Monetary and fiscal policy interactions in a micro-founded model of a monetary union

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Abstract

This paper analyzes in detail the mechanisms behind fiscal stabilization policy and the role of policy commitment in a micro-founded New-Keynesian model of a two-country monetary union, which is hit by supply shocks. We also explore the determinants of the gains from fiscal stabilization. While monetary policy with identical union members is concerned with stabilizing the union-wide economy, fiscal policy aims at stabilizing inflation differences and the terms of trade. Besides exploring optimal policies, we also consider monetary and fiscal rules. We study these rules both under coordination and non-coordination by the fiscal authorities.
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1. Introduction

An extensive amount of work has now been done on monetary policy in micro-founded models with sticky prices.[2] However, this literature has so far paid little attention to the role of fiscal policy in multi-country versions of these models and how monetary and fiscal policy interact in the stabilization of shocks. Early work on standard micro-founded models for fiscal policy in multi-country models includes, for example, Turnovsky (1988) and Devereux (1991). Among recent papers on monetary policy with micro-foundations and sticky prices that also include fiscal policy are Schmitt-Grohé and Uribe (2004) for a closed economy and Corsetti and Pesenti (2001a) in the context of a two-country model. In the context of European Monetary Union (EMU), the issue of the interaction between monetary and fiscal policy is of particular importance for a variety of reasons. Key questions are whether fiscal policy should be more active in stabilizing country-specific shocks now that monetary policy can no longer address these shocks and whether fiscal constraints (such as the Stability and Growth Pact) might hamper stabilization.

In this paper, we try to address the abovementioned gap in the literature by combining monetary and fiscal policy in a micro-founded, two-country sticky-price model of a monetary union.[3] The main objective of our analysis is to examine how government spending serves as a stabilization tool in the model as well as to identify the determinants of the gains from such fiscal stabilization. We also pay particular attention to the role of policy commitment. Our framework extends a recent model developed by Benigno (2004) by introducing national fiscal authorities pursuing active stabilization policies. The supply-side features forward-looking Phillips curves, with inflation not only driven by the terms of trade and consumption, as in Benigno (2004), but also by public spending. Given that in Europe there is an increasing discussion about the need to coordinate fiscal policies, we will primarily focus on the case in which policies are set in a coordinated fashion with the aim of maximizing welfare at the union level. Moreover, by mainly focusing on coordination, one may obtain valuable insights that can be of use for studying more complicated settings, such as non-coordinated policies. We shall also briefly address non-coordinated fiscal policies. All the outcomes are evaluated using a second-order approximation of a utilitarian social welfare function at the level of the union.

As a benchmark, we analyze the optimal monetary and fiscal policies when the authorities can commit and countries are characterized by an equal degree of price rigidity and are subject to imperfectly correlated supply shocks. The optimal monetary policy ensures that both union-wide inflation and consumption are at their natural (efficient) levels. While optimal monetary policy is exclusively concerned with stabilizing the union-wide economy, optimal fiscal policy focuses entirely on the stabilization of relative inflation and the terms of trade. We study in detail the determinants of the welfare gains

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[2] See, e.g., Woodford (2003), the volume edited by Taylor (1999) or the Special Issue of the *Journal of Monetary Economics* 43(3) (1999).

[3] Hence, we implicitly assume that monetary policy is coordinated because there is a common central bank that sets monetary policy for the entire union. Examples of papers that consider the desirability of monetary policy coordination in the context of recent open-economy models are Obstfeld and Rogoff (2002), Corsetti and Pesenti (2001a,b), Clarida et al. (2002), Canzoneri et al. (2002), Sutherland (2002) and Benigno and Benigno (2003).

from fiscal stabilization. In particular, we find that these gains are higher when products are closer substitutes, because relative price movements between countries lead to larger distortions in production effort and thus stabilizing them becomes more important. Similarly, a low elasticity of the labor supply calls for a more active fiscal policy, because the fluctuations in production effort associated with relative price movements are more costly. A smaller cross-country correlation of supply shocks does not enhance the relative importance of fiscal stabilization, in contrast to what one may immediately think. Because macroeconomic fluctuations only depend on the difference between the shocks of the two countries, welfare losses are always proportional to the variance of this relative shock. Hence, the ratio of the losses with and without fiscal stabilization is independent of this variance and thus of the correlation of the shocks.

The commitment case is characterized by inertial targeting rules for both monetary and fiscal policy. By committing to a prolonged monetary contraction, the policy authority can dampen expectations of future union-average inflation and thus stabilize current union inflation. Similarly, by committing to a relative (to the other country) fiscal contraction, it can dampen expectations of future relative inflation, thereby stabilizing current relative inflation and the terms of trade. With symmetric rigidities, monetary policy is not subject to a time-consistency problem, because there is no stabilization trade-off of fiscal policy; however, once expectations have been formed, the authority in the case would want to deviate from its commitment. In particular, a negative Home supply shock raises Home's relative inflation rate and calls for a relative fiscal contraction. The subsequent fall in relative inflation gives the authority an incentive to abandon its commitment to a prolonged contraction. Our numerical results suggest that a failure to commit fiscal policy can lead to non-trivial welfare losses. With asymmetric rigidities, monetary policy becomes relatively more concerned with stabilizing inflation in the more rigid country (this is reminiscent of the findings of Benigno, 2004 for the case of a strict weighted-average inflation-targeting policy). A stabilization trade-off, and thereby a commitment problem, now also arises for monetary policy.

As the final step in our analysis, we explore simple policy instrument rules. Their advantage is that they are relatively simple to understand and transparent. As a result, it may be easier to commit to them than to the optimal policy.[4] We start by exploring rules that are set in a coordinated fashion. A first set of rules mimics the optimal monetary policy as closely as possible and has public spending respond to the terms of trade, thereby stabilizing inflation differentials. In particular, a terms-of-trade deterioration leads to a contractionary fiscal policy in order to reduce the enhanced demand and thus upward pressure on inflation. This combination of policy rules improves on the optimal policy under discretion. A standard monetary policy Taylor rule, combined with rules in which public spending reacts to the output gap, also performs well in general.

We also consider the same sets of rules when the national governments do not coordinate in setting their fiscal rules and care only about national inflation, spending and

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[4] Note our qualifier "may". Svensson (2003), for example, argues strongly against such instrument rules and concludes that optimizing behavior implying targeting rules (essentially the first-order conditions resulting from optimization) is more transparent.

output. A delegation arrangement that assigns to the governments appropriate loss functions involving these national variables induces them to choose, as a Nash equilibrium, the abovementioned optimal combinations of rules that minimize the union-level social loss. When the relative weight that the non-coordinating governments attach to stabilizing output versus inflation increases, they have an incentive to choose more active fiscal rules. Optimal delegation then requires the governments to attach a larger relative weight to stabilizing spending fluctuations versus inflation. The analysis here also provides an instance of possible counterproductive (fiscal) coordination when policies are based on (national) loss functions that differ from the proper (union-level) social loss function.

The remainder of this paper is structured as follows. Section 2 presents the model. Section 3 derives the steady state, the flexible-price equilibrium and the sticky-price equilibrium conditional on the policy instruments. Section 4 discusses the setup of the policy analysis, while Section 5 presents and discusses the (numerical) results under the optimal policies and our rules. Finally, Section 6 concludes the main body of the paper. Appendices A and B contain some of the derivations, while the remainder of the derivations is contained in an additional appendix, which is available upon request from the authors or on http://www.eeon.ku.dk/personal/henrikj/.

2. The model

We extend the basic model developed by Benigno (2004) by introducing public spending as an instrument for stabilization and by introducing demand-side preference shocks. The presentation of the model and the notation closely parallels that of Benigno (2004).

2.1. Utilities and private consumption

There are two countries labeled H(ome) and F(oreign). These countries form a monetary union. The population of the union is a continuum of agents on the interval [0,1]. The population on the segment [0,n] belongs to country H, while the population on [n,l] belongs to country F. In period t, the utility of the representative household j living in country i is given by

$$U_t^j = E_t \sum_{s=t}^{\infty} \beta^{s-t} \left[U\left(C_s^j, \epsilon_s^i\right) + V\left(G_s^j\right) - v\left(y_s^j, z_s^i\right) \right], \qquad 0<\beta<1, \tag{1}$$

where C_s^j is consumption, G_s^j is per-capita public spending and y_s^j is the amount of goods that household j produces. The functions U and V are strictly increasing and strictly concave, and v is increasing and strictly convex in y_s^j. Thus, households receive utility from consumption and public spending, but experience disutility from their work effort. Further, ϵ_s^i is a shock, which affects the demand for consumption goods, and z_s^i is a shock affecting the disutility of work, which will throughout be interpreted as a supply (e.g.,

technology) shock.[5] We assume that these shocks are perfectly observable by all the agents (households and policymakers—introduced below). For convenience, we also assume that the variances of z_s^H and z_s^F are equal.

The consumption index C^j is defined as

$$C^j \equiv \frac{\left(C_H^j\right)^n \left(C_F^j\right)^{1-n}}{n^n (1-n)^{1-n}}, \tag{2}$$

where C_H^j and C_F^j are the Dixit and Stiglitz (1977) indices of the sets of imperfectly substitutable goods produced in countries H and F, respectively:

$$C_H^j \equiv \left[\left(\frac{1}{n}\right)^{1/\sigma} \int_0^n c^j(h)^{\frac{\sigma-1}{\sigma}} dh\right]^{\frac{\sigma}{\sigma-1}}, \quad C_F^j \equiv \left[\left(\frac{1}{1-n}\right)^{1/\sigma} \int_n^1 c^j(f)^{\frac{\sigma-1}{\sigma}} df\right]^{\frac{\sigma}{\sigma-1}}, \tag{3}$$

where $c^j(h)$ and $c^j(f)$ are j's consumption of Home- and Foreign-produced goods h and f, respectively, and $\sigma > 1$ is the elasticity of substitution across goods produced within a country.

The price index of country i is given by $P^i = (P_H^i)^n (P_F^i)^{1-n}$ where

$$P_H^i = \left[\left(\frac{1}{n}\right) \int_0^n p^i(h)^{1-\sigma} dh\right]^{\frac{1}{1-\sigma}}, \quad P_F^i = \left[\left(\frac{1}{1-n}\right) \int_n^1 p^i(f)^{1-\sigma} df\right]^{\frac{1}{1-\sigma}},$$

and where $p^i(h)$ and $p^i(f)$ are the prices in country i of the individual goods h and f produced in Home and Foreign, respectively. Because there are no trade barriers and the two countries share a common currency, the price of each good is the same in both countries. Combined with the fact that preferences are identical in the entire union, purchasing power parity holds. In the sequel, we will therefore drop the country superscript for prices. The terms of trade, T, is defined as the ratio of the price of a bundle of goods produced in country F and a bundle of goods produced in country H. That is, $T \equiv P_F / P_H$.

The allocation of resources over the various consumption goods takes place in three steps. The intertemporal trade-off, analyzed below, determines C^j. Given C^j, the household selects C_H^j and C_F^j so as to minimize total expenditure PC^j under restriction (2). Then, given C_H^j and C_F^j, the household optimally allocates spending over the individual goods by minimizing $P_H C_H^j$ and $P_F C_F^j$ under restriction (3). The implied demands for individual good h, produced in country H and individual good f, produced in country F, are, respectively,

$$c^j(h) = \left(\frac{p(h)}{P_H}\right)^{-\sigma} T^{1-n} C^j, \quad c^j(f) = \left(\frac{p(f)}{P_F}\right)^{-\sigma} T^{-n} C^j. \tag{4}$$

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[5] We could have introduced real money balances as an argument in (1). However, if it enters additively (as empirical evidence suggests—see Ireland, 2004 for the case of the U.S. and Andrés et al., 2001 for the case of EMU), money market equilibrium plays no role for the dynamics when the nominal interest rate is the monetary policy instrument. Therefore, we ignore money in the remainder.

We assume that public spending is financed either by debt issuance or lump-sum taxation, so that Ricardian equivalence holds. Public spending in countries H and F is given by the following indices, respectively:

$$G^{\mathrm{H}} = \left[\frac{1}{n} \int_0^n g(h)^{\frac{\sigma-1}{\sigma}} \mathrm{d}h\right]^{\frac{\sigma}{\sigma-1}}, \quad G^{\mathrm{F}} = \left[\frac{1}{1-n} \int_n^1 g(f)^{\frac{\sigma-1}{\sigma}} \mathrm{d}f\right]^{\frac{\sigma}{\sigma-1}},$$
(5)

where $g(h)$ and $g(f)$ are public spending on individual goods h and f produced in Home and Foreign, respectively. Hence, we assume that the national governments only purchase goods produced in their own country. While this is an extreme situation, fiscal policy remains effective at stabilizing the individual economies in the face of asymmetric disturbances as long as the public spending indices remain biased towards nationally produced goods. As will become evident below, government spending will be expansionary when prices are sticky.[6] In this respect, we should emphasize that government spending in this model is associated with government purchases and not with government outlays on public wages. The latter are often thought to be contractionary.[7]

Minimization of $P_{\mathrm{H}} G^{\mathrm{H}}$ and $P_{\mathrm{F}} G^{\mathrm{F}}$ under restriction (5) yields the governments' demands for the individual goods h and f:

$$g(h) = \left(\frac{p(h)}{P_{\mathrm{H}}}\right)^{-\sigma} G^{\mathrm{H}}, \quad g(f) = \left(\frac{p(f)}{P_{\mathrm{F}}}\right)^{-\sigma} G^{\mathrm{F}}.$$
(6)

Hence, combining (4) and (6), the total demands for the goods h and f are

$$y(h) = \left(\frac{p(h)}{P_{\mathrm{H}}}\right)^{-\sigma} \left[T^{1-n} C^{\mathrm{W}} + G^{\mathrm{H}}\right], \quad y(f) = \left(\frac{p(f)}{P_{\mathrm{F}}}\right)^{-\sigma} \left[T^{-n} C^{\mathrm{W}} + G^{\mathrm{F}}\right],$$
(7)

where $C^{\mathrm{W}} = \int_0^1 C^j \mathrm{d}j$ is aggregate consumption in the union.

Following Benigno and Benigno (2003), we assume that financial markets are complete both at the domestic and at the international level. Furthermore, each individual's initial holding of any type of asset is zero. These assumptions imply perfect consumption risk-sharing within each country and equalization of the marginal utilities of consumption between countries:

$$U_{\mathrm{C}}\left(C_t^{\mathrm{H}}, \epsilon_t^{\mathrm{H}}\right) = U_{\mathrm{C}}\left(C_t^{\mathrm{F}}, \epsilon_t^{\mathrm{F}}\right),$$
(8)

where a partial derivative is denoted with a subscript. Further, from the Euler equations, we derive

$$U_{\mathrm{C}}\left(C_t^i, \epsilon_t^i\right) = (1 + R_t)\beta E_t\left[U_{\mathrm{C}}\left(C_{t+1}^i, \epsilon_{t+1}^i\right)(P_t/P_{t+1})\right], \quad i = \mathrm{H}, \ \mathrm{F},$$
(9)

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[6] If we were to abolish the assumption that the government can levy lump-sum taxes, changes in the amount of public spending would lead to fluctuations in distortionary taxes, thereby affecting the supply-side of the economy and potentially diminishing the stimulating effect of an increase in government spending. However, this is beyond the scope of the present paper.

[7] See Wynne (1996) and Finn (1998) for theoretical examples, and Alesina et al. (1999) for empirical evidence for the OECD countries. However, Fatás and Mihov (2001b) cannot unambiguously confirm this finding for the U.S.

where R_t is the nominal interest rate on an internationally traded nominal bond. This is taken to be the union central bank's policy instrument. Finally, using the appropriate aggregators, aggregate demand in both countries is found as

$$Y^{\text{H}} = T^{1-n}C^{\text{W}} + G^{\text{H}}, \quad Y^{\text{F}} = T^{-n}C^{\text{W}} + G^{\text{F}}. \tag{10}$$

2.2. Firms

Individual j is the monopolist provider of good j. We use Calvo's (1983) approach to modelling price stickiness. In each period, there is a fixed probability $(1 - \alpha^i)$ that producer j who resides in i can adjust his prices. This producer takes account of the fact that a change in the price of his product affects the demand for it. However, because he is infinitesimally small, he neglects any effects of his actions on aggregate variables. Hence, if individual j has the "chance" to reset his price in period t, he chooses his price, denoted $p_t(j)$, to maximize

$$E_t \sum_{k=0}^{\infty} \left(\alpha^i \beta\right)^k \left[\lambda^i_{t+k}\left(1 - \tau^i\right)p_t(j)y_{t,t+k}(j) - v\left(y_{t,t+k}(j), z^i_{t+k}\right)\right],$$

where $y_{t,t+k}(j)$ is given by (7), given that $p_t(j)$ applies at $t+k$, $\lambda^i_{t+k} \equiv U_{\text{C}}(C^i_{t+k}, \epsilon^i_{t+k})/P_{t+k}$ is the marginal utility of nominal income and τ^i is a proportional tax rate on nominal income. This yields:

$$p_t(j) = \frac{\sigma}{(\sigma - 1)(1 - \tau^i)} \frac{E_t\left[\displaystyle\sum_{k=0}^{\infty} \left(\alpha^i \beta\right)^k v_y\left(y_{t,t+k}(j), z^i_{t+k}\right)y_{t,t+k}(j)\right]}{E_t\left[\displaystyle\sum_{k=0}^{\infty} \left(\alpha^i \beta\right)^k \lambda^i_{t+k}y_{t,t+k}(j)\right]}, \tag{11}$$

which shows that prices are set as a constant mark up, $\sigma/(\sigma - 1) > 1$, over "marginal costs", which in this set up are increasing in (current and expected future) disutility of work effort and decreasing in the marginal utility of after-tax nominal income. Realizing that, in equilibrium, each producer in a given country and a given period will set the same price when offered the chance to reset its price, it is easy to show that

$$P^{1-\sigma}_{\text{H},t} = \alpha^{\text{H}}P^{1-\sigma}_{\text{H},t-1} + \left(1 - \alpha^{\text{H}}\right)p_t(h)^{1-\sigma}, \tag{12}$$

$$P^{1-\sigma}_{\text{F},t} = \alpha^{\text{F}}P^{1-\sigma}_{\text{F},t-1} + \left(1 - \alpha^{\text{F}}\right)p_t(f)^{1-\sigma}. \tag{13}$$

3. Equilibrium

3.1. Steady-state and efficient flex-price equilibrium

Under flexible prices, (11) is replaced by

$$p_t(j) = \frac{\sigma}{(\sigma - 1)(1 - \tau^i)} \frac{v_y\left(y_{t,t}(j), z^i_t\right)}{\lambda^i_t}. \tag{14}$$

Because each agent in a given country chooses the same price, we have that $p_t(j)=P_{\mathrm{H},t}$ for all j living in Home, so that

$$U_{\mathrm{C}}\big(C_t^{\mathrm{H}},\epsilon_t^{\mathrm{H}}\big) = \frac{\sigma}{(\sigma-1)(1-\tau^{\mathrm{H}})} T_t^{1-n} v_y\big(T_t^{1-n}C_t^{\mathrm{W}} + G_t^{\mathrm{H}}, z_t^{\mathrm{H}}\big), \tag{15}$$

and that $p_t(j)=P_{\mathrm{F},t}$ for all j living in Foreign, so that,

$$U_{\mathrm{C}}\big(C_t^{\mathrm{F}},\epsilon_t^{\mathrm{F}}\big) = \frac{\sigma}{(\sigma-1)(1-\tau^{\mathrm{F}})} T_t^{-n} v_y\big(T_t^{-n}C_t^{\mathrm{W}} + G_t^{\mathrm{F}}, z_t^{\mathrm{F}}\big). \tag{16}$$

In the sequel, we confine ourselves to equilibria in which the tax rates τ^{H} and τ^{F} are set so as to offset the distortion arising from monopolistic competition:

$$\frac{\sigma}{(\sigma-1)(1-\tau^{\mathrm{H}})} = \frac{\sigma}{(\sigma-1)(1-\tau^{\mathrm{F}})} = 1. \tag{17}$$

We assume that the steady state is characterized by zero inflation in both countries, and denote by an upper-bar the steady-state value of a variable. The steady-state values $\bar{C} \equiv \bar{C}^{\mathrm{H}}=\bar{C}^{\mathrm{F}}=\bar{C}^{\mathrm{W}}$ and $\bar{T}$, conditional on $\bar{G}^{\mathrm{H}}$ and $\bar{G}^{\mathrm{F}}$, follow upon setting the shocks to zero in (15) and (16), with (17) imposed. Hence, they are implicitly defined by

$$U_{\mathrm{C}}(\bar{C},0) = \bar{T}^{1-n} v_y\big(\bar{T}^{1-n}\bar{C} + \bar{G}^{\mathrm{H}}, 0\big) = \bar{T}^{-n} v_y\big(\bar{T}^{-n}\bar{C} + \bar{G}^{\mathrm{F}}, 0\big). \tag{18}$$

With a symmetric steady state, it follows that $\bar{T}=1$. We obtain the steady-state values $\bar{G}^{\mathrm{H}}$ and $\bar{G}^{\mathrm{F}}$ by setting the shocks to zero in (21) below:

$$V_{\mathrm{G}}\big(\bar{G}^{\mathrm{H}}\big) = v_y\big(\bar{Y}^{\mathrm{H}},0\big), \quad V_{\mathrm{G}}\big(\bar{G}^{\mathrm{F}}\big) = v_y\big(\bar{Y}^{\mathrm{F}},0\big). \tag{19}$$

Finally, we obtain the steady-state nominal (=real) interest rate from (9) as $1+\bar{R}=1/\beta$.

Before we continue, we introduce some notation. Following Benigno (2004), we denote with a superscript "W" a world aggregate and with a superscript "R" a relative variable. Hence, for a generic variable X, we define $X^{\mathrm{W}} \equiv nX^{\mathrm{H}}+(1-n)X^{\mathrm{F}}$ and $X^{\mathrm{R}} \equiv X^{\mathrm{F}} - X^{\mathrm{H}}$. Further, we denote by a tilde the flex-price log-deviation from the steady state, i.e., $\widetilde{X} \equiv \ln(X/\bar{X})$.

For the flexible-price equilibrium that we consider, we assume that the fiscal authorities coordinate. Hence, they choose G_t^{H} and G_t^{F} to maximize

$$E_t \sum_{s=t}^{\infty} \beta^{s-t} \Big\{ n\big[U\big(C_s^{\mathrm{H}},\epsilon_s^{\mathrm{H}}\big) + V\big(G_s^{\mathrm{H}}\big) - v\big(Y_s^{\mathrm{H}},z_s^{\mathrm{H}}\big)\big] + (1-n)\big[U\big(C_s^{\mathrm{F}},\epsilon_s^{\mathrm{F}}\big) + V\big(G_s^{\mathrm{F}}\big)$$
$$- v\big(Y_s^{\mathrm{F}},z_s^{\mathrm{F}}\big)\Big\}, \tag{20}$$

again subject to (15) and (16), with (17) imposed. Because there are no distortions, this program yields the highest possible weighted welfare level. Therefore, we term the resulting equilibrium the *efficient flex-price equilibrium*. The fiscal choice problem implies the following optimality conditions:

$$V_{\mathrm{G}}\big(G_t^{\mathrm{H}}\big) = v_y\big(Y_t^{\mathrm{H}},z_t^{\mathrm{H}}\big), \quad V_{\mathrm{G}}\big(G_t^{\mathrm{F}}\big) = v_y\big(Y_t^{\mathrm{F}},z_t^{\mathrm{F}}\big). \tag{21}$$

These conditions are derived in Appendix A, where we also derive the complete solution for the efficient flex-price equilibrium:

$$\tilde{C}_t^{W} = \frac{\eta \rho_g}{\rho \left[\rho_g + \eta (1 - \xi_c) \right] + \eta \xi_c \rho_g} S_t^{W} - \frac{\rho \left[\rho_g + \eta (1 - \xi_c) \right]}{\rho \left[\rho_g + \eta (1 - \xi_c) \right] + \eta \xi_c \rho_g} D_t^{W}, \qquad (22)$$

$$\tilde{G}_t^{W} = \frac{\eta \rho}{\rho \left[\rho_g + \eta (1 - \xi_c) \right] + \eta \xi_c \rho_g} \left(S_t^{W} + \xi_c D_t^{W} \right), \qquad (23)$$

$$\tilde{G}_t^{R} = \frac{\eta}{\rho_g (1 + \eta \xi_c) + \eta (1 - \xi_c)} S_t^{R}, \qquad (24)$$

$$\tilde{T}_t = - \frac{\eta \rho_g}{\rho_g (1 + \eta \xi_c) + \eta (1 - \xi_c)} S_t^{R}, \qquad (25)$$

where $\rho \equiv U_{CC}(\bar{C}, \ 0)\bar{C} / U_C(\bar{C}, \ 0)$, $\rho_g \equiv - V_{GG}(\bar{G})\bar{G} / V_G(\bar{G})$, ξ_c is the steady-state consumption share of output and $\eta \equiv v_{yy}(\bar{Y}, \ 0)\bar{Y} / v_y(\bar{Y}, \ 0)$. Here, we have dropped the country superscripts because of symmetry. Furthermore, we have defined S_t^i ($i = $ H, F) such that $v_{yz}(\bar{Y}, \ 0)z_t^i = - \bar{Y} v_{yy}(\bar{Y}, \ 0)S_t^i$ and D_t^i such that $U_{C\epsilon}(\bar{C}, \ 0)\epsilon_t^i = \bar{C} U_{CC}(\bar{C}, \ 0)D_t^i$. Hence, S_t^i and D_t^i are proportional to the supply and demand shocks, respectively. We will refer to the outcomes of the above variables in the efficient flex-price equilibrium as the *(stochastic) natural rates*.

As we will see below, fluctuations in the natural terms of trade will be the source of the policy trade-offs in the model under sticky prices. As (25) shows, the natural terms of trade fluctuate when non-identical supply shocks hit the two economies. For example, a positive supply shock in Home relative to Foreign induces an increase in Home production relative to Foreign production. As trade is balanced, equilibrium is restored when the price of Home goods relative to Foreign goods decreases, i.e., when $\tilde{T}_t$ increases.[8]

Finally, assuming that the inflation rate in the flex-price equilibrium is zero, we derive the natural rate of the nominal interest rate as

$$\tilde{R}_t = \rho E_t \left[\left(\tilde{C}_{t+1}^{W} - \tilde{C}_t^{W} \right) + \left(D_{t+1}^{W} - D_t^{W} \right) \right]. \qquad (26)$$

3.2. Equilibrium dynamics under sticky prices

Under sticky prices, the aggregate demand block is given by (8), (9) and (10), while the aggregate supply block is (11), (12) and (13). Applying the appropriate linearizations (see Appendix B), together with the initial conditions, we end up with the following dynamic

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[8] Note that any demand disturbances, however, have *no* effect on the natural terms of trade. They merely alter the marginal utilities of consumption, but by the same of amount in both countries due to perfect risk sharing. Therefore, production effort changes by the same amount in both countries, leaving any relative price change superfluous.

system, where a hat indicates the log-deviation from the steady state when prices are sticky, i.e., $\hat{X} \equiv \ln(X/\bar{X})$:

$$E_t\big(\hat{C}_{t+1}^W - \tilde{C}_{t+1}^W\big) = \big(\hat{C}_t^W - \tilde{C}_t^W\big) + \rho^{-1}\big[\big(\hat{R}_t - \tilde{R}_t\big) - E_t\big(\pi_{t+1}^W\big)\big], \tag{27}$$

$$\hat{Y}_t^H = \xi_c\big[(1-n)\hat{T}_t + \hat{C}_t^W\big] + (1-\xi_c)\hat{G}_t^F, \tag{28}$$

$$\hat{Y}_t^F = \xi_c\big[-n\hat{T}_t + \hat{C}_t^W\big] + (1-\xi_c)\hat{G}_t^H, \tag{29}$$

$$\pi_t^H = \beta E_t\pi_{t+1}^H + k^H(1+\eta\xi_c)(1-n)\big(\hat{T}_t - \tilde{T}_t\big) + k^H(\rho+\eta\xi_c)\big(\hat{C}_t^W - \tilde{C}_t^W\big)$$
$$+ k^H\eta(1-\xi_c)\big(\hat{G}_t^H - \tilde{G}_t^H\big), \tag{30}$$

$$\pi_t^F = \beta E_t\pi_{t+1}^F - k^F(1+\eta\xi_c)n\big(\hat{T}_t - \tilde{T}_t\big) + k^F(\rho+\eta\xi_c)\big(\hat{C}_t^W - \tilde{C}_t^W\big)$$
$$+ k^F\eta(1-\xi_c)\big(\hat{G}_t^F - \tilde{G}_t^F\big), \tag{31}$$

$$\hat{T}_t - \tilde{T}_t = \hat{T}_{t-1} - \tilde{T}_{t-1} + \pi_t^R - \big(\tilde{T}_t - \tilde{T}_{t-1}\big), \tag{32}$$

where we have made use of the fact that, upon log-linearizing (8) under both flexible and sticky prices, we obtain $\hat{C}_t^W - \tilde{C}_t^W = \hat{C}_t^H - \tilde{C}_t^H = \hat{C}_t^F - \tilde{C}_t^F$, and where,

$$k^H \equiv \frac{(1-\alpha^H\beta)(1-\alpha^H)}{\alpha^H(1+\eta\sigma)}, \quad k^F \equiv \frac{(1-\alpha^F\beta)(1-\alpha^F)}{\alpha^F(1+\eta\sigma)}.$$

In the following, we define the *gap* of a variable as the difference between its sticky-price and its flex-price solution or natural rate.[9]

Eq. (27) is the "consumption Euler equation" expressed in terms of the world consumption gap and the world real interest rate gap. Eqs. (28) and (29) are the log-linearized counterparts of (10).

Eq. (30) is the Home inflation adjustment equation, i.e., the "Phillips curve".[10] Inflation depends positively on expected future inflation as agents setting prices in period t know there is a risk that they cannot change their prices in period $t+1$. Hence, to protect discounted real income, expected future aggregate prices are crucial for price setting. A positive terms-of-trade gap has inflationary implications, because demand is switched towards Home goods, which implies more Home work effort, and because Home agents' marginal utility of nominal income drops. Both effects are met with price increases. Likewise, a positive consumption gap leads to inflation as Home work effort increases and the marginal utility of Home nominal income drops. Finally, a positive government spending gap is inflationary due to the increased demand for Home goods, which leads

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[9] Note that this definition does not apply for the inflation rates. These may very well vary under flexible prices due to relative price adjustments. However, replicating this (efficient) pattern under sticky prices as modelled here would involve welfare costs, as any aggregate variation in prices implies inefficient dispersion of prices across the differentiated goods; cf. below. Hence, stable prices are, all things equal, optimal under sticky prices.

[10] To fix terminology national inflation is understood to be producer inflation.

to higher work effort. This, in turn, translates into higher "marginal costs", and thus higher Home prices. Eq. (31) is the analogous foreign inflation adjustment equation.

Note that, by using (28) and (29), and their efficient flex-price counterparts, we can express these inflation adjustment equations in terms of output and terms-of-trade (and public spending) gaps. As such, they resemble the open-economy versions of what Roberts (1995) labels the "New-Keynesian" Phillips curves.[11] Finally, Eq. (32) is the definition of the terms of trade expressed through the inflation differential. In sum, Eqs. (27)–(32) will for given paths of $\hat{R}_t$, $\hat{G}_t^{\mathrm{H}}$ and $\hat{G}_t^{\mathrm{F}}$, and for an initial $\hat{T}_{t-1}$, provide the solutions for the endogenous variables $\hat{C}_t^{\mathrm{W}}$, $\hat{Y}_t^{\mathrm{H}}$, $\hat{Y}_t^{\mathrm{F}}$, π_t^{H}, π_t^{F} and $\hat{T}_t$.

Before analyzing monetary and fiscal policies in detail, it is helpful to explore under what conditions relevant policy trade-offs arise in this model. To do so, we need to identify the cases in which the efficient flex-price equilibrium can be replicated. The first case, as shown in Additional Appendix B, is when public spending does not feature in Home and Foreign individuals' utility, but the steady states of public spending are fixed at given positive levels. Then, under flexible prices, it is optimal for the authority to move public spending so as to eliminate movements in the marginal disutility of effort across countries. By (15), (16) and (17), together with the assumption of consumption risk sharing, it thus follows that the natural terms of trade does not move. Combining a monetary policy that closes the consumption gap with spending gaps that offset the effect of the terms-of-trade gap on national inflation–see (30) and (31)–national inflation rates are perfectly stabilized. Hence, the terms-of-trade gap is always closed, which, in turn, implies that the public spending gaps are always closed.

Let us return to the case in which public spending enters the utility of all individuals. Another necessary condition for the presence of policy trade-offs is that *both* economies are characterized by price rigidities. This finding is analogous to what Aoki (2002) obtains for monetary policy in a closed-economy, two-sector model. Suppose that $\alpha^{\mathrm{F}}=0$. Hence, by (31),

$$\hat{T}_t - \tilde{T}_t = \frac{\rho + \eta \xi_{\mathrm{c}}}{n(1 + \eta \xi_{\mathrm{c}})} \left(\hat{C}_t^{\mathrm{W}} - \tilde{C}_t^{\mathrm{W}} \right) + \frac{\eta(1 - \xi_{\mathrm{c}})}{n(1 + \eta \xi_{\mathrm{c}})} \left(\hat{G}_t^{\mathrm{F}} - \tilde{G}_t^{\mathrm{F}} \right).$$

If we substitute this expression into (30), the Home Phillips curve only depends on the consumption gap and the two government spending gaps. With monetary policy closing the consumption gap and fiscal policy closing both spending gaps, fluctuations in Home inflation are eliminated. Moreover, the terms-of-trade gap is also eliminated, as the above expression shows. The implied movements in Foreign inflation (arising from the fact that $\hat{T}_t - \tilde{T}_t$, which, generally, is not equal to zero) are costless–see (34) below–because of the absence of price rigidities in Foreign.

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[11] Empirical support for the depicted forward-looking behavior in price setting can be found in Galí and Gertler (1999) and Sbordone (2002) for the U.S. and in Galí et al. (2001) for Euroland. Note that these studies use real marginal costs instead of the output gap as the driving variable. Recently, however, Neiss and Nelson (2002) have provided a theoretical and empirical reconciliation of marginal-cost-based and output-gap-based inflation equations. For empirical results for Euroland, see also Coenen and Wieland (2005).

Finally, to create meaningful policy trade-offs, the supply shocks should not be perfectly correlated. With perfectly correlated supply shocks, by (committing to) setting (for all $s \geq t$) $\hat{R}_s = \tilde{R}_s$, $\hat{G}_s^{\mathrm{H}} = \tilde{G}_s^{\mathrm{H}}$ and $\hat{G}_s^{\mathrm{F}} = \tilde{G}_s^{\mathrm{F}}$, and observing that $\tilde{T}_s = 0$, we obtain an equilibrium in which the consumption gap is closed and the national inflation rates are zero. With the starting condition $\hat{T}_{t-1} = 0$, this equilibrium is validated by observing that $\hat{T}_t = 0$ and, hence, that $\hat{T}_t = \tilde{T}_t$. This result holds irrespective of potential differences in the degree of price stickiness between the countries. Hence, in this special case, policy can be designed so as to replicate the efficient flex-price equilibrium.

Now, suppose that the supply shocks are *imperfectly* correlated. Is it still always possible to attain the efficient flex-price equilibrium through appropriate instrument settings? The answer is no. We formally state this result in the following proposition:

Proposition 1. *Assume that $\hat{T}_{t-1} = 0$ and that $\tilde{T}_t \neq 0$ (because of an asymmetric supply shock). Then, setting fiscal policy such that $\hat{G}_s^H = \tilde{G}_s^H$ and $\hat{G}_s^F = \tilde{G}_s^F$ and monetary policy such that $\hat{C}_s^W = \tilde{C}_s^W$, for all $s \geq t$, and imposing that $\hat{T}_s = \tilde{T}_s$, for all $s \geq t+1$, implies that $\hat{T}_t \neq \tilde{T}_t$.*

Proof. Let $\hat{T}_{t-1} = 0$ and $\tilde{T}_t \neq 0$. Suppose that, with $\hat{G}_s^{\mathrm{H}} = \tilde{G}_s^{\mathrm{H}}$ and $\hat{G}_s^{\mathrm{F}} = \tilde{G}_s^{\mathrm{F}}$ and $\hat{C}_s^{\mathrm{W}} = \tilde{C}_s^{\mathrm{W}}$ for all $s \geq t$, and $\hat{T}_s = \tilde{T}_s$ for all $s \geq t+1$, we would have $\hat{T}_t = \tilde{T}_t$. Then, by (30) and (31), $\pi_t^{\mathrm{H}} = \pi_t^{\mathrm{F}} = 0$. Hence, by (32), $\hat{T}_t = 0 \neq \tilde{T}_t$. Contradiction. $\square$

In other words, it is generally not possible to close all gaps at all times when supply shocks are imperfectly correlated. The reason is that the associated fluctuations in $\tilde{T}_t$ create a policy dilemma. On the one hand, when fiscal policies are aimed at securing efficient public spending levels, the common monetary policy cannot induce the required relative price change without destabilizing national inflation rates. In fact, as we discuss in more detail in Section 5, with equal nominal rigidities (i.e., $\alpha^{\mathrm{H}} = \alpha^{\mathrm{F}}$), the terms of trade are completely insulated from monetary policy (cf. Benigno, 2004). On the other hand, when fiscal policies are aimed at inducing the needed relative price change, public spending is no longer efficient. Hence, only in the special cases discussed earlier, policy trade-offs will vanish. Otherwise, it follows that national fiscal policies in our model cannot provide sufficient flexibility for attaining efficiency, as can independent currencies in Benigno (2004). Nevertheless, as we shall see below, fiscal policy may still be helpful in providing macroeconomic stabilization.

4. Setup of the policy analysis

4.1. The objective function

We shall evaluate all outcomes according to a second-order Taylor approximation of the utilitarian welfare function given by an equally weighted average of the utilities of all individuals in the union. This welfare criterion is derived under the assumption that all policies are coordinated and its minimization thus yields the highest possible welfare. There is an increasing pressure on the countries in the European Union to intensify the coordination of macroeconomic policies. Of course, by now there is a common monetary

policy, while countries monitor the budgetary policies of each other. However, there are frequent pressures for enhanced fiscal coordination. Therefore, the ensuing analysis mainly deals with case of policy coordination. Moreover, with our focus mainly on coordination, one may obtain valuable insights for the analysis of more coordinated settings, such as non-coordinated policies. We shall also briefly consider non-coordinated fiscal policymaking, which is still a more realistic description of the current European situation.

Ignoring an irrelevant proportionality factor as well as terms independent of policy or of third or higher order, we obtain (see Additional Appendix D) the following union-level loss function:

$$L = \sum_{s=t}^{\infty} \beta^{s-t} E_t[L_s], \tag{33}$$

where

$$
\begin{aligned}
L_s = {}& \lambda_C\big(\hat{C}_s^{\mathrm{W}} - \tilde{C}_s^{\mathrm{W}}\big)^2 + \lambda_T\big(\hat{T}_s - \tilde{T}_s\big)^2 + \lambda_G^{\mathrm{H}}\big(\hat{G}_s^{\mathrm{H}} - \tilde{G}_s^{\mathrm{H}}\big)^2 + \lambda_G^{\mathrm{F}}\big(\hat{G}_s^{\mathrm{F}} - \tilde{G}_s^{\mathrm{F}}\big)^2 \\
& + \lambda_\pi^{\mathrm{H}}\big(\pi_s^{\mathrm{H}}\big)^2 + \lambda_\pi^{\mathrm{F}}\big(\pi_s^{\mathrm{F}}\big)^2 + \lambda_{CG}\big(\hat{C}_s^{\mathrm{W}} - \tilde{C}_s^{\mathrm{W}}\big)\big(\hat{G}_s^{\mathrm{W}} - \tilde{G}_s^{\mathrm{W}}\big) \\
& - \lambda_{TG}\big(\hat{T}_s - \tilde{T}_s\big)\big(\hat{G}_s^{\mathrm{R}} - \tilde{G}_s^{\mathrm{R}}\big) \tag{34}
\end{aligned}
$$

and

$$\lambda_C \equiv \xi_{\mathrm{c}}(\rho + \eta\xi_{\mathrm{c}}), \quad \lambda_T \equiv n(1-n)\xi_{\mathrm{c}}(1+\eta\xi_{\mathrm{c}}), \quad \lambda_G^{\mathrm{H}} \equiv n(1-\xi_{\mathrm{c}})\big[\rho_{\mathrm{g}} + \eta(1-\xi_{\mathrm{c}})\big],$$

$$\lambda_G^{\mathrm{F}} \equiv (1-n)(1-\xi_{\mathrm{c}})\big[\rho_{\mathrm{g}} + \eta(1-\xi_{\mathrm{c}})\big], \quad \lambda_\pi^{\mathrm{H}} \equiv n\sigma/k^{\mathrm{H}}, \quad \lambda_\pi^{\mathrm{F}} \equiv (1-n)\sigma/k^{\mathrm{F}},$$

$$\lambda_{CG} \equiv 2\xi_{\mathrm{c}}(1-\xi_{\mathrm{c}})\eta, \quad \lambda_{TG} \equiv 2n(1-n)\xi_{\mathrm{c}}(1-\xi_{\mathrm{c}})\eta.$$

The loss function thus features quadratic terms in the national inflation rates and the terms-of-trade gap. Inflation at the national level induces dispersion in relative prices and thus differences in the demand for goods that are produced with the same technology. The ensuing distortionary losses are higher, the higher is the substitutability of the goods produced within a country, as captured by σ, and the higher is the degree of nominal rigidity. An increase in α^i implies a lower k^i and thus a larger weight on country i inflation. When price rigidities vanish in country i ($\alpha^i \to 0$), $k^i \to \infty$ and the welfare cost of inflation in country i vanishes. The misallocation of goods also applies at the international level for a non-zero terms-of-trade gap. The costs of this distortion increase in the consumption share of GDP as well as η, because fluctuations in the terms-of-trade gap cause variations in output. The welfare costs from fluctuations in the consumption and public spending gaps are rising in ρ, ρ_{g} and η, because individuals are averse towards consumption and public spending risk, as well as fluctuations in work effort.

Except for the quadratic terms in the public spending gaps, the terms just described also feature in Benigno's (2004) welfare criterion. They enter with different weights, though, because $\xi_{\mathrm{c}} < 1$. The loss function also differs from that of Benigno (2004) by the presence of the cross terms in the last line of (34). The cross term between the consumption gap and

world spending gap arises because positive co-movements between these two variables cause undesirable fluctuations in world work effort in addition to the effort fluctuations caused by consumption and spending fluctuations per se. The cross term between the terms of trade and the relative spending gap features in the loss function because a negative co-movement in these variables gives rise to undesirable effort fluctuations. In particular, a positive terms-of-trade gap provides the Home country with a competitive advantage, which, combined with a negative relative spending gap (thereby implying relatively more Home than Foreign spending), inefficiently shifts work effort from Foreign towards Home residents.

4.2. The policies

We consider several types of policies. One type concerns the *optimal policies*. Here, we distinguish between commitment and discretion, as there will generally be gains from commitment as mentioned in the Introduction. As one of our main questions concerns the contribution of fiscal policy to the stabilization of shocks, within the set of optimal policies, we consider "full" optimization over the complete vector of policy instruments $(\hat{R}_t, \hat{G}_t^H, \hat{G}_t^F)'$ and restricted optimization over monetary policy only, with fiscal policy restricted to be "passive" in the sense that $\hat{G}_t^H = \tilde{G}_t^H$ and $\hat{G}_t^F = \tilde{G}_t^F$. That is, fiscal policymaking is exclusively concerned with securing the efficient provision of public goods and takes no part in stabilizing other macroeconomic variables.

We also explore various policy rules. Although such rules are generally suboptimal relative to the optimal commitment policy, the latter is often merely regarded as a benchmark. In reality, this policy would be hard to achieve, because the policymaker would have an incentive to deviate from the optimal plan. Although policy rules also require commitment, the incentive to deviate from the rule would be weaker if it is transparent and simple, so that deviations can easily be detected and punished, either through a loss of confidence from the public/financial markets or by other policymakers (see, however, the caveat on policy rules versus fully optimal policy-making in Footnote 4).

The monetary and fiscal policy rules that we will consider all fall within the rather general class of rules given by

$$\hat{R}_t - \tilde{R}_t = b_H \pi_t^H + b_F \pi_t^F + b_C\left(\hat{C}_t^W - \tilde{C}_t^W\right) + b_T\left(\hat{T}_t - \tilde{T}_t\right) + d_H E_t \pi_{t+1}^H$$
$$+ d_F E_t \pi_{t+1}^F, \tag{35}$$

$$\hat{G}_t^H - \tilde{G}_t^H = -g_{CH}\left(\hat{C}_t^W - \tilde{C}_t^W\right) - g_{TH}\left(\hat{T}_t - \tilde{T}_t\right),$$

$$\hat{G}_t^F - \tilde{G}_t^F = -g_{CF}\left(\hat{C}_t^W - \tilde{C}_t^W\right) + g_{TF}\left(\hat{T}_t - \tilde{T}_t\right), \tag{36}$$

which, for example, allow for the possibility to contract monetary policy when inflation or the consumption gap increases and to contract fiscal policy when the consumption gap increases or the terms-of-trade gap deteriorates. As (30) and (31) suggest, this can help to stabilize national inflation. We will not optimize the combination (35) and (36) over all

parameters. This would require an immense amount of computing time. More importantly, in some instances, it would lead to coefficients of infinity (as we will explain below), which essentially makes no sense as a policy prescription. Therefore, we consider specializations of the combination of the rules (35) and (36).

4.3. The benchmark parameter combination

We partly follow Benigno (2004) in our choice of the baseline parameter combination, on which we shall also consider a number of variations. The calibration is based on the assumption that each period corresponds to a quarter of a year. We set $\beta=0.99$, which implies a steady-state real rate of return of 1% on a quarterly basis. Benigno calibrates his model to the EMU situation and divides the area into two groups, one corresponding to relatively low nominal wage rigidity and the other corresponding to relatively high wage rigidity. Both groups have a weight of approximately 50% in Euro-area GDP, so that in all our numerical computations we will set $n=0.5$. The benchmark values for α^H and α^F are selected so as to produce an average duration of a price contract of 1 year, so that $\alpha^H=\alpha^F=0.75$. We deviate from Benigno (2004) in our assumptions about the coefficient of relative risk aversion (RRA) for private consumption, as we assume that $\rho=2.5$ (for example, see Beetsma and Sehotman, 2001 and the references therein). We set the RRA coefficient for government spending, ρ_g, also at 2.5. Further, based on 0.6 and 0.2 being reasonable approximations for the private and government consumption shares of output in reality, we assume that $\xi_c=0.75$, so that steady-state private consumption is three times as large as government consumption.

In our choices of η and σ, we face the dilemma of on the one hand obtaining reasonable values for the implied labor supply elasticity and mark up, while on the other hand avoiding an unrealistically sluggish response of inflation to changes in real variables. We set $\eta=\sigma=3$, implying that in the benchmark case $k^H=k^F=0.0086$, so that, for example, the elasticity of inflation with respect to the consumption gap is around 0.04. This appears as a reasonable order of magnitude when compared with elasticities found in empirical work on inflation determination with quarterly data. Note, however, that the implied elasticities of the labor supply, respectively, mark-up, are rather large. Therefore, we will vary η and σ over large ranges in order to see how our results are affected.

The final choices concern the shocks. We already note that the particular process chosen for the demand shock plays no role (see below). For the supply shocks, we assume the following AR(1) process:

$$S_t^i = 0.97 S_{t-1}^i + \mu_{S,t}^i, \quad i = \text{H, F,}$$

where the $\mu_{S,t}^i$ and are white-noise innovations. The chosen degree of autocorrelation is high. However, this seems reasonable when we assume that the supply shocks represent technology shocks. We set the standard deviation of the innovations in the process for these shocks at 0.7%. This provides a reasonable unconditional standard deviation of the supply shocks and is in line with the standard assumptions of the real-business-cycle literature (e.g., see Cooley and Prescott, 1995).

5. The policy analysis

Before we proceed, we narrow down the number of cases that we need to investigate. In particular, we can exclude demand shocks from the analysis, as the following proposition shows:

Proposition 2. *The demand shocks are irrelevant for the equilibrium gaps and national inflation rates under the optimal policies and the policy rules we consider. Therefore, they are also irrelevant for the equilibrium welfare losses associated with these policies.*

Even though the demand shocks affect the efficient flex-price equilibrium and thereby also the deviations of variables under sticky prices from their steady-state values, the *gaps* of all the variables as well as the inflation rates are unaffected by the demand shocks. To see this, notice that the systems (33), (27), (30), (31) and (32) are exhaustively expressed as a set of relations among *gaps* of variables, national inflation rates and $\tilde{T}_t - \tilde{T}_{t-1}$. Hence, the only possible way for demand shocks to *potentially* affect this system is via the term $\tilde{T}_t - \tilde{T}_{t-1}$. However, (25) reveals that $\tilde{T}_t - \tilde{T}_{t-1}$ only depends on the (current and one-period lagged) relative supply shock, so that we are left with a system without demand shocks. Combining this with the fact that the objective function (33) is a function of gaps and national inflation rates only, it follows that the outcomes for the gaps and national inflation rates under optimal policies do not depend on the demand shocks. The same holds under the combination of rules (35) and (36), which are also a function of gaps and national inflation rates only.

The intuition for Proposition 2 is that, under international market completeness, the terms-of-trade are not affected by the demand shocks, because the relative consumption levels absorb these shocks. Indeed, in the absence of international market completeness, (8) would generally no longer hold. From the derivation in Appendix A (see also the Additional Appendix C), it is easy to see that $\tilde{T}_t$ would then also depend on the relative demand shock, D_t^R. Hence, relative demand shocks will affect the solutions for the national inflation rates and the gaps of variables in this case.

5.1. Optimal policies

5.1.1. Benchmark: commitment and equal rigidities

We start with the *benchmark case*, which assumes full optimization over all three policy instruments under commitment and equal rigidities in both countries (i.e., $\alpha^H = \alpha^F \equiv \alpha$ and thus $k^H = k^F \equiv k$). With equal rigidities, we can combine the two Phillips curves (30) and (31) into a "world" Phillips curve

$$\pi_t^W = \beta E_t \pi_{t+1}^W + k(\rho + \eta \xi_c)(\hat{C}_t^W - \tilde{C}_t^W) + k\eta(1 - \xi_c)(\hat{G}_t^W - \tilde{G}_t^W), \tag{37}$$

and a "relative" Phillips curve determining the dynamics of the terms of trade:

$$\pi_t^R = \beta E_t \pi_{t+1}^R - k(1 + \eta \xi_c)(\hat{T}_t - \tilde{T}_t) + k\eta(1 - \xi_c)(\hat{G}_t^R - \tilde{G}_t^R). \tag{38}$$

Moreover, with equal rigidities, we can rewrite (34) into a "world" and a "relative" part (see Additional Appendix F):

$$L_t = L_t^W + n(1-n)L_t^R,$$

where

$$L_t^W = \lambda_C^W (\hat{C}_t^W - \tilde{C}_t^W)^2 + \lambda_G^W (\hat{G}_t^W - \tilde{G}_t^W)^2 + (\pi_t^W)^2$$
$$+ 2\lambda_{CG}^W (\hat{C}_t^W - \tilde{C}_t^W)(\hat{G}_t^W - \tilde{G}_t^W),$$

$$L_t^R = \lambda_T^R (\hat{T}_t - \tilde{T}_t)^2 + (\pi_t^R)^2 + \lambda_G^R (\hat{G}_t^R - \tilde{G}_t^R)^2 - 2\lambda_{TG}^R (\hat{T}_t - \tilde{T}_t)(\hat{G}_t^R - \tilde{G}_t^R),$$

and where λ_C^W, λ_G^W, λ_{CG}^W, λ_T^R, λ_G^R and λ_{TG}^R are all positive functions of the structural parameters. Expression (38) shows that the terms of trade are completely insulated from monetary policy in this case, but not from fiscal policy. Hence, differences in national spending policies have a potential role in stabilizing the relative inflation rate and the terms-of-trade gap, both of which feature as arguments in L_t^R.

With the restatement of the loss function and the Phillips curves, the full optimization program can be split into a world and a relative part. Additional Appendix E sets up the relevant optimization program for the benchmark case, and derives the first-order conditions, which can be manipulated to yield the following system of equations:

$$\pi_t^W = -\frac{\xi_c}{\sigma} \Delta (\hat{C}_t^W - \tilde{C}_t^W), \quad \hat{G}_t^W = \tilde{G}_t^W, \tag{39}$$

$$\Delta(\hat{G}_t^R - \tilde{G}_t^R) = \phi_{3,t} - \frac{1}{\rho_g/\eta + (1-\xi_c)} \left[\sigma\pi_t^R - \xi_c\Delta(\hat{T}_t - \tilde{T}_t) \right], \tag{40}$$

$$\phi_{3,t} = -(1-n)nk(1+\eta\sigma)\left[1 + \frac{\rho_g\xi_c}{\rho_g/\eta + (1-\xi_c)}\right] \sum_{i=0}^{\infty} \beta^i (\hat{G}_{t+i}^R - \tilde{G}_{t+i}^R), \tag{41}$$

where $\phi_{3,t}$ is the Lagrange multiplier associated with (32) and $\Delta X_t \equiv X_t - X_{t-1}$ for a generic variable X. Leaving the Lagrange multipliers free at the initial period, this system together with (30)–(32) determines the optimal evolution of $\hat{C}_t^W - \tilde{C}_t^W$, π_t^H, π_t^F, $\hat{G}_t^H - \tilde{G}_t^H$, $\hat{G}_t^F - \tilde{G}_t^F$, $\hat{T}_t - \tilde{T}_t$ and $\phi_{3,t}$ with commitment under the "timeless principle" (cf. Woodford, 2003).

Expression (39) states the targeting rules for policies at the world level. Lagged consumption features in the first expression of (39), so that the relation between aggregate consumption and inflation has the format of the targeting rule for monetary policy under commitment in a closed economy; see, e.g., Clarida et al. (1999). An increase in inflation is met with a commitment to a prolonged monetary contraction, i.e., by raising the interest rate for several periods in order to induce a on-going negative consumption gap. This dampens expectations of future inflation and therefore also current inflation as (37) shows.

The inflation-consumption trade-off depends only on the parameters ξ_c and σ. When the consumption share ξ_c is larger, changes in consumption should be limited at the

expense of larger fluctuations in world inflation. An increase in the substitutability parameter σ increases the importance of stable inflation and thus requires a stronger monetary contraction for a given level of inflation. While monetary policy aims at stabilizing the world economy by closing the consumption gap, thereby producing zero world inflation, fiscal policy plays no role in stabilizing the world economy. The optimal fiscal policy sets world spending at its efficient level.

If we turn from the stabilization of the world economy to that of the national economies, the roles of monetary and fiscal policy are reversed. While fiscal policy is not used to stabilize the aggregate economy, monetary policy will not be employed to stabilize the local economies, because it cannot affect cross-country inflation differentials. Instead, (relative) fiscal policy takes on this role. Analogous to the monetary policy targeting rule at the world level, the targeting rule for relative fiscal policy under commitment, (40), features lagged relative public spending. While monetary policy is concerned with world inflation movements, relative fiscal policy is employed to dampen relative inflation differentials, and thereby also the terms-of-trade gap. Expression (40) reveals a commitment of the authorities to further contract fiscal policy if a future relative inflation differential emerges. Such a prolonged fiscal contraction will dampen expectations of future relative inflation, as (38) shows when it is forwarded by one period. This, in turn, stabilizes current relative inflation. An increase in the terms-of-trade gap leads individuals to switch away from Foreign products and causes a fall in relative inflation, as (38) shows. To stem the fall in relative inflation, the authority enacts a relative fiscal expansion, thereby dampening movements in production and effort.

Fig. 1 depicts the impulse responses to a one standard deviation positive Home supply shock ($\mu_{S,1}^{H} > 0$, $\mu_{S,1}^{F} = 0$).[12] All parameters are at their baseline values, except that we set the AR(1) coefficient of the shock to zero for illustrative purposes. Under flexible prices, Home output increases on impact and so does Home government spending, because the reduction in work effort at a given output level provides room for enhanced spending—as (21) shows. Foreign output decreases on impact, owing to an improvement of its terms-of-trade (i.e., an increase in $\tilde{T}$), which moves efficiently so as to share the cost of work effort between the two countries. This effect on Foreign output dominates both the effect of the increase in world consumption as well as the increase in Foreign government spending—see (21). In period 2, the economy is again in its initial steady state.

Due to the sluggish price adjustment, in the sticky-price case, the impact effect of the shock on the terms of trade is substantially smaller (though still positive) than under flexible prices. This implies a negative Home output gap (though Home output itself increases). The authority tries to mitigate the Home deflation by setting the Home public spending gap positive. Foreign output now increases on impact and thus the Foreign output gap is positive, owing not only to the positive consumption gap, but also to the negative terms-of-trade gap. The latter exerts upward pressure on Foreign inflation, thereby inducing the authority to set a negative Foreign public spending gap.

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[12] The details of the numerical computation of the optimal policies (and the associated losses) are available upon request from the authors. The solution algorithms are described by, e.g., Backus and Driffill (1986) and Söderlind (1999).
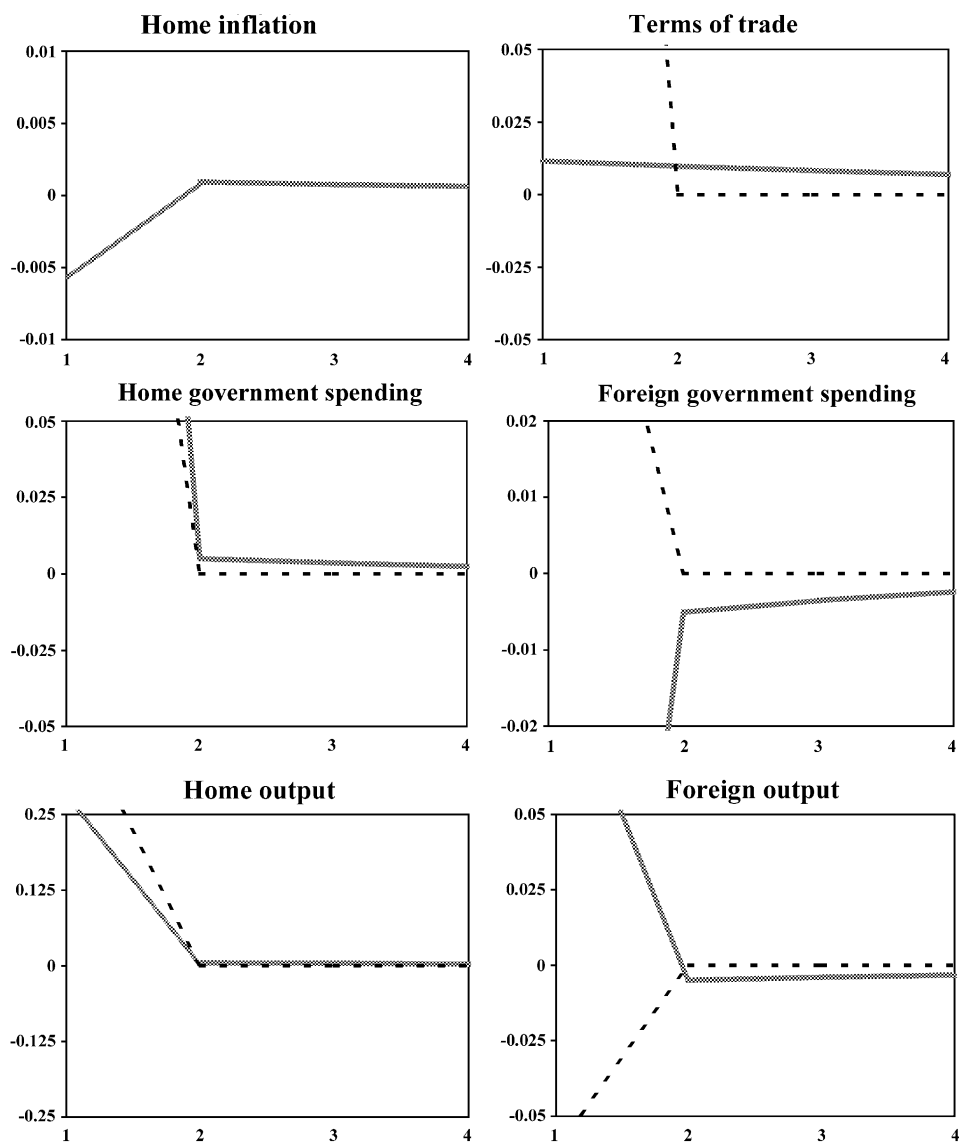
Fig. 1. Impulse responses to a positive Home supply shock under commitment. The size of the shock is one standard deviation ($\mu_{S,1}^H=0.7\%$, $\mu_{S,1}^F=0$). The dashed line denotes the flexible-price case; the solid line denotes the sticky-price case.

In contrast to the case with flexible prices, under sticky prices, the economy takes more than one period to return to its steady state. The Home government spending gap remains positive from period 2 onwards (but much smaller than upon impact), thus giving rise to the inertia under commitment discussed earlier. The terms-of-trade gap only dies out

Table 1
Results for optimal policies

	λ_π^H	λ_π^F	λ_C	λ_T	λ_G^H	λ_{CG}	λ_{TG}	s_G^C	s_G^D	D	CP	DP
Baseline	0.5	0.5	1.02	0.17	0.23	0.16	0.040	0.90	0.60	0.179	0.422	0.422
$\eta=2$	0.5	0.5	1.23	0.19	0.31	0.15	0.038	0.56	0.37	0.121	0.275	0.275
$\eta=10$	0.5	0.5	6.92	0.15	0.12	0.17	0.043	2.51	1.80	0.347	0.998	0.998
$\sigma=2$	0.5	0.5	2.18	0.37	0.50	0.34	0.086	0.66	0.51	0.093	0.306	0.306
$\sigma=10$	0.5	0.5	0.098	0.017	0.023	0.016	0.004	2.26	0.96	0.769	1.160	1.160
$\rho_g=1$	0.5	0.5	1.02	0.17	0.13	0.16	0.040	1.48	1.02	0.197	0.508	0.508
$\rho_g=5$	0.5	0.5	1.02	0.17	0.41	0.16	0.040	0.53	0.35	0.147	0.332	0.332
$\alpha^H=0.5$	0.15	0.85	1.74	0.30	0.39	0.28	0.069	0.65	0.48	0.133	0.305	0.316
$\rho_S=-1$	0.5	0.5	1.02	0.17	0.23	0.16	0.040	1.27	0.85	0.254	0.597	0.597
$\rho_S=0.5$	0.5	0.5	1.02	0.17	0.23	0.16	0.040	0.64	0.42	0.127	0.298	0.298

First column indicates which parameter has been varied away from the baseline value (the other parameters are all kept at the baseline value). Baseline parameter combination is $\eta=3$, $\sigma=3$, $\alpha^H=\alpha^F=0.75$. ρ_S=correlation between the supply shocks; λ_π^H, λ_π^F, λ_C, λ_T, λ_G^H, λ_{CG} and λ_{TG} are the weights in (34) (λ_π^H and λ_π^F: are the actual ones, while λ_C, λ_T and λ_G^H are the actual weights multiplied by 100); s_G^C and s_G^D are the standard deviations (*100) of the Home spending gap under full optimization commitment, respectively discretion; the figures in the columns D, CP and DP report, for the relevant regime, the welfare loss in permanent consumption equivalents (in %) relative to full optimization under commitment. Here, D=full optimization under discretion, CP=optimal monetary policy under commitment with fiscal policy restricted to $\hat{G}_t^i=\tilde{G}_t^i$ (i=H, F) and DP=idem for discretion.

slowly and in period 2 switches from negative to positive, thus exerting upward pressure on Home inflation, which becomes positive as of period 2 and then dies out slowly. The time consistency problem with the commitment solution manifests itself in a very nice way here. While the authority would now want to set a negative Home spending gap in order to reduce Home inflation, it has committed itself to maintaining a positive Home spending gap. Also the Foreign spending gap exhibits its inertia by remaining negative, despite the fact that Foreign inflation has fallen (slightly) below zero (and the Foreign output gap has fallen below zero).

We will now assess the gains from fiscal stabilization and how they depend on the values of the parameters. To do so, we compare the welfare loss under optimization over the full vector of policy instruments and the loss under restricted optimization over monetary policy only, with "passive" fiscal policy, such that $\hat{G}_t^H=\tilde{G}_t^H$, $\hat{G}_t^F=\tilde{G}_t^F$. To assess the welfare gain from fiscal stabilization in "real world terms", we follow Lucas (1987) and compute the permanent (and constant) percentage change in the consumption gap that would produce a given difference in losses (this approach has recently also been applied in Jensen, 2002). Call this percentage change c. We thus solve:

$$\frac{\lambda_C}{1-\beta}\left(\frac{c}{100}\right)^2 = L^i - L^c,$$

where L^c is the loss under commitment with full optimization and L^i is the loss under the alternative regime (in this case, "passive" fiscal policy, with the loss denoted by L^{cp}) that we want to compare with L^c in terms of "consumption equivalents". Table 1 reports the gains from fiscal stabilization for the baseline parameter combination as well as a number

of variations on it. The table suggests that these gains are generally non-negligible. The table also reports the relative weights that (34) attaches to the consumption, spending and terms-of-trade gap, as well as the national inflation rates.[13]

The coefficients of π_t^R and $\Delta(\hat{T}_t - \tilde{T}_t)$ in (40) reveal the role of the parameters in the trade-offs involving relative spending, the terms of trade and relative inflation. This, in turn, indicates the role of the parameters in determining the benefits from fiscal stabilization. As (40) shows, a lower elasticity of the labor supply (higher η) calls for a more active response of relative spending to relative inflation and movements in the terms-of-trade gap (the absolute value of the coefficients of these variables in (40) increases in η). When η is higher, fluctuations in effort arising from misallocations caused by relative price movements are more costly, so that a stronger response of relative spending is needed to dampen these fluctuations in effort. Also, when products becomes closer substitutes (a higher σ), relative price movements lead to larger distortions (dispersion) in production effort and thus require a more active response from relative government spending. As Table 1 shows, the welfare gain from fiscal stabilization indeed increases with η or σ. By contrast, an increase in the aversion to government spending fluctuations, as captured by ρ_g, calls for less active relative fiscal policy responses and thus leads to lower benefits from fiscal stabilization. An increase in the consumption share ξ_c raises the share of output that is sensitive to relative price movements between countries and calls for more active relative fiscal policy responses to relative inflation and movements in the terms-of-trade gap. Finally, a reduction in the degree of price rigidity (maintaining $\alpha^H = \alpha^F$) reduces the role of stabilization policies and thus leads to a reduction in the gains from fiscal stabilization.

We then vary the correlation between the Home and Foreign supply shocks. The rather common view that, in a monetary union, the benefits from fiscal stabilization policy at the national level become proportionally larger when the shock correlations fall is not correct here. The reason is that only the *relative* supply shock S_t^R enters the dynamic reduced-form systems (27), (30), (31) and (32) (via the term $\tilde{T}_t - \tilde{T}_{t-1}$). While the correlation of the supply shocks affects the variance of S_t^R and thus also the gains from fiscal stabilization in terms of permanent consumption equivalents (as Table 1 shows), it is only this variance which determines all losses. Because L^c and L^{cp} are proportional to the variance of SF, the ratio L^c / L^{cp} is independent of this variance.

5.1.2. Discretion

We now relax the commitment assumption, so that the authority selects its instruments under discretion. When Foreign inflation is expected to exceed Home inflation, the policymaker wants to make private agents believe that it will further contract the relative spending gap in order to induce the private sector to moderate its expectations about relative inflation. This, in turn, will stabilize current relative inflation. However, as we already saw above, once expectations about relative inflation have been formed and incorporated in price setting, the authority has an incentive to relax relative fiscal policy, thereby exploiting

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[13] As in any of the related literature (see, e.g., Woodford, 2003, Chapter 6), the relative weight attached to the latter vastly exceeds the other relative weights (in the baseline, by a factor of 50 to 300).

the predetermined inflation expectations. When the economies feature an equal degree of price rigidity, only fiscal policy suffers from a commitment problem, because there are no trade-offs in monetary policy since all gaps at the world level are closed.

The discretionary equilibrium can be obtained with dynamic programming. As Additional Appendix F shows, with equal rigidities, for fiscal policy the union-level relation (39) continues to hold.[14] As regards to the relative part of the model, the first-order conditions can be combined into a rather complicated expression involving the current and expected future terms-of-trade, relative inflation and relative spending gap. The main feature of this expression is that $(\hat{G}_{t-1}^R - \tilde{G}_{t-1}^R)$ is *absent* from it. Hence, in contrast to the commitment case, there is no policy inertia.

Fig. 2 depicts the impulse responses to a one-standard deviation positive Home productivity shock $(\mu_{S,1}^H > 0, \mu_{S,1}^F = 0)$. All parameters are at their baseline values, except that we again set the AR(1) coefficient of the shock to zero. Home inflation switches from negative to positive as of period 2. While no longer bound to maintaining a positive government spending gap as under commitment, the authority switches from a positive Home spending gap in period 1 to a negative government spending gap as of period 2, so as to reduce the Home inflation rate. Comparing commitment and discretion, the result is that the deflation in period 1 is larger under discretion, while the inflation in period 2 is higher under commitment. Because Foreign inflation has become negative in period 2, also the Foreign spending gap switches sign in period 2 and becomes positive. This way, Foreign deflation can be mitigated.

As discussed above, the authority could gain if it could commit to more aggressive and persistent policy responses towards shocks. Although these gains come at the cost of more variable public spending (cf. Table 1), they dominate this cost. Hence, the discretionary scenario where fiscal policy is less active and persistent towards stabilizing shocks is welfare inferior, as the inflation/spending trade-off is worse since inflation expectations are not affected as strongly as under commitment. Table 1 reports the welfare loss in permanent consumption equivalents arising from the failure to commit. The numbers suggest that this loss can be non-trivial. We observe that, because monetary policy does not suffer from a credibility problem when rigidities are equal, a passive fiscal policy leads to equal losses under commitment and discretion (compare the losses in the columns under CP and DP in Table 1).

5.1.3. Asymmetric rigidities

We return to benchmark case of commitment and allow for asymmetry in price rigidity between the countries. In particular, we consider the case in which $\alpha^H = 0.5$ and $\alpha^F = 0.75$. The estimates in Galí et al. (2001) of α for Euroland range from 0.67 to 0.81, while for the U.S. they range from 0.56 to 0.60. Hence, the degree of asymmetry in price rigidity that we consider here roughly covers the estimated range of variation for Euroland.

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[14] The inertia in monetary policy featuring in (39) disappears under discretion and the targeting rule becomes $\pi_t^W = -(\xi_c/\sigma)(\hat{C}_t^W - \tilde{C}_t^W)$.
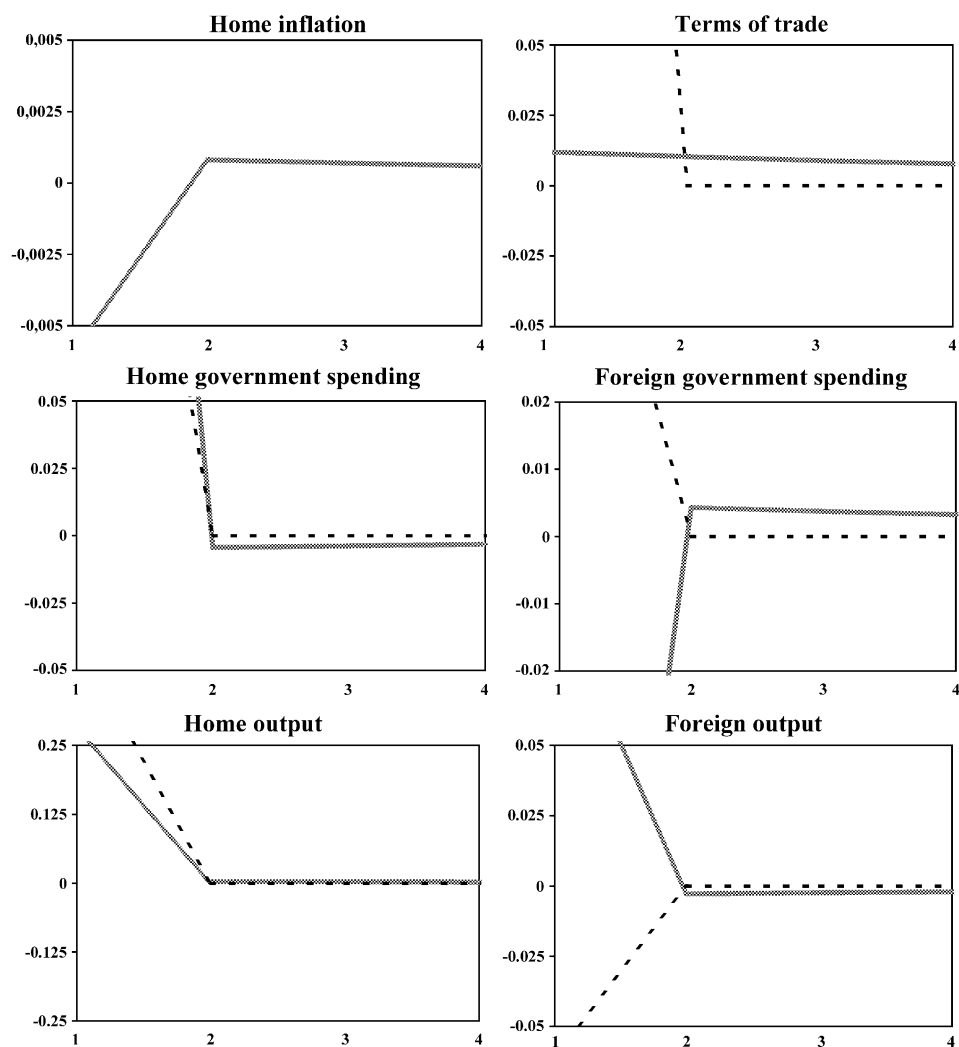
Fig. 2. Impulse responses to a positive Home supply shock under discretion. The size of the shock is one standard deviation ($\mu_{S,1}^{H}=0.7\%$, $\mu_{S,1}^{F}=0$). The dashed line denotes the flexible-price case; the solid line denotes the sticky-price case.

With differences in rigidity, monetary policy is subject to a stabilization trade-off and commitment of monetary policy does yield welfare gains.[15] The reason is that monetary policy now not only affects world variables, but also the terms of trade. Hence, monetary policy will no longer be exclusively focused on stabilizing world inflation, but also on reducing movements in national inflation rates and the terms-of-trade gap. More

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[15] This can be directly seen by comparing the losses under commitment versus discretion when fiscal policy is restricted to be passive (see the columns under CP and DP in Table 1).

Table 2
Results for the rules

	(35) and (36)			(42) and (43)		
	R	($g_{TH}^{opt}, g_{TF}^{opt}$)	RP	R	($g_{YH}^{opt}, g_{YF}^{opt}$)	RP
Baseline	0.128	(0.59, 0.59)	0.422	0.240	(1.10, 1.10)	0.427
$\eta=2$	0.089	(0.44, 0.44)	0.275	0.125	(1.12, 1.12)	0.280
$\eta=10$	0.203	(1.10, 1.10)	0.998	0.783	(1.07, 1.07)	1.004
$\sigma=2$	0.069	(0.49, 0.49)	0.306	0.147	(1.13, 1.13)	0.316
$\sigma=10$	0.476	(1.05, 1.05)	1.160	0.912	(1.05, 1.05)	1.160
$\rho_g=1$	0.130	(1.03, 1.03)	0.508	0.406	(1.10, 1.10)	0.528
$\rho_g=5$	0.108	(0.34, 0.34)	0.332	0.116	(1.10, 1.10)	0.334
$\rho_S=-1$	0.181	(0.59, 0.59)	0.597	0.324	(1.10, 1.10)	0.597
$\rho_S=0.5$	0.091	(0.59, 0.59)	0.298	0.184	(1.10, 1.10)	0.310

Columns under R and RP give welfare losses under the relevant regime (in terms of permanent consumption loss in % and relative to full optimization commitment). Numbers in columns 2–4 are based on monetary policy rule (35), with (b_H, b_F, b_C, b_T, d^H, d^F)=(0, 0, 75, 0, 125, 125)–aimed at closing world consumption gap and zero world inflation–, and fiscal policy rule (36), with $g_{CH}=g_{CF}=0$ and optimal combination (g_{TH}^{opt}, g_{TF}^{opt}) for (g_{TH}, g_{TF}) that minimizes (33). R reports the corresponding loss, while RP reports the loss under passive fiscal policy ($g_{TH}=g_{TF}=0$ as well). Numbers in columns 5–7 are based on the Taylor rule (42) and fiscal rule (43), with optimal combination (g_{YH}^{opt}, g_{YF}^{opt}) for (g_{YH}, g_{YF}) that minimizes (33). R reports the corresponding loss, while RP reports the loss under passive fiscal policy ($g_{YH}=g_{YF}=0$). For further explanation, see Table 1.

specifically, if Foreign prices are stickier, the optimal policy setting allows Home inflation to be more variable than Foreign inflation. The reason is that it is optimal to direct monetary policy at trying to keep Foreign inflation closer to zero, so that distortions resulting from relative price differences within Foreign are reduced. This is analogous to Benigno's (2004) result that, under a strict inflation targeting rule, the highest relative weight should be attached to the inflation rate of the country with the highest degree of price rigidity.

5.2. The rules

5.2.1. Coordination

As mentioned earlier, the advantage of a rule is that it may be easier to commit to than to the optimal policy, because the rule may be simpler and more transparent. The first combination of rules is suggested by the optimal policies derived above for equal rigidities. The monetary policy rule is chosen such that it (almost) closes the consumption gap. Perfect elimination of the consumption gap would require some infinitely large coefficients in the monetary policy rule. We approximate this situation by setting $b_H=b_F=b_T=0$ and choosing large values of d_H, $d_F=d_H(1-n)/n$ and b_C in (35).[16] With the consumption gap virtually eliminated, the public spending gap can be restricted to react to the terms-of-trade gap, so that $g_{CH}=g_{CF}=0$ in (36). Table 2 reports the optimal

[16] When the parameters d_H and d_F are chosen too large, a unique solution no longer exists. This reflects a well-known feature of these types of models: to ensure determinacy, the nominal interest rule should be "active", but not too active (see, e.g., Woodford, 2003).

coefficients of the public spending rules for the parameter combinations considered earlier under equal rigidities. The optimal rules are characterized by positive values of g_{TH} and g_{TF}, which indicates that a contraction (expansion) of the Home (Foreign) spending gap is used to (partly) offset the inflationary (deflationary) pressure from an increase in the terms-of-trade gap. We observe that, in all the cases reported, the optimal fiscal rule leads to a welfare loss lower than the loss under the full-optimization discretionary policy. We note also that, for the baseline case, the loss from having "passive" fiscal policies (i.e., also $g_{TH}=g_{TF}=0$) is (virtually) equal to that under "passive" fiscal policies when monetary policy is optimally conducted under commitment (compare columns CP in Table 1 and RP in Table 2). Finally, the rule coefficients are unaffected by the shock correlations. This reflects the result that the relative losses under optimal policymaking with or without active fiscal policy are invariant to the shock correlations.

The second combination of rules is based on output gaps. Monetary policy follows a standard Taylor rule, with the coefficients originally proposed by Taylor (1993):

$$\hat{R}_t - \tilde{R}_t = 1.5\pi_t^W + 0.5\big(\hat{Y}_t^W - \tilde{Y}_t^W\big). \tag{42}$$

This is sometimes seen as a reasonable description of how monetary policy has been conducted in the past, in particular in the U.S. Because it is regularly argued that having fiscal policy react to activity could help stabilize the economy,[17] we consider public spending rules of the following format:[18]

$$\hat{G}_t^H - \tilde{G}_t^H = -g_{YH}\big(\hat{Y}_t^H - \tilde{Y}_t^H\big), \quad \hat{G}_t^F - \tilde{G}_t^F = -g_{YF}\big(\hat{Y}_t^F - \tilde{Y}_t^F\big). \tag{43}$$

We report the results for the combination of rules (42) and (43) also in Table 2. The losses with passive fiscal policies (i.e., $g_{YH}=g_{YF}=0$) are close to the corresponding losses under the (approximately) optimal monetary policy rule (compare the losses reported in the two columns under RP in Table 2). Hence, a Taylor rule as such performs well in this model. To explore the contribution to stabilization of output-gap-based fiscal rules, we find the optimal coefficients g_{YH} and g_{YF}, while monetary policy follows the standard Taylor rule. In all cases, the spending gap reacts with a strong contraction to a positive output gap, so as to reduce the inflationary pressure exerted by a positive output gap. In welfare terms, however, this combination of rules does not perform as well as the combination (35) and (36).

5.2.2. Non-coordination

Now, we turn to the case in which the fiscal rules are set non-cooperatively. While a full-fledged analysis of optimal non-coordinated national fiscal policies is of high interest, it is complicated and beyond the scope of this paper. Nevertheless, a relatively simple rule-based approach can still yield some valuable insights. Because the derivation of the independent fiscal authorities' appropriate utility-based loss functions under non-

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[17] Several authors have recently explored the empirical relation between public spending and economic activity for European countries and/or OECD countries. See, for example, Lane (2003) and Fatás and Mihov (2001a,b).
[18] Note that the combination (42) and (43) is a special case of the combination (35) and (36), because $(\hat{Y}_t^H - \tilde{Y}_t^H)$ and $(\hat{Y}_t^F - \tilde{Y}_t^F)$ can be expressed in terms of consumption, public spending and terms-of-trade gaps.

coordination is algebraically extremely cumbersome,[19] we postulate these loss functions, but evaluate the policy outcomes according to the union-level social loss function (33).

We assume that the fiscal authorities' loss functions under non-coordination are domestically oriented and feature national output and spending gaps, as well as the national inflation rate:

$$L^i = \sum_{s=t}^{\infty} \beta^{s-t} E_t \left[w_y^i (\hat{Y}_s^i - \tilde{T}_s^i)^2 + (\pi_s^i)^2 + w_g^i (\hat{G}_s^i - \tilde{G}_s^i)^2 \right], \tag{44}$$

where L^i is the loss function of the fiscal authority of country i (i=H, F). Such a loss function appears reasonable as it contains the macroeconomic variables that politically matter a lot, if not most. The parameters w_y^i and w_g^i can be thought of as being determined by political considerations and/or a delegation arrangement made at the supranational level. We conduct the analysis of non-coordinated fiscal policies from two perspectives. From a positive point of view, we explore the cross-border spillovers of non-coordinated fiscal stabilization policies. From a normative perspective, we explore institutional design. Specifically, we ask whether one can find a delegation arrangement involving relative weights w_y^i and w_g^i (i=H, F), such that the non-coordinated setting of the fiscal rules reproduces the optimal combinations of rules found in the previous subsection that minimizes (33). From the perspective of minimizing (33), such a delegation arrangement would be optimal given the classes of fiscal rules under consideration.

We assume first that monetary policy follows the rule discussed above that (almost) closes the consumption gap, while the non-coordinating fiscal authorities follow rules of the format (36) with $g_{CH}=g_{CF}=0$. The Home fiscal authority chooses g_{TH} to minimize [(44), i=H], taking as given g_{TF}, and vice versa. Unless $w_y^i=0$, loss function (44) cannot be obtained from (33) by simplifying the latter. To enhance intuition, we therefore first consider the case of $w_y^i=0$ and $w_g^i=\lambda_G^i/\lambda_\pi^i$ so that the fiscal authority attaches the same relative weight to public spending gap versus inflation stabilization as the union-level social loss function requires. Hence, the fiscal authorities initially care only about minimizing fluctuations in national inflation and their own spending gap. A positive terms-of-trade gap exerts upward pressure on Home inflation and thus induces the Home government to contract the spending gap according to the rule (36), in order reduce Home inflation. However, this further magnifies the terms-of-trade gap by (32) and, thus, pushes Foreign inflation further below zero—see (31). In the absence of coordination between the two fiscal authorities, the Home government ignores this negative spill-over of its fiscal policy and thus has an incentive to set g_{TH} higher than when there is fiscal coordination (i.e., when the fiscal authorities jointly minimize L^H+L^F). Similarly, the Foreign government sets g_{TF} higher than under fiscal coordination. For the baseline parameter setting, the Nash equilibrium in the fiscal rules is given by the combination $g_{TH}=g_{TF}=0.24$. These coefficients indeed exceed the optimal coefficients $g_{TH}=g_{TF}=0.18$ that the fiscal authorities would choose when they would jointly minimize L^H+L^F. In fact,

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[19] One complication is that second-order approximations are needed of the equations of the underlying model. Benigno and Benigno (2003) provide derivations for the case of non-coordinated monetary policies. Our setup with fiscal policy adds another dimension of complexity.

for all the parameter combinations we considered earlier, we confirmed that non-coordinating fiscal authorities would prefer to set more active rules than when they jointly minimize $L^H + L^F$.[20]

We need to distinguish the case of fiscal coordination that we just discussed from the jointly optimal setting of the fiscal (and monetary) rules that minimizes the union-level social-loss function (33). Hence, we try to find a fiscal delegation arrangement w_g^i (maintaining $w_y^i = 0$), $i = $ H, F, that induces the non-coordinating fiscal authorities to reproduce, as a Nash equilibrium in rules, the union-level socially optimal combination of fiscal rules obtained in Section 5.2.1 [i.e., the combination (g_{TH}^{opt}, g_{TF}^{opt})–and $g_{CH} = g_{CF} = 0$– reported in Table 2 that minimizes (33)]. For all the parameter combinations considered earlier, we find that this is indeed possible, so that the macroeconomic equilibrium and the social loss (33) under (g_{TH}^{opt}, g_{TF}^{opt}) can be obtained under fiscal non-coordination with an appropriate delegation arrangement. In fact, for the parameter combinations that we considered before, we find that the associated weight w_g^i in (44) should be set *lower* than the relative weight $\lambda_G^i / \lambda_\pi^i$ in (33). For example, for the baseline parameter combination, w_g^i should be set at 0.75 ($\lambda_G^i / \lambda_\pi^i$). The intuition is that the term $-\lambda_{TG}(\hat{T}_s - \tilde{T}_s)(\hat{G}_s^R - \tilde{G}_s^R)$ in (34) gives rise to additional welfare benefits from a negative (positive) correlation between the terms-of-trade gap and the Home (Foreign) government spending gap. This benefit is neglected in (44) so that, ceteris paribus, the relative weight of the public spending gap versus inflation should be set lower in (44) than in (34), in order to induce the non-coordinating governments to select sufficiently active spending rules. Our findings provide an instance of the more general result that policy coordination can be harmful in the presence of a pre-existing distortion. In this case, the fiscal authorities feature loss functions that differ from the social loss function. When $w_g^i = \lambda_G^i / \lambda_\pi^i$, the already existing bias towards insufficient fiscal stabilization will worsen when the fiscal authorities shift from non-coordination towards coordination.

Suppose now that the governments also care about stabilizing the output gap ($w_y^i > 0$, $i = $ H, F). A positive terms-of-trade gap raises (reduces) the Home (Foreign) output gap and thus provides an additional reason for the Home (Foreign) government to contract (expand) the spending gap—see (28) and (29) with their flex-price counterparts subtracted. Hence, the Home (Foreign) government will ceteris paribus choose a larger value for

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[20] We also conducted an experiment where we "split" the per-period social loss function (34) into the following Home and Foreign fiscal authorities' loss functions, respectively,

$$n\lambda_C(\hat{C}_s^W - \tilde{C}_s^W)^2 + n\lambda_T(\hat{T}_s - \tilde{T}_s)^2 + \lambda_G^H(\hat{G}_s^H - \tilde{G}_s^H)^2 + \lambda_\pi^H(\pi_s^H)^2 + n\lambda_{CG}(\hat{C}_s^W - \tilde{C}_s^W)(\hat{G}_s^H - \tilde{G}_s^H)$$
$$+ \lambda_{TG}(\hat{T}_s - \tilde{T}_s)(\hat{G}_s^H - \tilde{G}_s^H),$$

and

$$(1-n)\lambda_C(\hat{C}_s^W - \tilde{C}_s^W)^2 + (1-n)\lambda_T(\hat{T}_s - \tilde{T}_s)^2 + \lambda_G^F(\hat{G}_s^F - \tilde{G}_s^F)^2 + \lambda_\pi^F(\pi_s^F)^2$$
$$+ (1-n)\lambda_{CG}(\hat{C}_s^W - \tilde{C}_s^W)(\hat{G}_s^F - \tilde{G}_s^F) - \lambda_{TG}(\hat{T}_s - \tilde{T}_s)(\hat{G}_s^F - \tilde{G}_s^F).$$

A numerical cheek for the baseline parameter setting revealed that also with these loss functions, non-coordinating fiscal authorities choose more active fiscal rules than when they coordinate. Observe that, because monetary policy closes the consumption gap, the associated terms in the national loss functions are in fact irrelevant.

$g_{TH}(g_{TF})$, taking as given $g_{TF}(g_{TH})$. To reproduce the combination of rules that minimizes (33), the appropriate delegation arrangement should raise the cost of fiscal stabilization compared to the case in which the governments do not care about the output gap. For the baseline parameter combination, we progressively increased $w_y^i > 0$, $i = $ H, F. Indeed, with a corresponding progressive increase in the relative weight on public spending, w_g^i, we could again replicate, as a Nash equilibrium, the socially optimal combination of fiscal rules (g_{TH}^{opt}, g_{TF}^{opt}) and $g_{CH} = g_{CF} = 0$.

In our final set of experiments, we assume that the monetary authority follows (42), while the non-coordinating fiscal authorities follow rules of the format (43). As before, to reproduce as a Nash equilibrium, the combination (43) that minimizes (33), public spending should be given a smaller weight (relative to inflation) than in (33). Moreover, an increase in $w_y^i > 0$ ($i = $ H, F) requires an increase in $w_g^i > 0$ ($i = $ H, F).

6. Conclusion

This paper has explored the interactions between monetary and fiscal policy in a micro-founded model of a monetary union with sticky prices. We explored the contribution of public purchases in economic stabilization in the presence of supply and demand shocks. This is an important issue in EMU, given that monetary policy is constrained to be attuned to European-wide economic developments. In selecting fiscal policies, either optimal or through a rule, we primarily took a union-wide perspective. This is the relevant perspective to be taken by supranational European institutions, in particular the ECB and the European Commission, the latter of which has to take initiatives on economic policies that promote welfare across the European Union. It is also the relevant perspective for the ECOFIN Council (or the Eurogroup) in case it moves towards more explicit coordination of fiscal policies. Our results suggest that there are non-trivial gains from fiscal stabilization and commitment.

While there is a pressure for more fiscal coordination in Europe, actual fiscal policies are primarily conducted with the objective of serving national interests rather than union-wide interests. Although we also explored the non-coordinated setting of fiscal policy rules, a more elaborate analysis of the strategic interaction of national fiscal policies in the current framework would be desirable. A relevant question then is whether current union-wide institutions, in particular the Stability and Growth Pact, suffice to induce fiscal policymakers to internalize the union-wide implications of their policies. More generally, one would want to assess more firmly the gains from fiscal policy coordination in a monetary union.

While the objective of this analysis was mainly to gain insight into the interaction of monetary and fiscal stabilization policies under sticky prices, the analysis could be extended into various other directions. One is to relax the assumption of Ricardian equivalence and allow for a richer menu of fiscal policies. In particular, public debt can be employed as an instrument to intertemporally smooth out the effects of shocks. It will be interesting to investigate how this combines with the use of public spending to stabilize current demand. Deficit ceilings, like those imposed under the Stability and Growth Pact, will then also become relevant from a welfare perspective. Further, one would expect that

the interaction between monetary and fiscal policy strengthens and that time consistency problems may deepen when the time profile of the taxes and/or transfers is no longer irrelevant and debt is nominal. Another extension would abolish the assumption of internationally complete markets. When centralized to a sufficient extent, fiscal policies could then be employed to provide for the sharing of country-specific risks. A third extension would allow not only for sticky prices, but also for sticky wages (e.g., Erceg et al., 2000). As a result, optimal policies would need to address more distortions. As a fourth elaboration on the current setup, one could introduce a time-varying mark up (along the lines of Giannoni, 2000), thereby giving rise to autonomous inefficient inflation fluctuations, which again would imply more distortions to be addressed. Finally, the model can be made more realistic by introducing lags in the transmission of policy, which is especially relevant for the implementation of fiscal policy. The suggested extensions may all affect the benefits from fiscal stabilization. While the last extension may reduce the gains from fiscal stabilization, the combination of incomplete markets and asymmetric demand shocks could provide an additional role for fiscal stabilization policies.

Acknowledgements

Appendix A. Derivation of the efficient flex-price equilibrium

Log-linearizing (15) around the steady state, and using the relevant definitions from the main text, we have:

$$- \rho \left(\tilde{C}_t^{\mathrm{H}} + D_t^{\mathrm{H}} \right) = (1-n)\tilde{T}_t + \eta \left[(1-n)\xi_c \tilde{T}_t + \xi_c \tilde{C}_t^{\mathrm{W}} + (1-\xi_c)\tilde{G}_t^{\mathrm{H}} \right] - \eta S_t^{\mathrm{H}}, \tag{45}$$

and an analogous equation for the Foreign country:

$$- \rho \left(\tilde{C}_t^{\mathrm{F}} + D_t^{\mathrm{F}} \right) = - n\tilde{T}_t + \eta \left[- n\xi_c \tilde{T}_t + \xi_c \tilde{C}_t^{\mathrm{W}} + (1-\xi_c)\tilde{G}_t^{\mathrm{F}} \right] - \eta S_t^{\mathrm{H}}. \tag{46}$$

Taking a weighted average (with weights n and $1-n$) of the latter two equations, we obtain $-\rho(\tilde{C}_t^{\mathrm{W}} + D_t^{\mathrm{W}}) = \eta[\xi_c \tilde{C}_t^{\mathrm{W}} + (1-\xi_c)\tilde{G}_t^{\mathrm{W}}] - \eta S_t^{\mathrm{W}}$. Hence,

$$\tilde{C}_t^{\mathrm{W}} = \frac{\eta}{\rho + \eta\xi_c} \left[S_t^{\mathrm{W}} - \frac{\rho}{\eta} D_t^{\mathrm{W}} - (1-\xi_c)\tilde{G}_t^{\mathrm{W}} \right]. \tag{47}$$

Subtracting (46) from (45) and using that $\tilde{C}_t^H + D_t^H = \tilde{C}_t^F + D_t^F$ [as follows by linearizing (8)], we obtain $0 = \tilde{T}_t + \eta[\xi_c \tilde{T}_t - (1 - \xi_c)\tilde{G}_t^R] + \eta S_t^R$ and thus

$$\tilde{T}_t = \frac{\eta}{1 + \eta \xi_c}\left[(1 - \xi_c)\tilde{G}_t^R - S_t^R\right]. \tag{48}$$

Further, because $\tilde{Y}_t^H = [(1 - n)]\bar{T}^{1-n}\bar{C}\,\tilde{C}\,\tilde{T}_t + \bar{T}^{1-n}\bar{C}\,\tilde{C}_t^W + \bar{G}^H\tilde{G}_t^H]/\bar{Y}^H$, we can also write (45) as $-\rho(\tilde{C}_t^H + D_t^H) = (1 - n)\tilde{T}_t + \eta \tilde{Y}_t^H - \eta S_t^H$ and (46) as $-\rho(\tilde{C}_t^F + D_t^F) = -n\tilde{T}_t + \eta \tilde{Y}_t^F - \eta S_t^F$. Taking a weighted average (with weights n and $1 - n$) of these two equations, we then obtain

$$-\rho(\tilde{C}_t^W + D_t^W) = \eta \tilde{Y}_t^W - \eta S_t^W. \tag{49}$$

Combining this with (47), we find that:

$$\tilde{Y}_t^W = \frac{\eta \xi_c}{\rho + \eta \xi_c}S_t^W - \frac{\rho \xi_c}{\rho + \eta \xi_c}D_t^W + \frac{\rho(1 - \xi_c)}{\rho + \eta \xi_c}\tilde{G}_t^W. \tag{50}$$

We solve now for $\tilde{G}_t^H$ and $\tilde{G}_t^F$, thereby completing the solution of the efficient flex-price equilibrium. The fiscal authorities maximize (20) over $\tilde{G}_t^H$ and $\tilde{G}_t^F$, where it is understood that the values of C_t^H, Y_t^H, C_t^F, and Y_t^F satisfy the private-sector optimality conditions (15) and (16). Differentiating (20) with respect to G_t^H yields the first-order condition:

$$\begin{aligned}
&E_t \sum_{s=t}^{\infty} \beta^{s-t}\left[nU_C(C_s^H, \varepsilon_s^H)\frac{\partial C_s^H}{\partial G_t^H} + (1 - n)U_C(C_s^F, \varepsilon_s^F)\frac{\partial C_s^F}{\partial G_t^H}\right] + nV_G(G_t^H) \\
&- E_t \sum_{s=t}^{\infty} \beta^{s-t}\left\{nv_y(Y_s^H, z_s^H)\left[(1 - n)T_s^{-n}C_s^W\frac{\partial T_s}{\partial G_t^H} + T_s^{1-n}\frac{\partial C_s^W}{\partial G_t^H}\right]\right\} - nv_y(Y_t^H, z_t^H) \\
&- E_t \sum_{s=t}^{\infty} \beta^{s-t}\left\{(1 - n)v_y(Y_s^F, z_s^F)\left[(-n)T_s^{-(n+1)}C_s^W\frac{\partial T_s}{\partial G_t^H} + T_s^{-n}\frac{\partial C_s^W}{\partial G_t^H}\right]\right\} = 0.
\end{aligned} \tag{51}$$

Combining (8), (15), (16) and (17), we have that $T_s v_y(Y_s^H, z_s^H) = v_y(Y_s^F, z_s^F)$, for all $s \geq t$. Using this along with the fact that $\partial C_t^W/\partial G_t^H = n(\partial C_t^H/\partial G_t^H) + (1 - n)(\partial C_t^F/\partial G_t^H)$, for all t, and again (15) and (16), with (17) imposed, we can simplify (51) to $V_G(G_t^H) = v_y(Y_t^H, z_t^H)$ — see also Additional Appendix A. We log-linearize this and find $-\rho_g\tilde{G}_t^H = \eta[(1 - n)\xi_c\tilde{T}_t + \xi_c\tilde{C}_t^W + (1 - \xi_c)\tilde{G}_t^H] - \eta S_t^H$, from which we obtain

$$\tilde{G}_t^H = \frac{\eta}{\rho_g + \eta(1 - \xi_c)}\left[S_t^H - \xi_c((1 - n)\tilde{T}_t + \tilde{C}_t^W)\right]. \tag{52}$$

For Foreign spending we similarly find

$$\tilde{G}_t^F = \frac{\eta}{\rho_g + \eta(1 - \xi_c)}\left[S_t^F - \xi_c(-n\tilde{T}_t + \tilde{C}_t^W)\right]. \tag{53}$$

Together with (47) and (48), we then have four equations in four unknowns: $\tilde{G}_t^H$, $\tilde{G}_t^F$, $\tilde{T}_t$ and $\tilde{C}_t^W$. Using (52) and (53), we get $\tilde{G}_t^R = \frac{\eta}{\rho_g + \eta(1 - \xi_c)}\left(S_t^R + \xi_c\tilde{T}_t\right)$. By substituting this into

(48), one then recovers (25). Next, combining (52) and (53) with weights n and $(1-n)$, respectively, gives $\tilde{G}_t^{\mathrm{W}} = \frac{\eta}{\rho_g + \eta(1-\xi_c)}\left(S_t^{\mathrm{W}} - \xi_c \tilde{C}_t^{\mathrm{W}}\right)$. Combining this with (47) and solving gives (23). Substituting (23) back into (47) and working out yield (22).

Appendix B. Derivation of (30)

We can rewrite (11), for $i=H$ and $j=h$, as

$$0 = E_t \sum_{k=0}^{\infty} \left(\alpha^{\mathrm{H}}\beta\right)^k \left\{ \left[\lambda_{t+k} p_t(h) - v_y\big(y_{t,t+k}(h), z_{t+k}^{\mathrm{H}}\big)\right] y_{t,t+k}(h) \right\},$$

where we have imposed (17). After substituting for λ_{t+k} we obtain

$$E_t \sum_{k=0}^{\infty} \left(\alpha^{\mathrm{H}}\beta\right)^k \left\{ \left[U_{\mathrm{C}}\big(C_{t+k}^{\mathrm{H}}, \varepsilon_{t+k}^{\mathrm{H}}\big) \frac{p_t(h)}{P_{\mathrm{H},t+k}} T_{t+k}^{n-1} - v_y\big(y_{t,t+k}(h), z_{t+k}^{\mathrm{H}}\big) \right] y_{t,t+k}(h) \right\} = 0.$$

We log-linearize this condition around the steady state and, using the relevant definitions from the main text, we obtain

$$0 = E_t \sum_{k=0}^{\infty} \left(\alpha^{\mathrm{H}}\beta\right)^k \left\{ \begin{array}{c} \hat{p}_{t,t+k} - (1-n)\hat{T}_{t+k} - \rho\big(\hat{C}_{t+k}^{\mathrm{W}} + D_{t+k}^{\mathrm{W}}\big) \\ -\eta\left[-\sigma\hat{p}_{t,t+k} + \xi_c\Big((1-n)\hat{T}_{t+k} + \hat{C}_{t+k}^{\mathrm{W}}\Big) + (1-\xi_c)\hat{G}_{t+k}^{\mathrm{H}} - S_{t+k}^{\mathrm{H}} \right] \end{array} \right\},$$

where $\hat{p}_{t,t+k} \equiv \ln\left(p_t(h)/P_{\mathrm{H},t+k}\right)$ and where we have used that $\tilde{C}_t^{\mathrm{H}} + D_t^{\mathrm{H}} = \tilde{C}_t^{\mathrm{W}} + D_t^{\mathrm{W}}$ by (8). We rewrite this expression, using $\hat{p}_{t,t+k} = \hat{p}_{t,t} - \sum_{s=1}^{k} \pi_{t+s}^{\mathrm{H}}$ as:

$$\frac{\hat{p}_{t,t}}{1-\alpha^{\mathrm{H}}\beta} = E_t \sum_{k=0}^{\infty} \left(\alpha^{\mathrm{H}}\beta\right)^k \left\{ \begin{array}{c} \dfrac{1+\eta\xi_c}{1+\eta\sigma}(1-n)\hat{T}_{t+k} + \dfrac{\rho+\eta\xi_c}{1+\eta\sigma}\hat{C}_{t+k}^{\mathrm{W}} + \dfrac{\rho}{1+\eta\sigma}D_{t+k}^{\mathrm{W}} \\ + \dfrac{\eta}{1+\eta\sigma}\big((1-\xi_c)\hat{G}_{t+k}^{\mathrm{H}} - S_{t+k}^{\mathrm{H}}\big) \end{array} \right\}$$
$$+ E_t \sum_{k=0}^{\infty} \left(\alpha^{\mathrm{H}}\beta\right)^k \left[\sum_{s=1}^{k} \pi_{t+s}^{\mathrm{H}} \right].$$

Log-linearizing (12), we obtain $\hat{p}_{t,t} = \frac{\alpha^{\mathrm{H}}}{1-\alpha^{\mathrm{H}}}\pi_t^{\mathrm{H}}$, which we use to simplify the previous expression:

$$\frac{\pi_t^{\mathrm{H}}}{1-\alpha^{\mathrm{H}}\beta} \frac{\alpha^{\mathrm{H}}}{1-\alpha^{\mathrm{H}}} = E_t \sum_{k=0}^{\infty} \left(\alpha^{\mathrm{H}}\beta\right)^k \left\{ \begin{array}{c} \dfrac{1+\eta\xi_c}{1+\eta\sigma}(1-n)\hat{T}_{t+k} + \dfrac{\rho+\eta\xi_c}{1+\eta\sigma}\hat{C}_{t+k}^{\mathrm{W}} + \dfrac{\rho}{1+\eta\sigma}D_{t+k}^{\mathrm{W}} \\ + \dfrac{\eta}{1+\eta\sigma}\big((1-\xi_c)\hat{G}_{t+k}^{\mathrm{H}} - S_{t+k}^{\mathrm{H}}\big) \end{array} \right\}$$
$$+ E_t \sum_{k=1}^{\infty} \left(\alpha^{\mathrm{H}}\beta\right)^k \frac{\pi_{t+k}^{\mathrm{H}}}{1-\alpha^{\mathrm{H}}\beta}.$$

Finally, we then obtain

$$\pi_t^{\text{H}} = \frac{(1-\alpha^{\text{H}}\beta)(1-\alpha^{\text{H}})}{\alpha^{\text{H}}} \left[\begin{array}{c} \dfrac{1+\eta\xi_c}{1+\eta\sigma}(1-n)\hat{T}_t + \dfrac{\rho+\eta\xi_c}{1+\eta\sigma}\hat{C}_t^{\text{W}} + \dfrac{\eta(1-\xi_c)}{1+\eta\sigma}\hat{G}_t^{\text{H}} \\[2mm] + \dfrac{\rho}{1+\eta\sigma}D_t^{\text{W}} - \dfrac{\eta}{1+\eta\sigma}S_t^{\text{H}} \end{array} \right] + \beta E_t \pi_{t+1}^{\text{H}}. \quad (54)$$

Combine (49) and (50) to find that $\tilde{C}_t^{\text{W}} = \frac{\eta}{\rho+\eta\xi_c}S_t^{\text{W}} - \frac{\rho}{\rho+\eta\xi_c}D_t^{\text{W}} - \frac{\eta(1-\xi_c)}{\rho+\eta\xi_c}\tilde{G}_t^{\text{W}}$. Using this expression and (48), it is straightforward to show that $-(1+\eta\xi_c)(1-n)\tilde{T}_t - (\rho+\eta\xi_c)\tilde{C}_t^{\text{W}} - \eta(1-\xi_c)\tilde{G}_t^{\text{H}} = \rho D_t^{\text{W}} - \eta S_t^{\text{H}}$. Hence, (54) can be rewritten as (30). In a similar way we derive (31).

Appendix C. Supplementary Material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jinteco.2005.03.001.

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