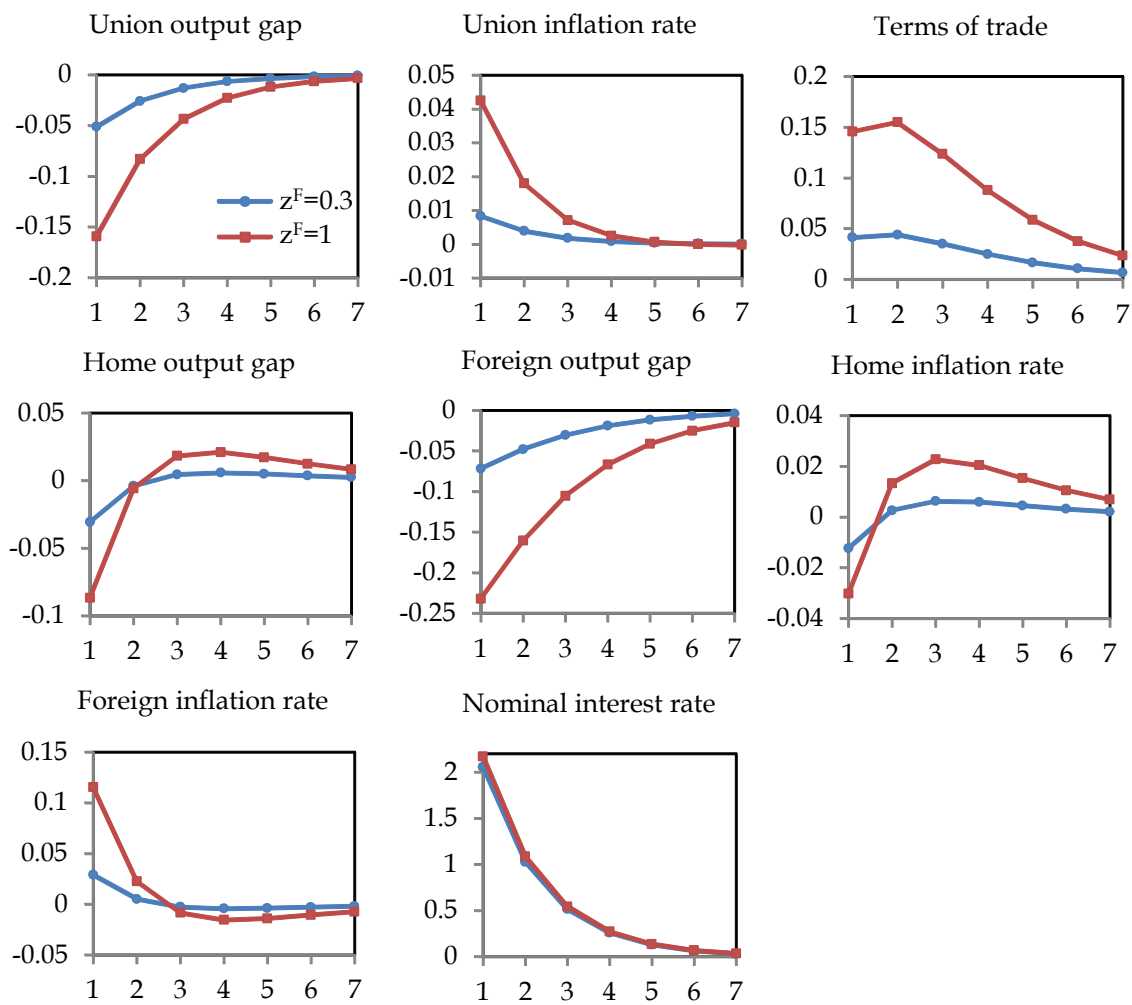


Figure 2: Aggregate demand shock with a Foreign cost channel



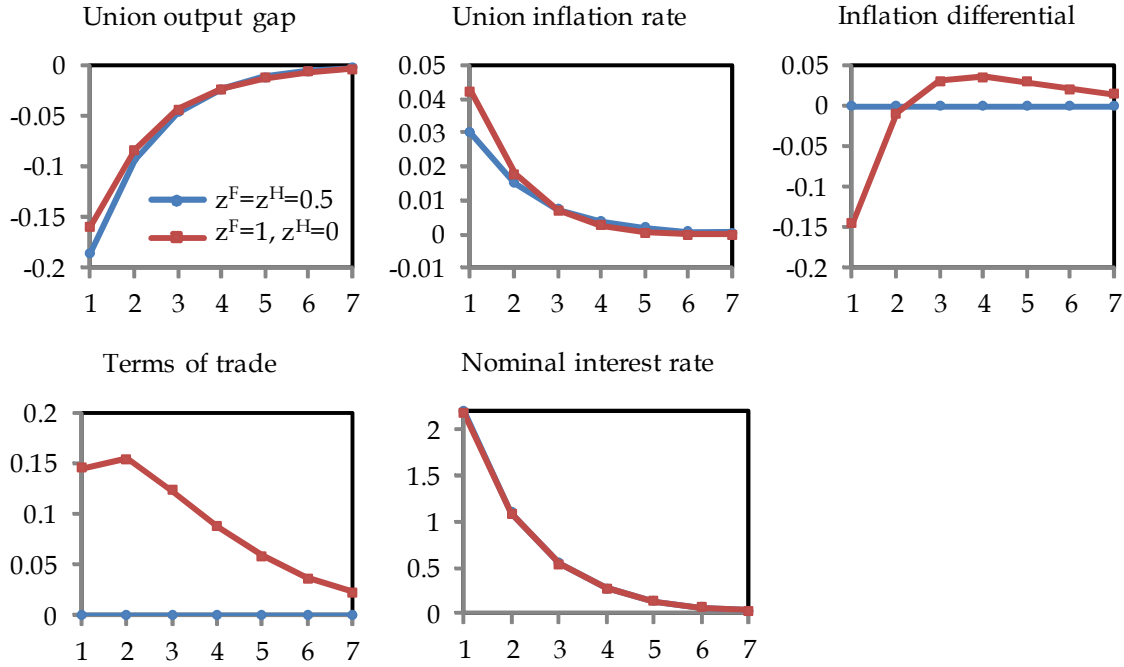


Figure 3: Aggregate demand shock in the case of identical cost channels and a cost channel differential

In the presence of a cost channel differential, the national variables matter for the loss function of the central bank. And the central bank is now able to influence both aggregate and relative variables. To illustrate the feedback on the design of the optimal policy, we compare the scenario  $z^F = z^H = 0.5$  with the scenario  $z^F = 1.0$  and  $z^H = 0$  (see Figure 3). In the case of full symmetry, all differentials are zero, all losses arise from the variability of union wide variables. In the case of a cost channel differential, the loss function contains two additional arguments, the inflation differential and the terms of trade gap. Since neither the weights of the union variables  $\hat{y}_t^w$  and  $\pi_t^w$  in the loss function nor the tradeoff between these two variables changes, heterogeneity always implies a decline in welfare (higher loss). The central bank takes into account the effects on the inflation differential and the terms of trade, it balances the tradeoff between a change in aggregate and relative variables. As a result, heterogeneity leads to a less aggressive monetary policy. The emergence of a cost channel differential lowers the optimal interest rate hike as response to the increase in aggregate demand. Compared to full symmetry, the increase in union inflation is higher and the drop in the union output gap is lower. The welfare loss arising from heterogeneity corresponds to 0.3349

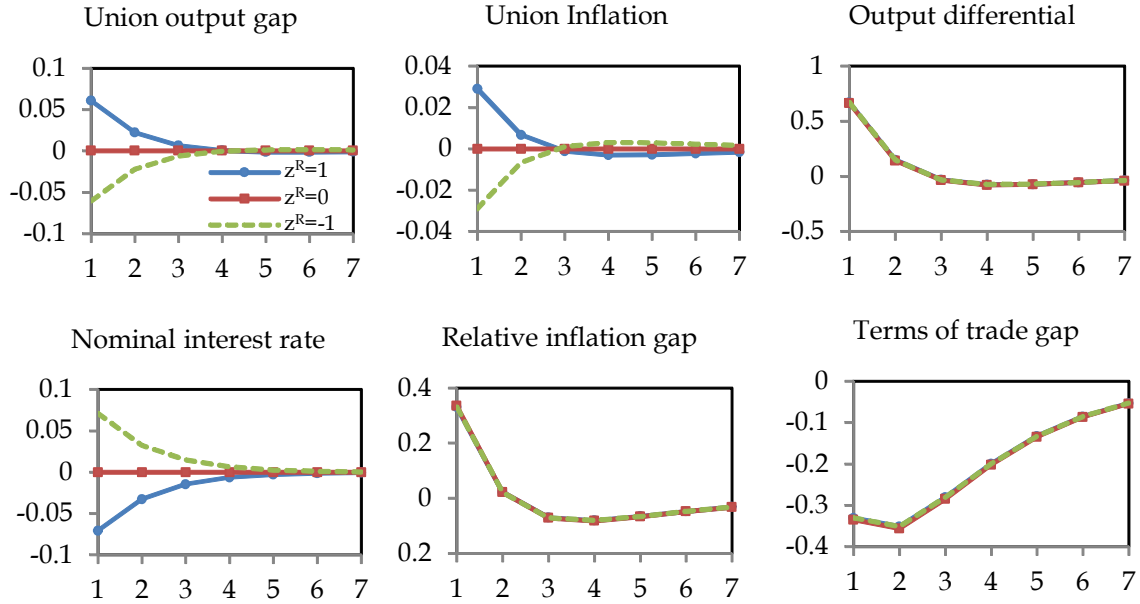


Figure 4: Perfect asymmetric demand shock under different cost channel differentials

percent of steady-state consumption.

The main results are summarized in

**Proposition 2** *Suppose that there is a cost channel differential with  $z^F > z^H$ . The cost channel differential a) gives rise to a terms of trade gap, demand switches from Foreign to Home; b) makes the optimal discretionary monetary policy less aggressive. c) Compared to the case of identical cost channels across countries, heterogeneity always lowers welfare. The welfare loss is increasing in the size of the cost channel differential.*

## 4.2 Discretionary Response to a Relative Demand Shock

We will focus on a perfect asymmetric (relative) demand shock, relative demand goes up,  $u_t^R = u_t^H - u_t^F > 0$ , whereas aggregate demand remains unaltered,  $u_t^w = 0$ . Such a shock gives rise to a positive output differential, a positive inflation differential and a negative terms of trade gap (see Figure 4). The optimal policy response and the impact on aggregate output and aggregate inflation very much depends on the sign of the cost channel differential. In the case of no or identical cost channels,  $z^R = z^H - z^F = 0$  (red line in Figure 4), a perfect asymmetric shock does not affect aggregate variables,  $\hat{y}_t^w = \pi_t^w = 0$ . The optimal policy is to do nothing, which replicates Lane (2000).

Because of the inflation differential and the terms of trade gap, the central bank faces a loss, but due to the assumed symmetry in the transmission process, the central bank can not affect country differentials and thus does not change the interest rate.

The "do nothing"-result does not hold in a world where the strength of the cost channel differs between Home and Foreign. Now, the central bank is able to influence the inflation differential and the terms of trade gap and it is optimal to do so. From the discussion of the Home and Foreign Phillips curve, see (14) and (15), we know that an increase in the interest rate leads to an increase (decrease) in the inflation differential for  $z^R > 0$  ( $z^R < 0$ ). The central bank aims at a lower inflation differential. Thus, for  $z^R > 0$  the central bank has to lower the interest rate (blue line), and for  $z^R < 0$  it has to raise the interest rate (green line). The decline in the inflation differential comes at a cost, for  $z^R > 0$  union output and union inflation increase, for  $z^R < 0$  union output and union inflation decrease (see Figure 4). We get

**Proposition 3** *A perfect asymmetric demand shock causes a positive inflation differential and a negative terms of trade gap. The optimal policy response depends on the cost channel differential. a) For  $z^R = 0$ , the optimal policy is to do nothing. b) For  $z^R > 0$ , the central bank reduces the inflation differential via a lower interest rate accepting an increase in aggregate output and aggregate inflation. c) For  $z^R < 0$ , the central reduces the inflation differential via a higher interest rate accepting a decline in aggregate output and aggregate inflation.*

### 4.3 Discretionary Response to a Home Demand Shock

National (idiosyncratic) shocks affect both aggregate and relative demand. Take, for instance, an unexpected increase in Home demand:  $u_t^H > 0$  and  $u_t^F = 0$ . Figure 5 displays the impulse responses of the endogenous variables for alternative values of the cost channel parameters  $z^H$  and  $z^F$ . Such a shock increases aggregate demand,  $u_t^w > 0$ , as well as relative demand,  $u_t^R > 0$ . A positive output differential and a positive inflation differential emerge, Home faces a deterioration of its terms of trade. Now the monetary authority comes into action. The loss-minimizing response to the increase in aggregate demand is a rise in the interest rate causing households to shift consumption from the current period into the future. Current consumption will then fall in Home and Foreign.

If there is no cost channel,  $z^H = z^F = 0$ , the decline in aggregate consumption neutralizes the positive demand shock, aggregate demand declines to the pre-shock level. The optimal monetary policy closes the output and inflation gap at the union level, but, due to the nature of the shock, not on the national level. From Home's point of view, there are three effects, the positive demand shock, the decline in consumption

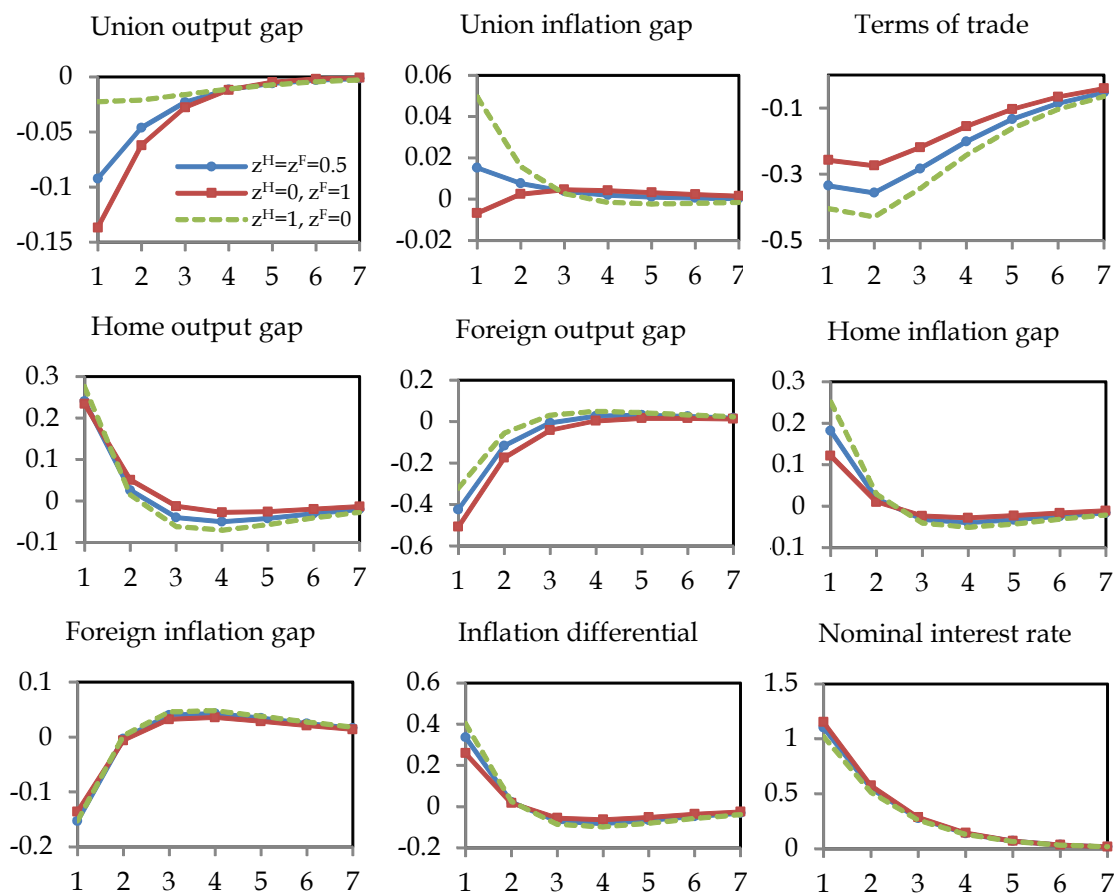


Figure 5: Home demand shock with country-specific cost channels

demand due to the upward shift in the interest rate, and the negative expenditure switching effect due to the deterioration of the terms of trade. The net effect is still positive, i.e. the positive demand shock dominates the sum of the interest rate and the expenditure switching effect. It follows immediately that the opposite must be true for Foreign output and inflation. From Foreign's point of view, the interest rate hike outweighs the positive terms of trade effect.

In the presence of a symmetric cost channel,  $z^H = z^F = 0.5$  (blue line), the central bank is no longer able to close the gaps in union output and inflation. The optimal policy is a stronger increase in the interest rate which leads to a negative union output gap and, due to the cost channel, to a positive union inflation gap (see Proposition 1). The sign of the national variables coincide with the just described case of no cost channel.

The monetary authority needs a cost channel differential in order to influence the inflation differential and the terms of trade. For  $z^R > 0$  (green line), any increase in the interest rate widens the inflation differential. The interest rate hike, which is optimal in the case of identical cost channels across countries, has a negative side effect now, it pushes up the inflation differential even more. As a consequence, it is optimal to mitigate the interest rate hike. The decline in the union output gap turns out to be weaker, the increase in the union inflation gap turns out to be stronger. For  $z^R < 0$  (red line), the reverse is true. The side effect of the interest rate hike is positive now, the inflation differential declines. The central bank reacts more aggressive by a stronger increase in the interest rate. The drop in union output will be magnified, and even the union inflation gap turns into negative.

The main results are summarized in

**Proposition 4** *Suppose a positive idiosyncratic shock in Home demand:  $u_t^H > 0$  and  $u_t^F = 0$ . The optimal policy response depends on the cost channel parameters. a) For  $z^H = z^F = 0$ , the central bank closes the union output gap and the union inflation gap perfectly by varying the interest rate. Foreign faces a negative output and a negative inflation gap. b) For  $z^H = z^F > 0$ , it is optimal to be more aggressive, the union output (inflation) gap will be negative (positive). c) For  $z^R > 0$ , the central bank mitigates the interest rate hike, compared to b), in order to reduce the increase in the inflation differential. d) For  $z^R < 0$ , the central bank magnifies the interest rate hike, compared to b), in order to accelerate the decline in the inflation differential.*

## 4.4 Supply shocks

In this subsection, we will discuss briefly the optimal discretionary monetary response to a negative cost-push shock. We focus on an aggregate cost-push shock and omit the straightforward extension to an asymmetric and/or idiosyncratic shock.

An aggregate cost-push shock ( $e_t^H = e_t^F = e_t^w > 0$ ) causes on impact union inflation to go up, whereas the union output gap remains unaltered. A cost-push shock drives a wedge between the output and the inflation target even in the absence of a cost channel. For  $z^H = z^F = 0$ , the optimal policy is an increase in the interest rate mitigating the inflationary effect of the cost-push. But there will be no full accommodation. Because of a negative output gap the optimal monetary policy will tolerate an inflation rate above the target. For  $z^H = z^F > 0$ , the trade off between inflation and output worsens. A given increase in the interest rate and thus a given decline in output is now accompanied by a higher inflation rate. The cost channel makes monetary policy less effective in combating inflation, but, in analogy to the case of a demand shock (see Proposition 1), the optimal response to the decline in effectiveness is a stronger use of the instrument. For  $z^R > 0$ , the trade-off between stabilizing inflation and output remains. However, the increase in the interest rate now also causes changes in the inflation differential and the terms of trade. As, by assumption,  $z^H$  exceeds  $z^F$ , Home inflation exceeds Foreign inflation,  $\pi_t^R > 0$ . Home's terms of trade deteriorate,  $q_t < 0$ , causing a demand switch from Home to Foreign. The result is a negative output differential,  $y_t^R < 0$ .

## 5 Welfare Comparison of Policy Regimes

In this section, we consider the welfare costs of demand shocks across the policy regimes discretion, commitment, strict inflation targeting and Taylor rule. As already mentioned in footnote 5, welfare costs are defined as fraction of steady-state consumption that much be given up to equate welfare in the stochastic economy to that in a deterministic steady-state. Our analysis so far considered only optimal monetary policy under discretion, i.e., the central bank can not anchor inflation expectations through a commitment technology. If, however, the monetary authority can credibly commit to follow a policy plan, the central bank will optimize over an enhanced opportunity set creating a welfare gain (see, for instance, Dennis and Söderström, 2006, and Sauer, 2010). We will thus consider commitment as our benchmark when analyzing welfare losses. In reality, such a commitment technology is hard to implement as policymakers have an incentive to deviate from the optimal plan. That is why we also include two simple rules in our analysis, strict inflation targeting (SIT), defined as  $\pi_t^w = 0$  for all  $t$ , and a Taylor rule. The Taylor rule is given by  $\widehat{R}_t = (\sigma + \eta)\widehat{y}_t^w + (\epsilon/\lambda^w)\pi_t^w$ . In order to allow for a meaningful welfare comparison, the weights of the respective gaps are identical to those of our microfounded welfare function (17). Note that this rule punishes inflation volatility about 18 times more than output volatility.<sup>6</sup>

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<sup>6</sup>It is a well-known feature of microfounded social welfare functions that the weight attached to inflation can be over ten or twenty times that attached to the output term (see Woodford, 2003, Ch.6).

Figure 6 displays the impulse responses to an aggregate demand shock under different policy regimes and identical cost channels ( $z^H = z^F = 1$ ). The commitment policy faces the best possible trade off between output and inflation, it thus needs a significant lower response of the interest rate in order to stabilize inflation and the output gap.<sup>7</sup> The output gap is lower compared to all policies and only SIT produces - by construction - a smaller union inflation gap. SIT stabilizes union inflation, but at the expense of a higher volatility in union output (and, for  $z^H \neq z^F$ , a higher volatility of inflation differentials and the terms of trade). For SIT, we observe the strongest increase in the interest rate and the largest decline in the union output gap. The discretion policy is second best in stabilizing the output gap, but allows the highest inflation compared to other policies. The Taylor rule performs well in terms of avoiding outliers in inflation and/or output.

Figure 7 compares the welfare losses relative to those of commitment as a function of the strength of the cost channel, the welfare loss of the commitment regime is normalized to zero. In accordance with Lam (2010) and Demirel (2013), we obtain the result that the welfare gain from a switch to commitment is increasing in the strength of the cost channel. Or to put it different, ignoring the cost channel leads to an underestimation of the welfare gain from commitment. For  $z^H = z^F = 0$ , commitment, discretion and SIT are equivalent. These regimes all lead to an interest rate reaction that closes both the union inflation and the union output gap. Only the Taylor rule fails to reproduce this outcome. Therefore, in the absence of a cost channel (and for very small  $z$ -values) the Taylor rule performs worst. For  $z^H = z^F > 0$ , the ability to commit to a low inflation target gains importance. There are two instruments to combat inflation, the interest rate and the commitment technology. Since the cost channel makes the interest rate less effective in combatting inflation, the importance of the commitment technology immediately increases. Under discretion the central bank is incapable to manipulate inflation expectations, so that discretion induces the largest welfare losses (except for very small  $z$ -values). The Taylor rule performs worst for very small  $z$ -values, but the picture changes when looking at medium and thus more plausible  $z$ -values. The Taylor rule successfully anchors inflation expectations but avoids an extreme output volatility

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For a majority of macroeconomist this sounds counterintuitive. There is no easy way out. 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).

<sup>7</sup>If the cost channel exceeds a well-defined threshold, the interest rate turns into a supply-side instrument. In quantitative terms, this threshold lies approximately around an aggregate cost channel value of 3.6 for the benchmark specification. Following the demand shock, it is now optimal to lower the interest rate. Even though hardly realistic, there is the theoretical possibility that the cost channel dominates the demand channel while still satisfying the Blanchard-Kahn conditions.

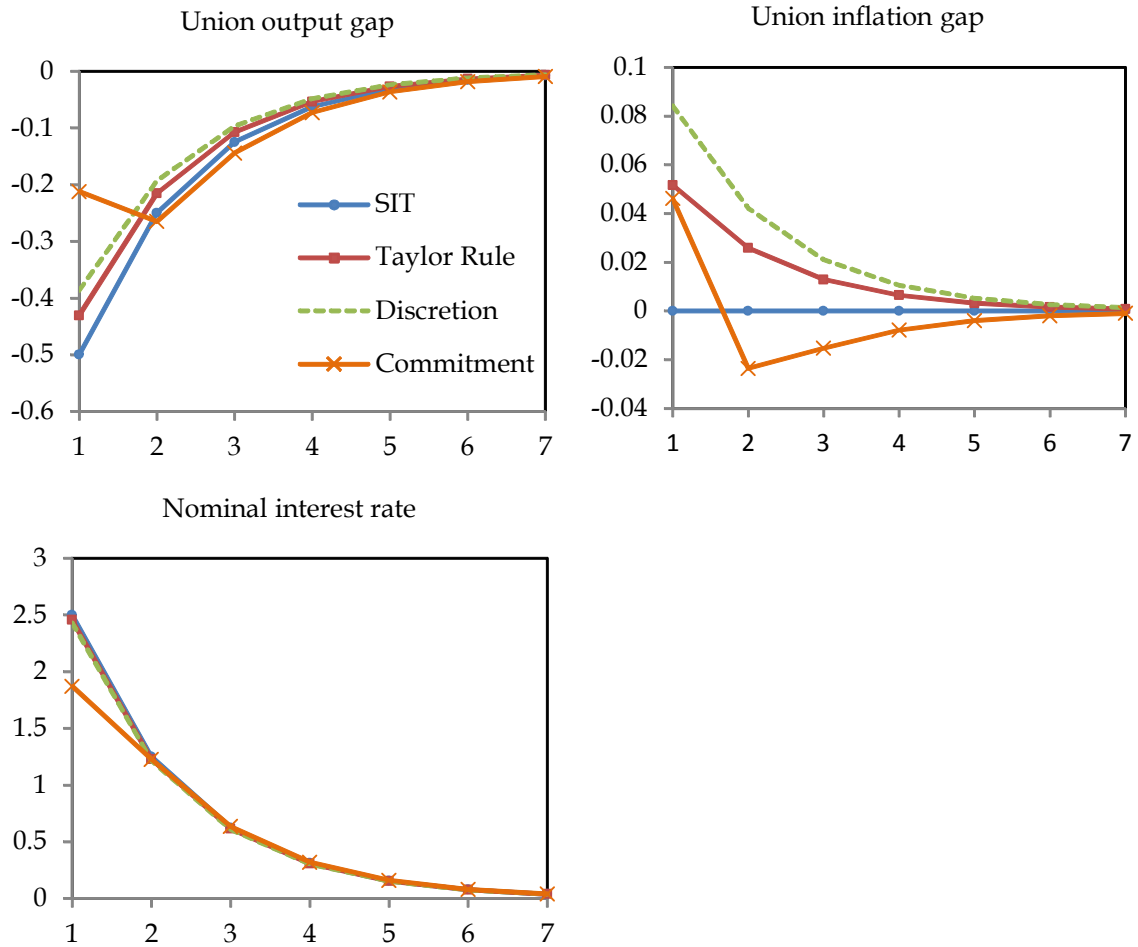


Figure 6: Aggregate demand shock under different policy regimes and identical cost channels



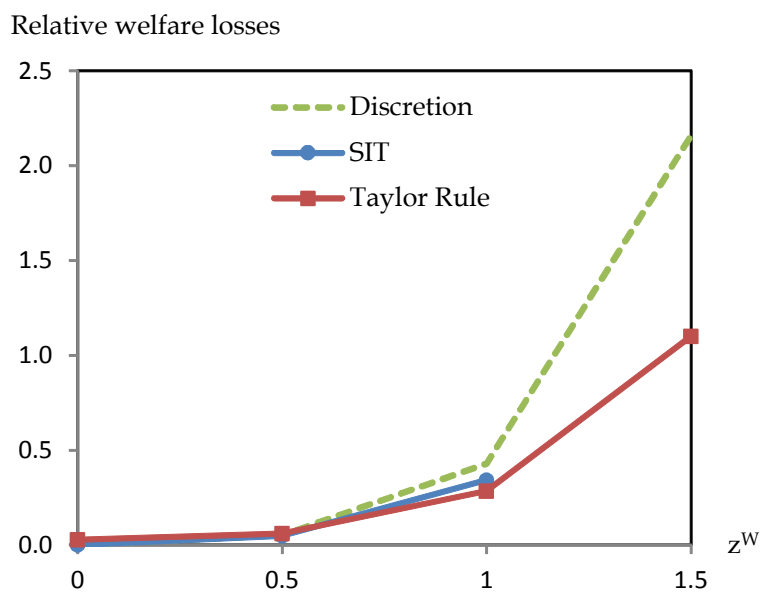


Figure 7: Relative welfare losses arising from an aggregate demand shock under different policy regimes and aggregate cost channel values

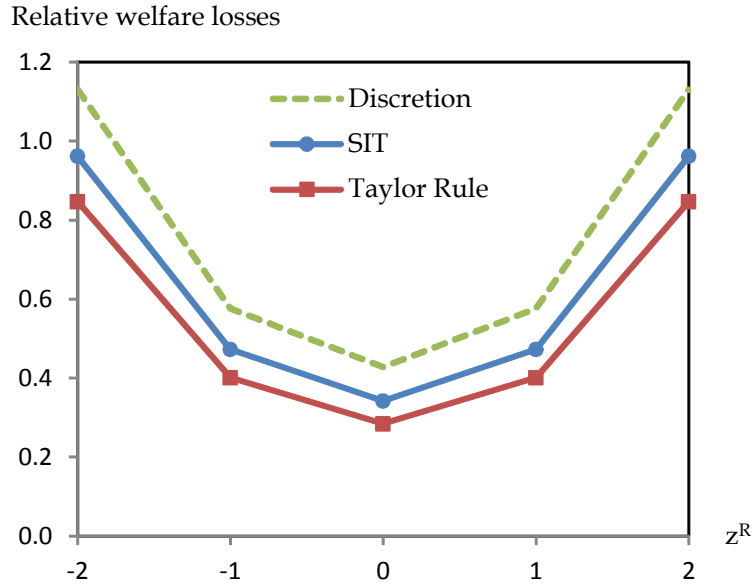


Figure 8: Relative welfare losses arising from an aggregate demand shock under different policy regimes and cost channel differentials

such as the SIT regime. As a consequence, the Taylor rule induces the smallest welfare costs compared to the full commitment solution. SIT generates higher costs than the Taylor rule but lower costs than discretion.<sup>8</sup>

As already pointed out for the discretion regime (see Section 4.1), the cost channel differential between Home and Foreign matters for welfare too, since such a differential causes inflation differentials and a terms of trade gap. As visualized in Figure 8, the welfare loss is increasing in the size of the cost channel differential. This result holds true for all regimes. We can thus conclude that the welfare gain from commitment is increasing in the heterogeneity of the cost channel. Figure 8 also indicates a clearcut ranking: independent of the size of the cost channel differential, the Taylor rule is superior to SIT, and SIT is superior to discretion.

When analyzing the relative demand shock, it stands out that as long as both countries are symmetrical, there are no welfare gains from commitment (see Figure 9). This is because for each policy regime, the "do-nothing" result holds. This changes

<sup>8</sup>For an aggregate cost channel value of 1.5 the Blanchard-Kahn conditions are not satisfied in the case of SIT. This is due to the circumstance that an increasing cost channel requires a stronger interest rate response which in turn implies an exploding output volatility.

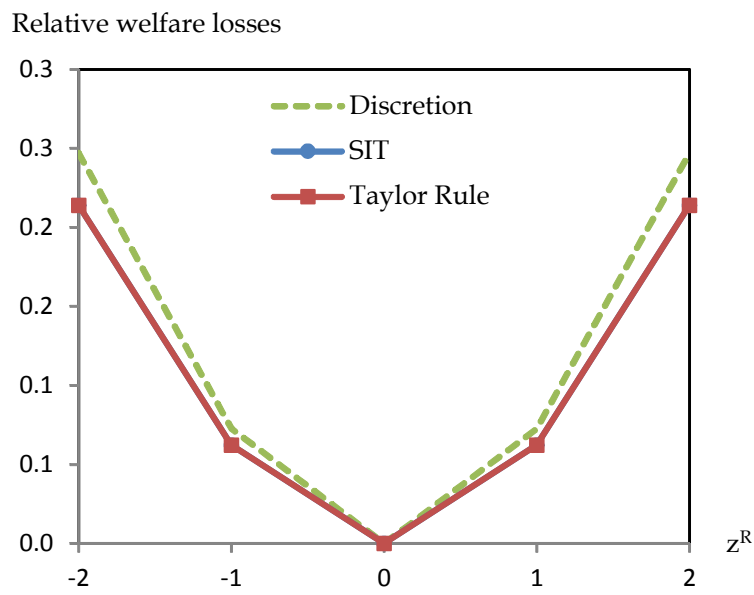


Figure 9: Relative welfare losses for a relative demand shock under different policy regimes and cost channel differentials

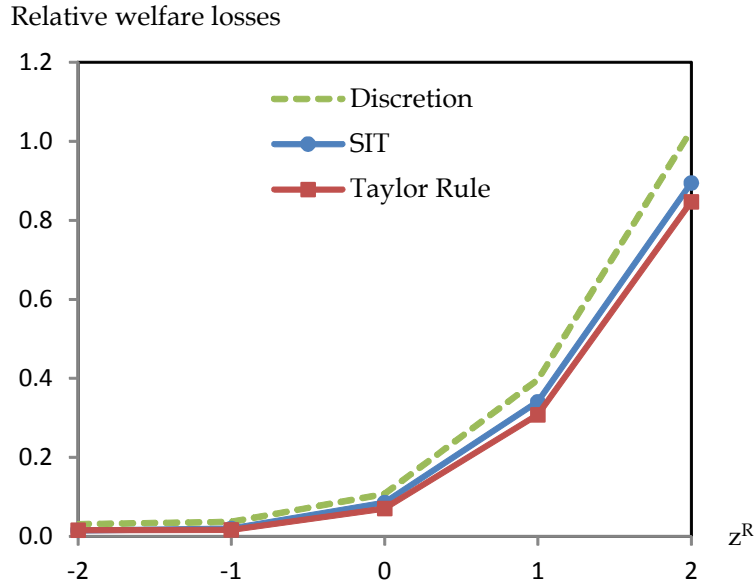


Figure 10: Relative welfare losses arising from a Home demand shock under different policy regimes and cost channel differentials

when the cost channel differs across countries. Both optimal policies now also minimize inflation differentials and thus alter the interest rate. The rules on the other side are designed to target union variables only; they ignore welfare losses associated with deviations of relative target variables. Hence, the "do-nothing" result even holds when the central bank is able to influence the inflation differential. Regarding welfare we obtain the following ranking: independent of the size of the cost channel differential, the Taylor rule is equal-ranking to SIT, and both rules are superior to discretion.

For an idiosyncratic shock, e.g. an increase in Home demand, even the sign of the cost channel differential matters for the welfare effect. The positive demand shock necessitates an increase in the interest rate. For  $z^R = z^H - z^F < 0$ , there is a harmony of objectives. The interest rate hike taken to attain a lower union inflation rate and a lower union output gap also decreases the inflation differential and the terms of trade gap. The larger the difference in the national cost channels, the lower is the welfare loss associated with discretion, SIT and the Taylor rule. In Figure 10, where  $z^R = -2$  maximizes the cost channel differential, all three regimes generate a negligible loss compared to commitment (Figure 10 is based on the assumption that the union-wide cost channel is set constant at a level of unity,  $z^w = nz^H + (1-n)z^F = 1$ , and that  $n = 0.5$ ). For

$z^R > 0$ , however, the harmony of objectives turns into a conflict of objectives. Now the interest rate rate hike leads to an increase in the inflation differential and the terms of trade gap. For all three regimes we observe a positive relationship between the welfare gains from commitment and the cost channel differential. The ranking of the regimes is robust: the Taylor rule is superior to SIT, and SIT is superior to discretion. We summarize these results in

**Proposition 5** *a) For an aggregate demand shock, the welfare gain of a switch from discretion, SIT or the Taylor rule to commitment is increasing in both the size and the heterogeneity of the cost channel. Regarding the ranking in terms of welfare we get the following results: for the most plausible values of  $z$  commitment outperforms the Taylor rule, the Taylor rule outperforms strict inflation targeting, and strict inflation targeting outperforms discretion. Only for very small  $z$ -values, the Taylor rule performs worst. b) For an idiosyncratic shock, the Taylor rule outperforms SIT, and SIT outperforms discretion. c) For a relative demand shock, the Taylor rule is equal-ranking to SIT, and both rules are superior to discretion.*

## 6 Conclusions

This paper investigates the conduct of optimal monetary policy in the presence of country-specific cost channels of monetary transmission. The framework is a two-country New Keynesian model, where these countries constitute a currency union with a single central bank. It is shown how the optimal response to aggregate, asymmetric and idiosyncratic shocks depends on the strength of the cost channel. The cost channel makes monetary policy less effective in combating inflation, but it is shown that the optimal response to the decline in effectiveness is a stronger use of the instrument. On the other hand, the larger the cost channel differential, the less aggressive will the optimal monetary policy be.

Finally, we compare the welfare losses associated with the different kind of demand shocks under discretion, commitment and two simple rules (strict inflation targeting SIT and Taylor rule). In the presence of a cost channel, a commitment technology gains importance as it can be regarded as a second instrument to combat deviations of the target variables from their natural level. For almost all parameter constellations and shocks, we get the following ranking in terms of welfare: commitment outperforms the Taylor rule, the Taylor rule outperforms SIT, and SIT outperforms discretion. The welfare gain of a switch from discretion, SIT or the Taylor rule to commitment is increasing in both the size and the heterogeneity of the cost channel.

# Appendix

## Appendix A: Aggregate Demand

The allocation of resources encompasses three choices: the choice between consumption today and consumption tomorrow, the choice between the baskets of Home and Foreign goods, and the choice between brands. The solution of the intertemporal utility maximization problem is given by the standard Euler equation

$$c_t^w = E_t c_{t+1}^w - \sigma^{-1}(R_t - E_t \pi_{t+1}^w). \quad (\text{A.1})$$

Here  $c_t^w$  is aggregate consumption in the union, and  $R_t$  is the nominal interest rate. In a next step, households split consumption expenditure into purchases of Home and Foreign goods. Aggregate demand for Home and Foreign goods,  $c_t^H$  and  $c_t^F$ , respectively, can be expressed as

$$c_t^H = (1 - n)q_t + c_t^w ; \quad c_t^F = -nq_t + c_t^w. \quad (\text{A.2})$$

The demand for Home (Foreign) goods is increasing in aggregate demand and increasing (decreasing) in the terms of trade  $q_t$ . The goods market equilibrium in Home and Foreign requires  $c_t^H = y_t^H$  and  $c_t^F = y_t^F$ , where  $y_t^H$  and  $y_t^F$  are real output in Home and Foreign, respectively. At the union level, we have  $c_t^w = y_t^w$  with  $y_t^w$  as aggregate (union) output. With this at hand, we derive Home output as  $y_t^H = (1 - n)q_t + E_t y_{t+1}^w - \sigma^{-1}(R_t - E_t \pi_{t+1}^w)$ . Foreign output is given by  $y_t^F = -nq_t + E_t y_{t+1}^w - \sigma^{-1}(R_t - E_t \pi_{t+1}^w)$ . By rewriting these equations in terms of log deviations from the steady state, we obtain equations (4) and (5) in the main text.

## Appendix B: Derivation of the Home Phillips curve

By inserting the wage (13) into (12), observing technology (11) and the definition of the consumer price index, we yield for Home marginal costs:  $mc_t^H = (1 - n)q_t + \sigma c_t(H) + \eta y_t^H + z^H R_t$ . Assuming that households have access to a complete set of state contingent securities (complete asset markets), the marginal utility of consumption and thus (per-capita) consumption itself is equalized across countries,  $c_t(H) = c_t(F) = c_t^w$ .<sup>9</sup> Subsequently we use  $c_t^w = y_t^w = y_t^H - (1 - n)q_t$  to arrive at  $mc_t^H = (1 - n)(1 - \sigma)q_t + (\sigma + \eta)y_t^H + z^H R_t$ . Subtracting the steady-state real marginal costs from  $mc_t^H$  yields the log deviation of real marginal costs from steady state as  $\widehat{mc}_t^H = (1 - n)(1 - \sigma)q_t +$

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<sup>9</sup>If asset markets are incomplete and/or purchasing power parity does not hold, a risk sharing condition is needed to ensure an optimal risk allocation (see de Paoli, 2009).

$(\sigma + \eta)\widehat{y}_t^H + z^H\widehat{R}_t$ . Inserting this equation into (9) leads to the Home Phillips curve (14).

## Appendix C: Union's Welfare Loss

The central bank's loss function is given by

$$\mathcal{L}_t = U(C_t) - [nV(L_t^H) + (1 - n)V(L_t^F)] \quad (\text{C.1})$$

where we implicitly assume perfect risk-sharing. Subtracting the corresponding steady-state values, this can be rewritten as

$$\mathcal{L}_t - \bar{\mathcal{L}} = U(C_t) - U(\bar{C}) - [n(V(L_t^H) - V(\bar{L}^H)) + (1 - n)(V(L_t^F) - V(\bar{L}^F))] \quad (\text{C.2})$$

A second-order approximation of the consumption part in the utility function (1),  $U(C_t)$  around its steady-state value  $\bar{C}$  yields

$$U(C_t) - U(\bar{C}) = U_C\bar{C} \left[ \widehat{c}_t + \frac{1 - \sigma}{2}\widehat{c}_t^2 \right] + o(\|\xi\|^3) \quad (\text{C.3})$$

Taking a second-order expansion of the labor supply term, we get

$$V(L_t^H) - V(\bar{L}^H) = V_L\bar{L}^H \left[ \widehat{l}_t^H + \frac{1 + \eta}{2}(\widehat{l}_t^H)^2 \right] + o(\|\xi\|^3) \quad (\text{C.4})$$

for Home and

$$V(L_t^F) - V(\bar{L}^F) = V_L\bar{L}^F \left[ \widehat{l}_t^F + \frac{1 + \eta}{2}(\widehat{l}_t^F)^2 \right] + o(\|\xi\|^3) \quad (\text{C.5})$$

for Foreign.

Now, we want to relate labor supply to the output gap. Combining the production function with the total demand for  $h$  yields

$$L_t^H = Q_t^{1-n} Y_t^W \int_0^n \left( \frac{p_t(h)}{P_{H,t}} \right)^{-\epsilon} dh. \quad (\text{C.6})$$

It can be shown (see Galí and Monacelli 2008) that

$$\begin{aligned}
\widehat{l}_t^H &= (1-n)q_t + \widehat{y}_t^w + \ln \int_0^n \left( \frac{p_t(h)}{P_{H,t}} \right)^{-\epsilon} dh \\
&= \widehat{y}_t^w + (1-n)q_t + \frac{\epsilon}{2} \text{var}_h p_t(h).
\end{aligned} \tag{C.7}$$

Similarly, the Foreign labor supply gap can be stated as

$$\widehat{l}_t^F = \widehat{y}_t^w - nq_t + \frac{\epsilon}{2} \text{var}_f p_t(f). \tag{C.8}$$

Now, we insert (C.3), (C.4), (C.5), (C.7) and (C.8) in (C.2) and write the loss function as

$$\begin{aligned}
\mathcal{L}_t - \bar{\mathcal{L}} &= U_C \bar{C} \left[ \widehat{c}_t + \frac{1-\sigma}{2} \widehat{c}_t^2 \right] - nV_L \bar{L}^H \left[ \widehat{l}_t^H + \frac{1+\eta}{2} (\widehat{l}_t^H)^2 \right] \\
&\quad - (1-n)V_L \bar{L}^F \left[ \widehat{l}_t^F + \frac{1+\eta}{2} (\widehat{l}_t^F)^2 \right] + o(\|\xi\|^3) \\
&= U_C \bar{C} \left[ \widehat{c}_t + \frac{1-\sigma}{2} \widehat{c}_t^2 \right] \\
&\quad - nV_L \bar{L}^H \left[ \widehat{y}_t^w + (1-n)q_t + \frac{\epsilon}{2} \text{var}_h p_t(h) + \frac{1+\eta}{2} (\widehat{y}_t^w + (1-n)q_t)^2 \right] \\
&\quad - (1-n)V_L \bar{L}^F \left[ \widehat{y}_t^w - nq_t + \frac{\epsilon}{2} \text{var}_f p_t(f) + \frac{1+\eta}{2} (\widehat{y}_t^w - nq_t)^2 \right] + o(\|\xi\|^3).
\end{aligned} \tag{C.9}$$

From the household's labor supply relation, we have

$$\frac{V_L}{U_C} = (1-\tau^i) \frac{W_t}{P_{i,t}}, \tag{C.10}$$

where  $\tau^i$  is a (constant) steady-state employment subsidy. Optimal price setting and the definition of marginal costs imply

$$\frac{V_L}{U_C} = (1-\tau^i) \frac{\epsilon}{\epsilon-1} \frac{1}{R^{z^i}}. \tag{C.11}$$

The distortions caused by monopolistic competition and the presence of a cost chan-



nel are offset by the steady-state subsidy. The degree of these distortions is defined as

$$(1 - \Phi^i) \equiv (1 - \tau^i) \frac{\varepsilon}{\varepsilon - 1} \frac{1}{\bar{R}^{z^i}}. \quad (\text{C.12})$$

Thus

$$V_L \bar{L}^i = (1 - \Phi^i) U_C \bar{C}. \quad (\text{C.13})$$

Now we can rewrite (C.9) as

$$\begin{aligned} \frac{\mathcal{L}_t - \bar{\mathcal{L}}}{U_C \bar{C}} &= \hat{c}_t + \frac{1 - \sigma}{2} \hat{c}_t^2 \\ &\quad - n(1 - \Phi^H) \left[ \hat{y}_t^w + (1 - n)q_t + \frac{\varepsilon}{2} \text{var}_h p_t(h) + \frac{1 + \eta}{2} (\hat{y}_t^w + (1 - n)q_t)^2 \right] \\ &\quad - (1 - n)(1 - \Phi^F) \left[ \hat{y}_t^w - nq_t + \frac{\varepsilon}{2} \text{var}_f p_t(f) + \frac{1 + \eta}{2} (\hat{y}_t^w - nq_t)^2 \right] \\ &\quad + o(\|\xi\|^3). \end{aligned} \quad (\text{C.14})$$

Assuming that  $\Phi^H = \Phi^F = \Phi$  and that terms of higher order than one interacting with  $\Phi$  are set equal to zero we get

$$\begin{aligned} \frac{\mathcal{L}_t - \bar{\mathcal{L}}}{U_C \bar{C}} &= \hat{c}_t + \frac{1 - \sigma}{2} \hat{c}_t^2 - (1 - \Phi) \hat{y}_t^w - n \frac{\varepsilon}{2} \text{var}_h p_t(h) - (1 - n) \frac{\varepsilon}{2} \text{var}_f p_t(f) \\ &\quad - n \frac{1 + \eta}{2} (\hat{y}_t^w + (1 - n)q_t)^2 \\ &\quad - (1 - n) \frac{1 + \eta}{2} (\hat{y}_t^w - nq_t)^2 + o(\|\xi\|^3). \end{aligned} \quad (\text{C.15})$$

Goods market clearing requires  $\hat{c}_t = \hat{y}_t^w$ . Hence

$$\begin{aligned} \frac{\mathcal{L}_t - \bar{\mathcal{L}}}{U_C \bar{C}} &= \Phi \hat{y}_t^w + \frac{1 - \sigma}{2} (\hat{y}_t^w)^2 - n \frac{\varepsilon}{2} \text{var}_h p_t(h) - (1 - n) \frac{\varepsilon}{2} \text{var}_f p_t(f) \\ &\quad - \frac{1 + \eta}{2} ((\hat{y}_t^w)^2 + n(1 - n)q_t^2 + o(\|\xi\|^3)) \\ &= \Phi \hat{y}_t^w - \frac{1}{2} [(\eta + \sigma)(\hat{y}_t^w)^2 + n\varepsilon \text{var}_h p_t(h) + (1 - n)\varepsilon \text{var}_f p_t(f) + n(1 - n)(1 + \eta)q_t^2] \\ &\quad + o(\|\xi\|^3). \end{aligned} \quad (\text{C.16})$$

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

$$\sum_{t=0}^{\infty} \beta^t \text{var}_i p_t(i) = \frac{\theta^i}{(1-\theta^i)(1-\beta\theta^i)} \sum_{t=0}^{\infty} \beta^t (\pi_t^i)^2. \quad (\text{C.17})$$

The union's welfare function is given by

$$W = E_0 \sum_{t=0}^{\infty} \beta^t \frac{\mathcal{L}_t - \bar{\mathcal{L}}}{U_C \bar{C}}. \quad (\text{C.18})$$

Assuming that the subsidy ensures an efficient steady-state,  $\Phi = 0$ , welfare can be written as

$$W = -E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{2} [(\eta + \sigma)(\hat{y}_t^w)^2 + n \varepsilon \text{var}_h p_t(h) + (1-n) \varepsilon \text{var}_f p_t(f) + n(1-n)(1+\eta)q_t^2] \right\} + o(\|\xi\|^3). \quad (\text{C.19})$$

Combining (C.17) and (C.19) yields the expression which corresponds to equation (16) in the main text.

## Appendix D: Optimality conditions

The Lagrangean associated with the optimization problem can be written as:

$$\begin{aligned} \Lambda = & E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{1}{2} (\sigma + \eta) \cdot (\hat{y}_t^w)^2 + \frac{1}{2} \frac{\varepsilon}{\lambda^H} n \cdot (\pi_t^H)^2 \right. \\ & + \frac{1}{2} \frac{\varepsilon}{\lambda^F} (1-n) \cdot (\pi_t^F)^2 + \frac{1}{2} n(1-n)(1+\eta) \cdot (q_t)^2 \\ & - \mu_{1t}^w \left[ \hat{y}_t^w - E_t \hat{y}_{t+1}^w + \sigma^{-1} \left( \hat{R}_t - E_t (n\pi_{t+1}^H + (1-n)\pi_{t+1}^F) \right) - u_t^w \right] \\ & - \mu_{2t}^H \left[ \pi_t^H - \beta E_t \pi_{t+1}^H - \lambda^H (1-n)(1-\sigma)q_t - \lambda^H (\sigma + \eta) (\hat{y}_t^w + (1-n)(q_t + u_t^R)) \right. \\ & \quad \left. - \lambda^H z^H \hat{R}_t - e_t^H \right] \\ & - \mu_{3t}^F \left[ \pi_t^F - \beta E_t \pi_{t+1}^F + \lambda^F n(1-\sigma)q_t - \lambda^F (\sigma + \eta) (\hat{y}_t^w - n(q_t + u_t^R)) - \lambda^F z^F \hat{R}_t - e_t^F \right] \\ & \left. - \mu_{4t} \left[ q_t - q_{t-1} + \pi_t^H - \pi_t^F \right] \right] \quad (\text{D.1}) \end{aligned}$$

where  $\mu_{1t}^w$ ,  $\mu_{2t}^H$ ,  $\mu_{3t}^F$  and  $\mu_{4t}$  are the Lagrange multipliers.

The first order conditions for the optimal discretionary policy read:

$$\widehat{y}_t^w : (\sigma + \eta)\widehat{y}_t^w - \mu_{1t}^w + \lambda^H(\sigma + \eta)\mu_{2t}^H + \lambda^F(\sigma + \eta)\mu_{3t}^F = 0 \quad (\text{D.2})$$

$$\pi_t^H : \frac{\varepsilon n}{\lambda^H}\pi_t^H - \mu_{2t}^H - \mu_{4t} = 0 \quad (\text{D.3})$$

$$\pi_t^F : \frac{\varepsilon(1-n)}{\lambda^F}\pi_t^F - \mu_{3t}^F + \mu_{4t} = 0 \quad (\text{D.4})$$

$$q_t : n(1-n)(1+\eta)q_t + \lambda^H(1-n)(1+\eta)\mu_{2t}^H - \lambda^F n(1+\eta)\mu_{3t}^F - \mu_{4t} + \beta E_t \mu_{4t+1} = 0 \quad (\text{D.5})$$

$$\widehat{R}_t : -\sigma^{-1}\mu_{1t}^w + \lambda^H z^H \mu_{2t}^H + \lambda^F z^F \mu_{3t}^F = 0 \quad (\text{D.6})$$

The optimality conditions for the optimal policy under commitment are:

$$\widehat{y}_t^w : (\sigma + \eta)\widehat{y}_t^w - \mu_{1t}^w + \frac{1}{\beta}\mu_{1t-1}^w + \lambda^H(\sigma + \eta)\mu_{2t}^H + \lambda^F(\sigma + \eta)\mu_{3t}^F = 0 \quad (\text{D.7})$$

$$\pi_t^H : \frac{\varepsilon n}{\lambda^H}\pi_t^H + \frac{1}{\beta}\frac{n}{\sigma}\mu_{1t-1}^w - \mu_{2t}^H + \mu_{2t-1}^H - \mu_{4t} = 0 \quad (\text{D.8})$$

$$\pi_t^F : \frac{\varepsilon(1-n)}{\lambda^F}\pi_t^F + \frac{1}{\beta}\frac{1-n}{\sigma}\mu_{1t-1}^w - \mu_{3t}^F + \mu_{3t-1}^F + \mu_{4t} = 0 \quad (\text{D.9})$$

$$q_t : n(1-n)(1+\eta)q_t + \lambda^H(1-n)(1+\eta)\mu_{2t}^H - \lambda^F n(1+\eta)\mu_{3t}^F - \mu_{4t} + \beta E_t \mu_{4t+1} = 0 \quad (\text{D.10})$$

$$\widehat{R}_t : -\sigma^{-1}\mu_{1t}^w + \lambda^H z^H \mu_{2t}^H + \lambda^F z^F \mu_{3t}^F = 0 \quad (\text{D.11})$$

The first order conditions combined with the constraints can be used to solve for the optimal policies. In order to derive the optimal commitment policy, the initial Lagrange multipliers are assumed to be zero:  $\mu_{1t-1}^w = \mu_{2t-1}^H = \mu_{3t-1}^F = 0$  for  $t = 0$ . The economy starts in the deterministic steady state.

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