International transmission and monetary policy cooperation[†]

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PRELIMINARY AND INCOMPLETE

Abstract

We use a version of the New Area-Wide Model (NAWM) developed at the ECB in order to quantify the gains from monetary policy cooperation. The model is calibrated in order to match a set of empirical moments. We then derive the cooperatinve and (open-loop) Nash monetary policies, assuming that the central banks' objectives reflect the preferences of the households. Our main results are threefold. First, in line with the recent literature, we find that the gains from cooperation are small in the benchmark model. They amount to about 0.03 percent of steady-state consumption. Second, decomposing the sources of the gains from cooperation with respect to the various shocks, we find that mark-up shocks are the most important source for gains from international monetary policy cooperation. Third, a sensitivity analysis with respect to various key parameters of the model suggests that the gains from cooperation become larger the more open the economy.

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[†]The views expressed are solely our own and do not necessarily reflect those of the European Central Bank of the Eurosystem. All remaining errors are ours.

1 Introduction

The analysis of the implications of international economic interdependencies for the gains from cross-country cooperation between monetary authorities has a long history. More than three decades ago, Hamada (1976) recognized that "[m]ost traditional approaches do not seem to pay due attention to the interdependent nature of monetary policies". Since then a large literature has addressed this issue using a variety of models, methodologies and game-theoretic concepts. The literature of the 1980s (e.g. Canzoneri and Gray (1985) and Canzoneri and Henderson (1992)) has shown that the potential gains from cooperation are proportional to the size of the international policy spillovers and these, in turn, depend on the parameter values of the model. Since then, open economy models have changed considerably calling for a reconsideration of the earlier wisdom. In particular, efforts to give stronger micro-foundations to the parameters of the model have resulted in the so-called New Open-Economy Macroeconomics (NOEM) literature (Lane, 2001). Using a stylized representative NOEM model, Obstfeld and Rogoff (2002) came to the conclusion that the gains from cooperation are at best very small. However, Canzoneri et al. (2002) pointed out that the NOEM literature, per se, does not imply that self-oriented policymaking should be recommended. The results, once more, strongly depend on the value of some crucial parameters (see also Benigno (2002) and Sutherland (2004) on this point). Moreover, Benigno and Benigno (2006) argued that the gains from cooperation are also crucially dependent on the sources of the shocks affecting the economy, again a finding that was also true in the earlier literature. There is therefore a need to move away from the stylized NOEM models and consider richer models with a variety of shocks and frictions that have been calibrated or estimated to match international business cycle properties. In the end, whether the potential gains from cooperation are large or small is an empirical question. In this paper, we attempt to move in that direction and therefore to close the circle with papers like Oudiz and Sachs (1984) two decades ago, that addressed similar issues using traditional large-scale models.[1] Two main differences with this older literature are that our analysis does not impose certainty equivalence and that the welfare measure is based on the preferences of the agents.

In order to quantify the gains from cooperation, we use a version of the New Area-Wide Model (NAWM) developed at the ECB. The NAWM is a two-region Dynamic Stochastic General Equilibrium (DSGE) model that is calibrated to represent the euro area (EA) and US economies. The version used in this paper is a simplified version of the model presented in Coenen et al. (2007), which has been re-calibrated in order to capture a number of empirical stylized facts. It contains nominal and real frictions such as nominal stickiness and indexation in intermediate goods prices, wages and import prices, monopolistic competition in goods and labor markets, habit formation, investment adjustment

[1] De Fiore and Lombardo (2007) perform a similar analysis in a three-country DSGE model with trade in oil. They also find that the gains from cooperation are small.

costs, home bias in consumption and incomplete international financial markets. In addition, it features a number of different sources of shocks including technology, labor supply, investment, preference, mark-up and exchange rate shocks.

We then use the model to derive the welfare-based optimal monetary policy under cooperation and under a particular definition of an (open-loop) Nash-equilibrium. In this context, our paper relates to the literature that addresses optimal monetary and/or fiscal policy in DSGE models with steady state distortions, such as in Benigno and Woodford (2004a,b) and Schmitt-Grohé and Uribe (2004a,b, 2005). We carry out a similar welfare-based optimal monetary policy analysis in a medium-scale two-country open-economy model, thereby complementing the analytical results in a very stylized version of a similar model in Clarida et al. (2002) and Benigno and Benigno (2002). In the Nash-equilibrium, we assume that each central bank takes the money growth path of the foreign central bank as given.

Four conclusions of our analysis are worth highlighting. First, in line with the recent literature, we find that the gains from cooperation are small in the benchmark model. They amount to about 0.03 percent of steady-state consumption. This is an order of magnitude higher than the gains suggested by Obstfeld and Rogoff (2002), but nevertheless very small. Second, decomposing the sources of the gains from cooperation with respect to the various shocks, we confirm the findings of Benigno and Benigno (2006). Overall, the gains from cooperation are an order of magnitude larger for the mark-up shocks than for each of the other shocks we consider. This may reflect the fact that those shocks are the most important source of inflation variability in the economy and that they are the most problematic for the monetary authorities in terms of creating policy trade-offs. Third, we perform a sensitivity analysis with respect to various key parameters of the model and find that the gains from cooperation become considerably larger when prices in the domestic intermediate goods sector become less sticky or the home bias in demand is reduced. For example, if the trade shares are increased from around 10-15 percent in the baseline calibration to one third, the gains from cooperation increase to almost one percent of steady-state consumption in both regions. With respect to most other parameters that we investigate, the gains from cooperation remain very small. For example, in line with the results of Obstfeld and Rogoff (2002), we find that complete international financial markets further reduce the gains from cooperation. Finally, it is worth mentioning that in the benchmark model the gains from cooperation are quite symmetric. However, this result appears to be quite sensitive to the precise calibration of the model.

The rest of the paper is structured as follows. Section 2 lays out the main structure of the two-region DSGE model. Section 3 discusses its calibration. Section 4 presents the two monetary policy games we study. Section 5 discusses the main results. Section 6 contains the conclusions.

2 A Two Region DSGE Model

As discussed in the introduction, the model we use to investigate the gains from international monetary policy cooperation is a version of the NAWM. This model builds on recent advances in developing micro-founded DSGE models suitable for quantitative policy analysis. It is a simplified version of the model discussed in Coenen et al. (2007). In particular, relative to Coenen et al. (2007) three main differences are worth mentioning. First, it has only one type of representative household for each country. Second, the fiscal sector is simplified by assuming the budget is balanced at all times. And, third, there are no import adjustment costs. These simplifications were mainly done for computational reasons.

Nevertheless, in order to investigate the interaction between market imperfections and the gains of cooperation, the model consists of several real and nominal frictions. In particular, the domestic goods and import sector as well as the labor market are subject to monopolistic competition and staggered price and wage setting, respectively. Notice that we only allow for a stochastic mark-up in the domestic goods market. Furthermore, we also assume incomplete international asset markets in order the investigate the impact of imperfect risk-sharing on the gains of cooperation.

The model consists of two symmetric regions of normalized population size s and $1-s$, respectively the euro area (EA), denoted as home country, and the United States.[2] In each country, there are four types of economic agents: households, firms, a fiscal authority, and a monetary authority.

In the following, we outline the behavior of the different types of agents and state the market clearing conditions and resource constraints which need to be satisfied in equilibrium. We focus on the exposition of the home country, with the understanding that the foreign country is similarly characterized. To the extent needed, foreign variables and parameters are indexed with an asterisk, '*'.

[2]The model builds on recent advances in developing micro-founded DSGE models suitable for quantitative policy analysis, as exemplified by the closed-economy model of the euro area by Smets and Wouters (2003), the International Monetary Fund's Global Economy Model (GEM; Bayoumi et al. (2001)) or the Federal Reserve Board's new open economy model named SIGMA (Erceg et al., 2006).

2.1 Households

The preferences of Household i are described by the following intertemporal CRRA utility function

$$\mathrm{E}_t\left[\sum_{k=0}^{\infty}\beta^k\varepsilon_t^C\left(\frac{1}{1-\sigma}\left(C_{i,t+k}-\kappa\,C_{i,t+k-1}\right)^{1-\sigma}-\frac{\varepsilon_t^N}{1+\zeta}\left(N_{i,t+k}\right)^{1+\zeta}+\frac{\varepsilon^M}{1-\psi}\left(\frac{M_{i,t}}{P_t}\right)^{1-\psi}\right)\right], \tag{1}$$

where $C_{i,t}$ is a consumption index, $N_{i,t}$ is labor services (differentiated across Households) and $M_{i,t}$ are nominal money balances. β is the discount factor, σ denotes the inverse of the intertemporal elasticity of substitution and ζ is the inverse of the elasticity of work effort with respect to the real wage. The parameter κ measures the degree of habit formation in consumption, and ε_t^C and ε_t^N are AR(1) preference and labor supply shocks, respectively. Thus, the utility of household depends positively on the quasi-difference between current and lagged individual consumption, and negatively on individual labor supply. Money is introduced in the utility function in order to obtain a money demand equation (used for monetary policy as described below). The inverse of the interest rate elasticity of money denoted by ψ and its corresponding weight in the utility function ϖ. P_t is the consumption price index (CPI), defined later. Following most of the open-economy related literature we assume that the weight of real balances in the household preferences is negligible (i.e. $\varepsilon^M \to 0$)

Households face the following period-by-period budget constraint:

$$\begin{aligned}(1+\tau_t^C)P_t\,C_{i,t}+P_t\,I_{i,t}+\;&R_t^{-1}B_{i,t+1}+M_{i,t+1}+\left(\left(1-\Gamma_{B^F}(B_t^F)\right)R_{F,t}\right)^{-1}S_t\,B_{i,t+1}^F\\ =\;&\left(1-\tau_t^N\right)W_{i,t}\,N_{i,t}+\;R_{K,t}\;K_{i,t}+\;D_{i,t}+T_{i,t}+B_{i,t}+S_t\,B_{i,t}^F+M_{i,t}\end{aligned}$$

where R_t and R_t^F denote the risk-less returns on domestic bonds and internationally traded bonds, respectively. Internationally traded bonds are denominated in foreign currency and, thus, their domestic value depends on the nominal exchange rate S_t (expressed in terms of units of home currency per unit of foreign currency). $N_{i,t}$ denotes the labor services provided to firms at wage rate $W_{i,t}$, and $R_{K,t}$ indicates the rental rate for the capital services rented to firms $K_{i,t}$, and $D_{i,t}$ are the dividends paid by household-owned firms from the domestic production and import sector. Furthermore, we have introduced distortionary consumption τ_t^c and wage income taxes τ_t^N into the model.

Similarly, $\Gamma_{B^F}(B_t^F)$ represents a financial intermediation premium that households must pay when taking a position in the international bond market. The premium is a function of the aggregate net-foreign asset position of the country and not on the single household's position. Finally, it is implicitly assumed that households hold state-contingent securities. These securities are traded amongst households and provide insurance against individual wage-income risk. This guarantees that the marginal utility

of consumption out of wage income is identical across individual household members. As a result, all household members will choose identical allocations in equilibrium (for simplicity these securities are not shown).

The capital stock owned by households evolves according to the following capital accumulation equation,

$$K_{i,t+1} = (1-\delta)\, K_{i,t} + (1 - \Gamma_I(\varepsilon_t^I I_{i,t}/I_{i,t-1}))\, I_{i,t},$$

where δ is the depreciation rate and $\Gamma_I(\varepsilon_t^C I_{i,t}/I_{i,t-1})$ is the adjustment cost function formulated in terms of changes in investment subject to a time varying AR(1) shock process ε_t^I.

Choice of Allocations
Defining as Λ_t/P_t and $\Lambda_t\, Q_t$ the Lagrange multipliers associated with the budget constraint and the capital accumulation equation , respectively, the first-order conditions for maximizing the household member's lifetime utility function with respect to $C_{i,t}$, $I_{i,t}$, $K_{i,t+1}$, $B_{i,t+1}$, $B_{i,t+1}^F, M_{i,t}$ are given by:

$$\frac{\Lambda_{i,t}}{P_t} = \varepsilon_t^C \frac{(C_{i,t} - \kappa\, C_{i,t-1})^{-\sigma}}{(1+\tau_t^C)},$$

$$1 = Q_t \left(1 - \Gamma_I(I_{i,t}/I_{i,t-1}) - \Gamma_I'(\varepsilon_t^I I_{i,t}/I_{i,t-1})\, \frac{I_{i,t}}{I_{i,t-1}}\right) \tag{2}$$
$$+\ \beta\, \mathrm{E}_t \left[\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}}\, Q_{t+1}\, \Gamma_I'(\varepsilon_t^I I_{i,t+1}/I_{i,t})\, \frac{I_{i,t+1}^2}{I_{i,t}^2}\right],$$

$$Q_t = \beta\, \mathrm{E}_t \frac{\Lambda_{i,t+1} P_t}{\Lambda_{i,t} P_{t+1}} \Big((1-\delta)\, Q_{t+1} \frac{R_{K,t+1}}{P_{t+1}} \Big),$$

$$\beta\, R_t\, \mathrm{E}_t \left[\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}}\, \frac{P_t}{P_{t+1}}\right] = 1,$$

$$\beta\, (1 - \Gamma_{B^F}(B_t^F))\, R_{F,t}\, \mathrm{E}_t \left[\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}}\, \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t}\right] + \varepsilon_t^{UIP} = 1,$$

$$\Lambda_{i,t} = \varepsilon_t^C \varepsilon^M \left(\frac{M_{i,t}}{P_t}\right)^{-\psi} + \beta \mathrm{E}_t \left[\Lambda_{i,t+1} \frac{P_t}{P_{t+1}}\right],$$

where Λ_t is the marginal utility of consumption; Q_t measures the shadow price of a unit of the investment good (Tobin's Q) and ε_t^{UIP} stand for a white noise UIP shock. Combining the first-order conditions with respect to the holdings of internationally traded bonds in the economies, yields a risk-adjusted uncovered-interest-parity condition, reflecting that

the return on internationally traded bonds is subject to both a financial intermediation and risk premium.

Wage Setting
Households act as wage setters for their differentiated labor services N_t in monopolistically competitive markets. We assume that the wages for the differentiated labor services, $\tilde{W}_t$, are determined by staggered nominal wage contracts à la Calvo (1983). Thus, households receive permission to optimally reset their nominal wage contract in a given period t with probability $1 - \xi_W$. All household members that receive permission to reset their wage contract choose the same wage rate $\tilde{W}_t$. Those households that do not receive permission are allowed to adjust the wage contract at least partially according to the following scheme:

$$W_{i,t} = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\chi_W} \pi^{1-\chi_W} W_{i,t-1},$$

where parameter χ_W measures the degree of indexation to past changes in the price level P_t and π is the steady-state inflation, and i is the index of an individual household.

Households that receive permission to optimally reset their wage contracts in period t are assumed to maximize lifetime utility, as represented by equation (1), taking into account the wage-indexation scheme and the demand for their labor services (the formal derivation of which we postpone until we consider the firms' problem).

Each household faces the following demand for its labor services:

$$N_{i,t} = \left(\frac{\tilde{W}_{i,t}}{W_t}\right)^{-\eta} N_t$$

where η is the wage-elasticity of labor demand, W_t is the aggregate nominal wage index and $N_t = \int_0^1 N_{i,t}$.

Hence, we obtain the following first-order condition for the optimal wage-setting decision in period t:

$$\mathrm{E}_t\left[\sum_{k=0}^{\infty} \xi_W^k \, \beta^k \, \Lambda_{i,t+k} \, (1-\tau_t^N) \, \frac{\tilde{W}_{i,t}}{P_{t+k}} \left(\frac{P_{t+k-1}}{P_{t-1}}\right)^{\chi_W} \pi^{(1-\chi_W)k} - \frac{\eta}{\eta-1} \varepsilon_t^N \, (N_{i,t+k})^{\zeta}\right) N_{i,t+k}\right] = 0.$$

This expression states that in those labor markets in which wage contracts are re-optimized, the latter are set so as to equate the household members' discounted sum of expected after-tax marginal revenues to the discounted sum of expected marginal disutility of labor.

2.2 Firms

There are three types of firms. A continuum of monopolistically competitive domestic firms, each of which produces a single tradable differentiated intermediate good, $Y_{f,t}$, a

monopolistically competitive import sector receiving foreign goods "at the dock", and a set of representative firms, which combine purchases of domestically-produced intermediate goods with purchases of imported intermediate goods into a distinct non-tradable intermediate goods $Q_{f,t}$. All firms are indexed by $f \in [\,0,1\,]$

2.2.1 Intermediate-Good Firms

Each intermediate-good firm f produces its differentiated output using a Cobb-Douglas technology,

$$Y_{f,t} = z_t \, K_{f,t}^{\alpha} \, N_{f,t}^{(1-\alpha)} \,, \tag{3}$$

utilizing as inputs homogeneous private capital services, $K_{f,t}$, that are rent from household in fully competitive markets, and labor services, N_t. For variable z_t, we assume that is part of symmetric bivariate first-order autoregressive process defining global productivity shock with similar cross-correlations of innovations as in Backus and Crucini (2000).

Capital and Labour Inputs
Taking the rental cost of capital $R_{K,t}$ and wage W_t as given, the firm's optimal demand for capital and labor services must solve the problem of minimizing total input cost $R_{K,t} \, K_{f,t} + W_t \, N_{f,t}$ subject to the technology constraint (3).

Defining as $MC_{f,t}$ the Lagrange multiplier associated with the technology constraint (3), the first-order conditions of the firm's cost minimization problem with respect to capital and labor inputs are given by

$$\alpha \, \frac{Y_{f,t}}{K_{f,t}} (1 - \tau_t^f) \, MC_{f,t} = R_{K,t}, \tag{4}$$

$$(1-\alpha) \, \frac{Y_{f,t}}{N_{f,t}} (1 - \tau_t^f) \, MC_{f,t} = \, W_t. \tag{5}$$

where τ_t^f is a stochastic (i.i.d.) subsidy to firms. We introduce this subsidy à la Benigno and Benigno (2006) in order to generate cost-push shocks.[3] In what follows we refer to this shock as a mark-up shock.

The Lagrange multiplier $MC_{f,t}$ measures the nominal marginal cost. We note that, since all firms f face the same input prices and since they all have access to the same production technology, nominal marginal cost $MC_{f,t}$ are identical across firms; that is, $MC_{f,t} = MC_t$

[3]Often cost-push shocks are modelled as stochastic elasticity of substitution between goods (e.g. Smets and Wouters, 2003). Such an assumption generate firm-specific pricing equations when solved to higher orders of approximation, making the model intractable.

Price Setting

Each firm f sells its differentiated output $H_{f,t}$ in the domestic markets or to foreign importers (which demand is denoted by $X_{f,t+k}$) under monopolistic competition and there is sluggish price adjustment due to staggered price contracts à la Calvo (1983). Accordingly, firm f receives permission to optimally reset prices in a given period t either with probability $1-\xi_H$.

Defining as $P_{H,f,t}$ the domestic price of good f , all firms that receive permission to reset their price contracts in a given period t choose the same price $\tilde{P}_{H,f,t} = \tilde{P}_{H,t}$. Those firms which do not receive permission are allowed to adjust their prices according to the following schemes:

$$P_{H,f,t} = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\chi_H} \pi^{1-\chi_H} P_{H,f,t-1},$$

that is, the price contracts are indexed to a geometric average of past changes in the aggregate price indexes, $P_{H,t}$, and the steady-state inflation rates, π where χ_H is the indexation parameter.

Each firm f receiving permission to optimally reset its domestic and/or foreign price in period t maximizes the discounted sum of its expected after-tax real profits,

$$\mathrm{E}_t\left[\sum_{k=0}^{\infty} \Lambda_{t,t+k}\left(\xi_H^k\, D_{H,f,t+k}\right)\right],$$

subject to the price-indexation schemes and taking as given the aggregate domestic (H_t) and foreign (X_t) demand for home produced goods and subject to an elastic demand for its produce defined as

$$Y_{f,t} = \left(\frac{P_{H,f,t}}{P_{H,t}}\right)^{-\theta} (H_t + X_t)$$

Here, $\Lambda_{t,t+k}$ is the firm's discount rate defined as the households' real discount factor, while $D_{H,f,t} = (P_{H,f,t} - MC_t)\, Y_{f,t}$ are period-t nominal profits.

Hence, we obtain the following first-order condition characterizing the firm's optimal pricing decision for its output sold in the domestic and foreign market assuming producer currency pricing:

$$\mathrm{E}_t\left[\sum_{k=0}^{\infty} \xi_H^k\, \Lambda_{t,t+k}\left(\tilde{P}_{H,t}\left(\frac{P_{t+k-1}}{P_{t-1}}\right)^{\chi_H} \pi^{(1-\chi_H)k} - \frac{\left(1-\tau_t^f\right)\theta}{\theta-1}\, MC_{t+k}\right) Y_{f,t}\right] = 0.$$

This expressions state that in those intermediate-good markets in which price contracts are re-optimized, the latter are set so as to equate the firms' discounted sum of expected revenues to the discounted sum of expected marginal cost.

2.2.2 Import sector

In this section, we discuss briefly the optimization problem of the local importers who import foreign goods for which the law of one price holds, that is $P^D_{IM,t}(f) = S_t P_{F,t}(f)$ as discussed in Monacelli (2005). Note $P^D_{IM,t}(f)$ is the "price at the dock " of the imported good f, where perfect pass-through still holds. Imperfect exchange rate pass-through, however, is ensured via nominal rigidities in the import sector. This feature implies a deviation from both extreme assumptions on import pricing namely local versus producer currency pricing that characterize a wide array of the papers in the New Open Macroeconomics literature. The empirical evidence appears to be in favor of the chosen specification implying that the degree of pass-through is partial in the short-run but complete in the long-run , as demonstrated for example by Campa and Goldber (2002).

In contrast to Monacelli (2005), however, in our set-up differentiated intermediate imported goods are combined at the dock to a composite of imported goods at the dock using a CES technology. The demand faced by each single importer is defined as

$$IM_{f,t} = \left(\frac{P_{IM,f,t}}{P_{IM,t}}\right)^{-\theta_{IM}} IM_t$$

Price adjustment in the import sector is also sluggish due to staggered price contracts à la

Calvo (1983). As a result, the following first-order condition characterizes the importer's optimal pricing decision:

$$\mathrm{E}_t\left[\sum_{k=0}^{\infty} \xi^k_{IM}\, \Lambda_{t,t+k}\left(\tilde{P}_{IM,t}\left(\frac{P_{t+k-1}}{P_{t-1}}\right)^{\chi_{IM}} \pi^{(1-\chi_{IM})k} - \frac{\theta_{IM}}{\theta_{IM}-1} P^D_{IM,t}\right)\, IM_{f,t+k}\right] = 0.$$

where$P^D_{IM,t}$ is the price of the composite of the infinite number of intermediate imported goods "at the dock", θ_{IM} is the elasticity of substitution between different types of imported goods, and $\tilde{P}_{IM,t}$ is the price chosen by importers that receive permission to reset their price contracts in a given period t . Note also that the Calvo-parameter ξ_{IM} can be interpreted as the degree of exchange rate pass-through in the model.

2.2.3 Final-Good Firms

The representative final-good firm (we neglect the indexation in what follows) produces the non-tradable intermediate good, Q_t, combines purchases of a bundle of domestically-produced intermediate goods, H_t, with purchases of a bundle of goods from the import sector , IM_t using a constant-returns-to-scale CES technology,

$$Q_t = \left(\nu^{\frac{1}{\mu}} H_t^{1-\frac{1}{\mu}} + (1-\nu)^{\frac{1}{\mu}} IM_t)^{1-\frac{1}{\mu}}\right)^{\frac{\mu}{\mu-1}}, \tag{6}$$

where the parameter μ denotes the intratemporal elasticity of substitution between the distinct bundles of domestic and imported goods, while $\nu \in (0, 1)$ is a measures of home bias in the production of the intermediate good. The demand function for domestic intermediate and imported goods are defined as:

$$H_t = \left(\frac{P_{H,t}}{P_t}\right)^{-\mu} Q_t$$

$$IM_t = \left(\frac{P_{IM,t}}{P_t}\right)^{-\mu} Q_t$$

where the corresponding price index (CPI) P_t is defined as

$$P_t = \left(\nu \left(P_{H,t}\right)^{1-\mu} + (1-\nu) P_{IM_t,t}^{1-\mu}\right)^{\frac{1}{1-\mu}}$$

Note that we assume implicitly that the share of foreign goods in investment, consumption and government spending are the same, and that there are no differences in the corresponding price indices of the variables.

2.3 Fiscal and Monetary Authorities

The fiscal authority purchases intermediate good, G_t, and levies lumps sum taxes T_t and distortionary taxes (subsidies) on households (firms). The fiscal authority's period-by-period budget constraint then has the following form:

$$P_t\, G_t = T_t + \tau_t^C P_t\, C_t + \tau_t^l W_t\, N_t + \tau_t^f\, D_t,$$

In the benchmark New Area Wide Model the monetary authority is assumed to follow a Taylor-type interest-rate rule (Taylor, 1993) specified in terms of consumer-price inflation and output,

$$R_t = \phi_R\, R_{t-1} + (1-\phi_R)\left[R + \phi_\Pi \left(\frac{P_t}{P_{t-1}} - \Pi\right)\right] + \phi_{g_Y} Y_t + \varepsilon_{R,t},$$

where $R = \beta^{-1}\,\Pi$ is the equilibrium nominal interest rate, Π denotes the monetary authority's inflation target and the term $\varepsilon_{R,t}$ represents a serially uncorrelated monetary policy shock.

2.4 Aggregation and Aggregate Resource Constraint

The model is closed by imposing market clearing conditions and formulating the aggregate resource constraint.

2.4.1 Aggregation

Aggregate Wage Dynamics
With households setting their wage contracts W_t according to the described scheme, the aggregate wage index evolves according to

$$W_t = \left((1-\xi_W)(\tilde{W}_t)^{1-\eta} + \xi_W \left(\left(\frac{P_{t-1}}{P_{t-2}} \right)^{\chi_W} \pi^{(1-\chi_W)} W_{t-1} \right)^{1-\eta} \right)^{\frac{1}{1-\eta}}.$$

Aggregate Price Dynamics
With intermediate-good firms f setting their price contracts for the differentiated products sold domestically, $P_{H,f,t}$, according to described scheme, the aggregate nominal price index evolves according to

$$P_{H,t} = \left((1-\xi_H)(\tilde{P}_{H,t})^{1-\theta} + \xi_H \left(\left(\frac{P_{t-1}}{P_{t-2}} \right)^{\chi_H} \pi^{(1-\chi_H)} P_{H,t-1} \right)^{1-\theta} \right)^{\frac{1}{1-\theta}}.$$

Similarly, prices in the import prices $P_{IM,t}$ evolve according to:

$$P_{IM,t} = \left((1-\xi_{IM})(\tilde{P}_{IM,t})^{1-\theta_{IM}} + \xi_{IM} \left(\left(\frac{P_{t-1}}{P_{t-2}} \right)^{\chi_{IM}} \pi^{(1-\chi)} P_{IM,t-1} \right)^{1-\theta_{IM}} \right)^{\frac{1}{1-\theta_{IM}}}.$$

2.4.2 Aggregate Resource Constraint

The imposed market-clearing conditions imply the following aggregate resource constraint:

$$\int_0^1 P_{f,t} Y_{f,t} = P_t C_t + P_t I_t + P_t G_t + TB_t,$$

where $TB_t = P_{H,t} X_t - P^D_{IM,t} IM_t$ is the home country's trade balance.

Given the aggregate resource constraint, the domestic holdings of internationally traded bonds (that is, the home country's (net) foreign assets), denominated in foreign currency, evolve over time according to

$$((1 - \Gamma_{B^F}(B^F_t))\, R_{F,t})^{-1} B^F_{t+1} = B^F_t + \frac{TB_t}{S_t}. \tag{7}$$

Overall, the model contains six domestic sources of stochastic shocks in each country: a productivity, an investment, a preference, a labor supply, a mark-up and a monetary policy shock. In addition, there is a white noise exchange rate shock (UIP) which results from variations in the costs of international financial intermediation.

3 Calibration

In order to be able to derive realistic empirical estimates of the gains from cooperation, ideally we would want to have an estimated version of the two-region model discussed above. In the absence of such an estimated version, we have applied three different criteria for parametrizing the model.[4] First, our intention was to keep the impulse response functions of the model close enough to the extended NAWM as described in Coenen et al. (2007). Therefore, we have left some of the parameters that are key in determining the dynamics of the model close to their values chosen in the NAWM. Second, we set the properties of the shocks and the parameter values of the model such as i) to replicate the volatility and correlations of some relevant variables such as output, consumption and investment and ii) to generate realistic contributions of structural shocks to the variances of key endogenous variables. One benchmark in this respect is de Walque et al. (2005).

We set the size of the home country to 0.43 in the model corresponding to the relative GDP share of the euro area with respect to the US. The home bias in the euro area is set to 0.85 and in the U.S. to 0.9 reflecting the fact that the euro area is relatively more open than the US. We have set the habit persistence parameter in both countries to 0.6, which is in line with a weighted average of estimates reported by Schorfheide and Lubik (2005) and de de Walque et al. (2005). The elasticity of labor supply are set in both countries to 2.5. The inverse of the intertemporal elasticity of substitution σ is set to 2.5 in the euro area and to 2 in the US, reflecting the observed relatively higher interest rate sensitivity in the US.

The technology parameter α is set in both countries to 0.36, while the parameters determining the adjustment costs in investment is calibrated to 1.3 in the euro area and 1.1 in the US, reflecting the lower investment volatility in the euro area data. At the same time, the parameter shaping the premium on foreign bonds holding equals 0.001. In both countries, we set the elasticity of substitution between different types of intermediate and imported goods to 6, while the elasticity of substitution between different labor types equals 3. Furthermore, in order to match the negative correlation between output and trade balance in the data, we have calibrated the elasticity of substitution between home and imported goods to 0.7. Price and wage indexation are equal in both countries and are set to 0.6, while the Calvo probabilities in the domestic intermediate goods and import sector as well as in the labor market are set to 0.7 in line with the estimates Schorfheide and Lubik (2005) and de Walque et al. (2005). Finally, the simple monetary policy rule is calibrated as follows. We set the degree of interest rate smoothing at 0.7, the interest rate response to inflation at 1.7, and the interest rate response to output elasticity at 0.1,

[4] In developing the NAWM a two-track strategy is followed. A relative large calibrated two-country version is used for policy analysis (as in Coenen et al. (2007)). An simplified estimated version is used for projections (see Christoffel et al., 2007). The estimated version is still in development and treats the foreign block as exogenous and generated by a VAR.

in both countries.

With regards to the tax rates, we have chosen the values reported in Coenen et al. (2007) and based on OECD data. Namely, we set the consumption tax rate at 0.183 in the euro area and at 0.077 in the US, while labor income tax equals 0.24 in the euro area and 0.22 in the US. Furthermore, the share of government spending in GDP is assumed to equal 20 percent in both regions. The subsidy to firms (τ^f) is set to zero in the steady state.

The calibrated standard deviations of the shocks are shown given in Table 1, while Table 2 compares some of the moments generated by the model with the data for the euro area and the United States. More or less the calibrated model gets right the relative standard deviation of real GDP and its components. However, the standard deviation of inflation generated by the model is too low (a bit more than half that in the data). Also the volatility of the real exchange rate is too low in spite of the addition of uncovered-interest-rate-parity shocks. Importantly for our purposes, the correlation of real GDP, consumption and investment across the two regions is captured quite well. This is partly due to our assumption that productivity shocks have spillover effects across countries (the coefficient of correlation of the two shocks is about 0.74). As highlighted by Justiniano and Preston (2006), open-economy DSGE models have difficulties explaining the comovement of business cycles in the absence of a common component in the underlying shocks. The model captures the negative correlation between GDP and net trade, although it is less than in the data.

Finally, as the source of the shocks is a potentially important determinant of the gains from cooperation, we also make sure that the contributions of the various shocks to the variance of the core macro-variables is reasonable. Table 3 and 4 report the variance decomposition for the euro area and the United States respectively. In line with estimated closed-economy models, we observe that technology and labor supply shocks are the most important drivers of output in the long run. Investment and preference shocks are important sources of variation of investment and consumption respectively, but have only a significant short to medium-run contribution to the variance of output. In both regions, the mark-up shocks in the domestic intermediate goods sector are the most important drivers of inflation, followed by technology shocks. The only shocks that have a non-negligible impact on the variance decomposition of foreign output are the technology shocks. This is a result of the assumption that domestic technology shocks have spill-over effects on foreign productivity as in Backus et al. (1994).

4 Definition of the monetary policy game

The open economy dimension of our model gives rise to an international dimension of monetary policy. While we have used an empirical monetary policy reaction function

to calibrate the two-region model, for the analysis of the gains from cooperation in the next section, we consider two concepts of equilibrium in the game played by the two central banks.[5] In the cooperative equilibrium, both central banks commit to implementing monetary policies that maximize the joint welfare of the euro area and the United States. The joint welfare is a population-weighted sum of the utility of the representative households in both economies. If we denote the aggregate welfare function of each country by $\mathbb{W}_t^i : i = \{EA, US\}$, the global cooperative objective function would be $\mathbb{W}_t^{coop} = s\,\mathbb{W}_t^{EA} + (1-s)\,\mathbb{W}_t^{US}$.

In contrast, in the non-cooperative equilibrium, each central bank maximizes the aggregate welfare function of its own country taking as given the entire path of the foreign central bank's instrument. This corresponds to an open-loop Nash equilibrium (Blake and Westaway, 1995).[6] The non-cooperative equilibrium that emerges from the strategic game played by the central banks depends crucially on the instrument chosen by the two players, as discussed in Canzoneri and Henderson (1989), Henderson and Zhu (1990), Turnovsky and d'Orey (1989) and more recently Lombardo and Sutherland (2006), among others.[7] It is well known that changing the strategy space (i.e. selecting different instrument variables) can give rise to different Nash-equilibria. The current literature on this subject displays a variety of approaches.[8] For example, Obstfeld and Rogoff (2002) consider feedback money supply rules, while Benigno and Benigno (2006) define the strategies in terms of the inflation rate of the domestic GDP-deflators. In this paper, we assume that the central bank is able to control the money supply and define the strategy space of the

[5] Given the dimension of our model, we were forced to neglect optimal fiscal policy issues. Obviously, a complete normative analysis of optimal policies should take into account all available policy instruments. See Lombardo and Sutherland (2004) for a discussion of the global dimension of fiscal and monetary policy in a micro-founded stylized two-periods two-country model. Beetsma and Jensen (2005) discuss the monetary-fiscal interaction in a monetary union in a dynamic two-country model.

[6] The open-loop Nash equilibrium implies that each central bank chooses its inflation rate as the best response to the set of current and future inflation rates chosen by the foreign central bank (Blake and Westaway, 1995). The alternative Nash equilibrium would be a closed-loop equilibrium "for which the sequence of foreign inflation rates is known to be dependent on the other system variables" (Levine et al. (2006)). For reason of tractability we follow the current literature and discuss only the open-loop Nash equilibrium (see e.g. Benigno and Benigno (2006) and Levine et al. (2006)). Clarida et al. (2002) discuss open-loop equilibria in models with monetary policy discretion. Feedback-loop Nash equilibria (i.e. closed-loop) have been studied in small models by Obstfeld and Rogoff (2002), Lombardo and Sutherland (2004). In these models, as in the older literature the distinction between open-loop and closed-loop is less important as the models are essentially static (with pre-set prices). See Canzoneri and Henderson (1992) for examples of strategic set-ups in older models.

[7] The different equilibrium allocation brought about by a Bertrand equilibrium as compared to, say, a Cournot equilibrium, exemplifies the effect that the choice of alternative instruments might have on the outcome.

[8] The older literature on this subject focused more closely on the classical monetary policy instruments, i.e. money supply or interest rates (see Canzoneri and Henderson, 1989). Rogoff (1985) discusses a special case in which taking the price of domestic goods as policy strategy is equivalent to using money supply as strategic variable. In general, though, this is not the case.

non-cooperative equilibrium in terms of the growth rate of nominal money balances. The alternative option of choosing the nominal interest rate as the policy instrument does not deliver saddle-path stable equilibria in the open-loop Nash game (Blake and Westaway, 1995), and therefore would produce a much inferior welfare outcome (at least locally).[9]

A brief description of the solution method is given in the Appendix.

5 The gains from cooperation: results

In the next section we report the welfare differences in terms of the amount of consumption that the typical household would need to give up in order to incur the same loss in a deterministic world.[10]

5.1 Welfare decomposition: baseline results

Table 5 presents our baseline results. The first two lines report the decomposition of the gains from monetary policy cooperation in the euro area and the United States (i.e. the difference in welfare between the cooperative and non-cooperative equilibrium) into the different contributions of the shocks. Furthermore, the table also shows the difference between the conditional mean and variance of consumption, labor, real GDP, inflation and the terms of trade in the cooperative and non-cooperative equilibrium, as well as the contribution of each of the shocks to these differences. The first two variables, consumption and labor, are of interest as they are the primitive arguments of the welfare function. Real GDP and inflation are of interest as they are often used in describing the objective function of central banks. In particular, in first-generation models of monetary policy cooperation inflation and output volatility were often used as the sole arguments of the central bank's objective function.[11] Finally, the terms of trade is a crucial variable in the strategic interaction between the two central banks. The welfare gains of cooperation ($E_{t0}[Welf^{EA}]$ and $E_{t0}[Welf^{US}]$) are expressed in permanent steady-state consumption units (percentages). The other variables are expressed as percentage of their steady-state value. The first column of Table 5 reports the values for the baseline calibration. The other columns display the values for each type of shock separately. Except for the

[9]The equilibrium produced under such a game is locally explosive. One should note that when a central bank chooses the optimal allocation taking as given the foreign interest rate, a locally indeterminate equilibrium would emerge. We conjecture that the central bank would choose a best response to the exogenously given foreign rate such that a the saddle-path equilibrium is re-established. When two such strategies are combined together, they would produce excessive unstable roots.

[10]Denot Δ^W as the welfare gap between two monetary policies. We then solve for λ such that $\Delta^W = (1-\beta)^{-1}\{U((1-\lambda)C_{ss}) - U(C_{ss})\}$

[11]E.g. Rogoff (1985), Canzoneri and Gray (1985) and Sachs (1983), on the second point and Woodford (2003) on the first point.

conditional mean of welfare, the first column is the sum of all the subsequent columns. For welfare the sum is not identically equal to the first column due to the transformation in consumption units. For each single shock, the values that have a different sign from that obtained under all shocks have been underlined.

Based on Table 5 a number of observations are worth highlighting. First of all, the first column of Table 5 shows that the overall gains from cooperation are quite modest, thereby confirming much of the recent literature. For both countries they amount to about 0.03% of steady-state consumption. This value is about one order of magnitude larger than the values suggested by Obstfeld and Rogoff (2002) and within the range of values discussed by Benigno (2001).[12] For the sake of concreteness, making average pro-capita consumption equal to $\$28,000$ per year, the gains from cooperation would amount to a mere \$8.4 per year per head.

In spite of a number of cross-country asymmetries imposed in the calibration, the gains from cooperation are quite similar in both areas. Besides the differences in some of the values of the parameters and standard deviations, an important source of asymmetry is the fact that only dollar-denominated bonds issued by the US are assumed to be traded internationally. This assumption implies that the euro area has an advantage over the US in terms of increased risk-hedging options (e.g. Devereux and Sutherland (2006)). Abstracting from the foreign-asset-return premium, for the US internationally traded bonds provide the same return as domestically traded bonds. It should be noted that the asymmetry discussed here captures only one aspect of the issues related with the currency denomination of foreign assets. Another aspect would emerge had we assumed a non-zero initial (steady-state) net foreign-asset position. In this case there would be a first-order effect of inflation on real income, as discussed by Benigno (2001). As we will show below, the results of broadly symmetric gains across the euro area and the United States does not appear to be very robust as we change some of the parameters.

Turning to some of the key variables in the welfare calculations such as consumption and labor, it is clear from the first column in Table 5 that the gains in welfare come mostly from an increase in the average level of consumption by between 0.04 and 0.05 percent. This gain is partly offset by the fact that both euro area and US households work more in the cooperative equilibrium. As a result, average GDP increases by 0.1 percent in the euro area and 0.07 percent in the United States. Overall, the volatility of the main variables is lower under cooperation, but generally by not much. Turning to inflation, inflation is

[12] Oudiz and Sachs (1984) using large-scale multicountry econometric models came to the conclusion that a coordinated expansion in the face of a global shock, like an oil-price shock of the magnitude seen in the 1970s, would increase US GNP by about 0.5% "...[for] the next few years". Their results, as those of all the first generation literature on this topic, are based on rather different mechanisms than those highlighted by the current-generation literature. In the new literature, certainty equivalence is not imposed so that "... the monetary policy rule does affect the expected trajectory of the economy via agents' responses to risk" (Obstfeld and Rogoff, 2002).

on average lower in the cooperative equilibrium (by 0.07 and 0.05 percent respectively in the euro area and the United States). In other words, lack of cooperation leads to a small inflationary bias. On the other hand, cooperation leads to a small improvement of the terms of trade of the euro area by 0.05 percent.

A second important observation from Table 5 is that the most important source of gains from cooperation are the mark-up shocks. In our model, all shocks produce policy trade-offs due to the large number of inefficiencies (incomplete markets, monopolistic competition, distortionary taxes, sticky wages, sticky prices and imperfect exchange rate pass-through). As a result, cooperation is always better than non-cooperation in response to all of the shocks. However, as argued by Benigno and Benigno (2006), some shocks produce larger incentives for the central banks to move the relative price to their own advantage. This is particularly true for mark-up shocks. This is confirmed by the analysis in Table 5. The mark-up shocks explain more than three fourths of the gains from cooperation. From the variance decomposition in Tables 3 and 4, we know that the mark-up shocks are also the single largest source of inflation volatility, while they account only for a modest share of the volatility of the real variables. In contrast, although productivity shocks play the major role in explaining the volatility in real activity of the euro area and US economies, they don't generate wide discrepancies between the cooperative and the non-cooperative allocations in terms of welfare. Similarly, the contribution of all the other shocks to the gains from cooperation is an order of magnitude smaller than those of the mark-up shocks.

As argued by Canzoneri et al. (2002), the gains from cooperation are increasing in the size of the policy trade-offs generated by the shocks. Shocks that can be easily off-set by a self-oriented central bank do not produce international conflicts of interests. In that case, cooperation would not be welfare improving as also argued by Obstfeld and Rogoff (2002). In contrast, shocks that produce large trade-offs generate strong incentives for the self-oriented central banks to export some of the costs to the other country. When both central banks pursue "beggar-thy-neighbor" policies, the net result will be a deterioration of global welfare. Cooperation, in this case, will be welfare improving.

Figures 1 and 2 compare the response of the euro area and US economy to a mark-up shock and a productivity shock, respectively, under the cooperative and non-cooperative equilibrium and the calibrated monetary policy reaction function. Under the cooperative equilibrium, a positive euro area mark-up shock has the usual negative impact on output and consumption in the euro area. Moreover, in order to stabilize inflation, the nominal interest rate increases and the terms of trade appreciate (although only marginally). More interestingly, the euro area mark-up shock generates positive comovement between euro area and US GDP. In both countries inflation rises and the real wage falls.

The latter is in contrast with the impulse responses under the optimal cooperative policy derived by Benigno and Benigno (2006). In their much simpler open-economy model which only incorporates monopolistic competition and sticky prices, a domestic mark-up

shock generates negative co-movement between economic activity in both countries. As discussed by Benigno and Benigno (2006), in their simple model the crucial determinant of the sign of the international spillovers is the relative size of the intratemporal and intertemporal elasticity of substitution. If the intratemporal elasticity dominates, home and foreign goods are substitutes in the utility function (Corsetti and Pesenti, 2001). In this case a foreign deterioration of the terms of trade will bring about a foreign expansion of production. In contrast, if the intertemporal elasticity of substitution dominates, the two goods are complements and both home and foreign production will contract.

These two parameters, though, are insufficient to describe the relative response of home and foreign output if capital accumulation is introduced in the model. In our model, as it would happen in the Benigno and Benigno (2006) setup cum capital accumulation, the spillovers are positive under the optimal cooperative policy, at least on impact.

Qualitatively, the responses under the optimal cooperative policy are very similar to those under the calibrated monetary policy reaction functions. The discrepancy with the non-cooperative policies is, however, quite large. The short-term interest rates and the terms of trade respond in a much more volatile fashion and this is reflected in a more volatile response of consumption and GDP. It is also clear that the initial response of GDP is negative in the euro area, but positive in the US as the euro area monetary authorities attempt to export some of the volatility in the labor costs to the foreign country.

A quite different picture is obtained in Figure 2 regarding the effects of a productivity shock. In this case, the impulse responses under the cooperative and non-cooperative equilibrium are quite similar, confirming the limited contribution of those shocks to the gains from cooperation. These impulse responses are also quite similar to those under the calibrated policy rule. As is to be expected following a temporary positive productivity shock in both countries, consumption, output and wages rise persistently, while nominal interest rates and inflation fall. The domestic terms of trade deteriorate as the productivity shock increases relative supply of the domestic goods.

As mentioned earlier, the single most important shock in accounting for the gains from cooperation (i.e. summing up the EA and US welfare gains) is the mark-up shock. We should expect that the randomness in the home mark-up will partially spill-over to the volatility of the home firms' optimal price. The home domestic-price index is a concave function of individual prices. This implies that the expected home domestic-price index is lower than its non-stochastic value. This is true also when we measure the expected home domestic-price index relative to the CPI index. The lower expected price implies a higher expected demand and, ceteris paribus, lower expected average profits, as firms expect, on average, to be off their supply curve. The expected foreign domestic-price index, relative to the CPI, will be higher, as the CPI is partially affected by the drop in the home domestic-price index. Therefore, demand is expected to switch partially from the foreign goods to the home goods. Whether this effect is welfare increasing or not will

likely depend on the net increase in consumption and labor effort.[13] Each central bank, taken in isolation, will try to increase consumption while reducing labor effort.[14] The policy makers would attempt to do this by affecting the (expected) terms of trade. When both banks act in this way, the net result will be a deterioration of welfare compared to the cooperative equilibrium.

5.2 Welfare decomposition: sensitivity analysis with respect to nominal rigidities

While Table 5 shows the results for the calibrated (benchmark) model, Tables 6 and 7 report the results from a sensitivity analysis. We report in each case the overall gain in welfare and its various components, as well as the contribution of the euro area and US mark-up shock and the sum of the other shocks in each region. Also in these cases, the mark-up shocks are by far the most important contributors to the welfare gains. In interpreting many of these exercises, it is important to realize that the size of the welfare losses in general ceases to have a solid empirical basis. For example, imposing flexible prices, while maintaining all other parameters unchanged, gives the mark-up shocks a disproportionate effect on output.[15] These results, therefore, should only be taken as indicative of the sensitivity of the welfare losses to some of the parameters of the model. Deriving empirically sound confidence bands for the welfare losses would require a more complex approach that is beyond the scope of the present work and that we leave for future research.[16]

We first investigate the role of indexation in the intermediate-goods sector (Table 6). The Table shows that without indexation, the gains from cooperation rise only marginally from about 0.05 to 0.09 percent of steady-state consumption. However, the cross-country "spillover effects" change sign: i.e. while euro area welfare gains increase in their own mark-up shock and decrease in the US mark-up shock, the reverse happens in the foreign country. In other words, according to these results the EA would be better off not to adopt the cooperative policy if there were only US mark-up shocks. Turning to the

[13] That welfare could be higher in the stochastic equilibrium as compared to the non-stochastic equilibrium is a well known fact in economics. Cho and Cooley (2003) offer a recent discussion of this result.

[14] Using a simple two-country model à la Benigno and Benigno (2006), we can see that the optimizing (cooperative) central bank will try to increase consumption and labor more under an inefficient steady state than under an efficient steady state.

[15] For example, the terms of trade would have a standard deviation about seven times larger than in the data. EA and US GDP volatility would be twice as large as in the data, while they would be negatively cross-correlated. A number of other moments would be strongly altered. Finally, mark-up shocks would explain between 54% (EA) and 45% (US) of the volatility of GDP (at 12 quarters).

[16] In this regard the ranges suggested by Benigno (2001) should also be taken with a grain of salt, as they derive from varying some parameters without discussion of the implications for the empirical fit of the model.

degree of price stickiness in the intermediate-goods sector itself, Table 6 shows the effect of reducing price stickiness by half in the intermediate-good sector. Higher flexibility in the intermediate-goods sector increases the gains from cooperation quite drastically. In particular, halving the Calvo probability leads to welfare gains of 10 and 17 percent. As mentioned earlier, this result should be interpreted with particular caution, as reducing the degree of price rigidity increases the weight of mark-up volatility in the volatility of the whole economy beyond what we observe in the data.

It is also of particular interest to study the role of the incomplete pass-through of the exchange rate in generating gains from cooperation. In Table 6, the degree of pass-through was increased by assuming that retail prices of imported goods are twice as flexible as in the benchmark model. A higher pass-through marginally reduces the overall gains from cooperation. However, under this assumption domestic mark-up shocks reduce the domestic welfare gains while they improve the foreign welfare gains.[17] Notice, furthermore, that the welfare gains associated to mark-up shocks cease to be symmetric. Table 6 shows what happens if import prices are not indexed to domestic CPI inflation. The sign of the contribution of mark-up shocks to the gain from cooperation is the same as in the previous case. In this case, though, symmetry is preserved.

Finally, we also had a look at the impact of changes in nominal wage rigidity and wage indexation. Somewhat surprisingly, those nominal rigidities do not seem to have a large impact on the gains from cooperation.

5.3 Some critical parameters

In this section, we discuss the implications of differences in some of the parameters of our model that have received particular attention in the international monetary policy cooperation literature. We discuss them in the following paragraphs.

Home bias in consumption The first experiment relates to the role of home bias in demand. This is a particularly important aspect of our model. It is natural to expect that the gains from cooperation would be higher the higher the economic integration of the countries involved. Quoting Oudiz and Sachs (1984, p.5-6) "... the direct effects of commodity trade on macroeconomic interdependence remain surprisingly small; at the core, it is these relatively small trade links that condition our conclusions regarding the returns to coordination". These authors were talking about export and import shares to GNP between the European Community and the US (1982) of between 1.4 and 2.2

[17] For the sake of comparison, we ran a similar experiment on the simple two-country model à la Benigno and Benigno (2006). This simple model would predict that domestic mark-up shocks are detrimental for domestic welfare gains from cooperation and beneficial for the foreign gains. This result is strongly sensitive to whether wages are flexible or not and to whether international financial markets are complete or not. The model-dependence of these results make a generalization of them nearly impossible.

percent. While these numbers have increased somewhat since then, they remain relatively small. Our calibration implies that, in the non-stochastic steady state, US exports to the EA is about 8% of US GDP while US imports from the EA is about 11% of US GDP. EA exports to the US is about 14% of EA GDP, while EA imports from the US is about 11% of EA GDP. Table 7 shows the polar case of equal sized countries and no home bias. Although this assumption might look extreme if compared with our benchmark parametrization, the variance decomposition of shocks and the moments (standard deviations and cross-correlations) of the model are not dramatically different from those obtained in our benchmark calibration. Nevertheless, the gains from coordination, absent home bias, are huge. They reach 21.5% for the EA and 25.3% for the US. Almost all of these gains are due to mark-up volatility.

Table 7 offers an intermediate case, where the trade shares have been increased to about 32% of GDP in both countries (equal size and home-bias parameter set to 0.65). In this case the welfare gains are almost two orders of magnitude larger than in the benchmark calibration, reaching about 0.74% of steady-state consumption in the EA and about 1.0% of steady-state consumption for the US.

Inter- and intra-temporal elasticity of substitution Corsetti and Pesenti (2001) show that the cross-country spill-over effect of monetary policy crucially depends on the size of the inter-temporal elasticity of substitution relative to the intra-temporal elasticity (i.e. the elasticity of substitution between imported goods and domestically produced goods). With CES goods aggregators and CRRA utility function, the sign of the cross derivative of the utility function with respect to the domestically produced bundle of goods and the imported bundle of goods depends on the size of the intra-temporal elasticity of substitution relative to the size of the inter-temporal elasticity of substitution. If the former is larger than the latter, the two bundles are substitutes, if smaller, they are complements. If they have the same size, the consumption spill-overs are nil. Nevertheless, even in the latter case, policy spill-overs could still be present if monetary policy can affect the international distribution of labor effort. So, for example, an improvement of the terms of trade would tend to export labor effort abroad. While the extent of this effect increases in the intra-temporal elasticity of substitution, the income gains decrease in this elasticity: In the spirit of the "optimum tariff" argument, the lower is the intra-temporal elasticity of substitution, the larger the monopolistic rent that the country can extract internationally.

Table 7 shows the welfare-decomposition results for different values of the inter- and intra-temporal elasticity of substitution. The main result of our paper remains unchanged: the gains from cooperation are very modest.

A more detailed look at the results shows that the gains from cooperation seem to

decrease in the intra-temporal elasticity of substitution (Table 7).[18]

Market completeness In Obstfeld and Rogoff (2002) the cooperative central banks face a trade-off between stabilization and increased tradable-consumption risk sharing.[19] This holds true also in our benchmark calibration, although the trade-off is more complex involving a larger number of margins.

Increasing the degree of consumption risk sharing is welfare improving. Nevertheless, without cooperation risk sharing cannot be achieved. This fact, per se, will generate a gap between the cooperative and non-cooperative allocations.

Table 7 reports the results of our decomposition of the welfare gains from cooperation when international financial markets are complete. Now the gains from cooperation are about one order of magnitude smaller than in the benchmark calibration. In the same table we show that a sizable reduction of the gains from cooperation is obtained by introducing market completeness in a model with larger trade shares.

6 Performance of simple rules

This paper does not focus on the performance of simple interest rate rules nor on the welfare gains from cooperation when the central banks commit to simple rules. Nevertheless, it is of interest to assess the performance of the simple rule used in the calibration vis-à-vis the cooperative rule. Table 8 shows that the loss incurred in adopting the calibrated rule as opposed to the optimal cooperative policy are not very large. Levin et al. (2005) in a closed economy model estimated with US data, find that the loss incurred by adopting the estimated simple interest rate rule as opposed to the optimal policy, implies a welfare cost of about 0.56% of steady-state consumption. We find a welfare cost that is about five time smaller.

It is indeed not difficult to find a very simple interest rate rule, in our model, that reduces the costs even further. In order to address this point we performed a rather simple experiment. We assumed that the two central banks can commit themselves to interest rate rules that merely respond to current CPI inflation. We then computed the difference between the total welfare (euro area plus US in consumption units) under these rules for different values of the response coefficients.[20] The result is shown in Figure 3. One can see that a strong response to inflation reduces the distance from the optimal cooperative

[18] Benigno (2001) shows that the gains are not monotonic in the intra-temporal elasticity. We have considered also values of 2, 4, and 6 for the intra-temporal elasticity confirming that in this range the welfare gains seem to be lower the larger this elasticity.

[19] In their model the risk sharing motive is absent when the intertemporal elasticity of substitution is unitary.

[20] Adding the steady-state consumption equivalents introduces an imprecision due to the non-linear transformation (as opposed to adding the welfare levels). The imprecision is negligible and does not alter the results.

rule. In particular, we find that the best simple rule (within the range considered) implies a loss of 0.1361% for the EA and 0.0762% for the US.

7 Conclusion

In this paper, we have analyzed the gains from monetary policy cooperation in a quantitative two-region DSGE model for the euro area and the United States. Our main results are threefold. First, in line with the recent literature, we find that the gains from cooperation are small in the benchmark model. They amount to about 0.03 percent of steady-state consumption. This is an order of magnitude higher than the gains suggested by Obstfeld and Rogoff (2002), but nevertheless very small. Second, decomposing the sources of the gains from cooperation with respect to the various shocks, we find that mark-up shocks are the most important source for gains from international monetary policy cooperation. Third, a sensitivity analysis with respect to various key parameters of the model suggests that the gains from cooperation become larger the more open the economy. With import and export shares of 30 percent, the gains from cooperation can be of the order of magnitude of 1 percent of steady-state consumption.

There are various potentially fruitful avenues for further research. First, in the absence of a fully estimated two-region version of the NAWM, we have used a calibrated version of the model. Performing the same analysis on an estimated model would be useful in providing a benchmark for performing robustness and sensitivity analysis. In particular, one could use the posterior distribution of the model to calculate the empirically relevant range of the gains from cooperation given the structure of the economy. Second, we have focused on price mark-up shocks as the only inefficient sources of variation in the dynamics of the economy (with the exception of the exchange rate shocks). A full empirical analysis should also investigate the impact of mark-up shocks in the labor market and the imported goods sector. Third, we have limited our analysis of the non-cooperative equilibrium to an open-loop Nash equilibrium where the monetary policy instruments are defined in terms of nominal money growth rates. An alternative and possibly more plausible game is one where each monetary authority takes the reaction function of the foreign central bank as given. Solving such closed-loop Nash games in medium-scaled DSGE models is, however, still a computational challenge. Fourth, the importance of mark-up shocks for the gains from cooperation raises questions about the micro-foundations of those shocks. A deeper theory of why prices are sticky and what are the sources of the high-frequency variation in some prices would be important to gain more confidence in the welfare implications of such mark-up shocks.

Appendix

Description of the solution method

The cooperative and non-cooperative (open-loop Nash) non-linear first-order conditions of the policymakers' problem were derived using our Matlab code (compatible with DYNARE (Juillard, 1996)). This code ("Lq-solution") is available from the authors on request. The derivation of the policy maker's first order conditions is based on Benigno and Woodford (2006).

As money is neutral in the steady state of our model, the solution of the steady state value of the endogenous variables is independent of the solution of the steady-state value of the Lagrange's multipliers of the policy problem. The steady-state of the structural equations was solved using a suite of non-linear solvers (SolvOpt, by Kuntsevich and Kappel (1997), SA (simulated annealing) by Goffe (1996) and Matlab's fsolve with use of the analytical Jacobian of the model). The steady-state value of the Lagrange's multipliers is then obtained by solving a simple Least-squares problem.

The (first- and second-order accurate) state-space solution of the model (under the different specifications of monetary policy) was then obtained using Dynare (version 4).

The conditional moments were constructed by iterating the first- and second-order accurate state-space solutions returned by Dynare.

For the calibration exercise we used a combination of Dynare output and our own Matlab codes (including HP filtering).

Tables

Table 1: Standard Deviation of the Shocks

Preference Shock Home	0.018
Preference Shock Foreign	0.018
Investment Home	0.044
Investment Foreign	0.009
Monetary Policy Home	0.002
Monetary Policy Foreign	0.0026
Productivity Home	0.0054863
Productivity Foreign	0.0054863
Mark-up Home	0.06
Mark-up Foreign	0.06
Labour Supply Foreign	0.07
Labour Supply Home	0.06
UIP	0.01

Table 2: Stylized Facts of the Model

	Euro Area				US	
Standard Deviation	Model	Data	Model	Data	Model	Data
GDP	0.89	0.93			1.01	1.02
Consumption	0.59	0.80			0.76	0.90
Investment	2.56	2.60			3.71	4.9
Inflation	0.57	1.05			0.65	1.20
Real Exchange Rate			2.00	7.00		
Net Trade			0.26	0.46		
Cross Correlation over Countries						
GDP			0.43	0.29		
Consumption			0.14	0.14		
Investment			0.25	0.17		
Cross Correlation within Countries						
GDP-Net Trade	-0.28	-0.69			-0.47	-0.39
Consumption -Net Trade	-0.19	-0.75			-0.17	-0.45
Investment - Net Trade	-0.23	-0.79			-0.23	-0.51

Table 3: Variance Decomposition

	Euro Area				
	Output	Consumption	Investment	Inflation	REX
Euro Area Shocks					
Technology	55.4	25.7	42.4	27.9	9.33
Labour Supply	19.3	5.5	15.4	8.19	10.9
Investment	1.01	0.81	6.41	0.13	0.31
Preferences	2.37	51.3	16.1	3.55	7.71
Markup	5.57	1.16	1.82	52	8.76
Monetary Policy	1.00	0.41	0.64	1.69	4.42
US Shocks					
Technology	14.8	13.5	12.1	4.92	13.7
Labour Supply	0.17	0.89	0.38	0.10	16.5
Investment	0.14	0.26	4.14	0.91	3.18
Preferences	0.12	0.29	0.56	0.26	3.72
Markup	0.06	0.06	0.02	0.22	9.8
Monetary Policy	0.04	0.07	0.01	0.07	7.43
UIP	0.00	0.00	0.00	0.02	4.24

Table 4: Variance Decomposition

	United States			
	Output	Consumption	Investment	Inflation
Euro Area Shocks				
Technology	10.9	9.29	6.48	3.78
Labour Supply	0.02	0.12	0.07	0.02
Investment	0.00	0.00	0.03	0.01
Preferences	0.02	0.13	0.17	0.05
Markup	0.00	0.01	0.00	0.04
Monetary Policy	0.00	0.00	0.00	0.01
US Shocks				
Technology	47	26.9	28.7	24.6
Labour Supply	22.9	9.71	15.1	47.3
Investment	9.67	14.8	39.2	3.15
Preferences	2.2	36.5	7.34	2.65
Markup	5.53	1.59	1.95	53.8
Monetary Policy	1.73	0.86	0.94	2.47
UIP	0.00	0.00	0.00	0.00

Table 5: Welfare Decomposition: Benchmark calibration

Variable	All shocks	UIP	mkp^{EA}	$prod^{EA}$	lab^{EA}	inv^{EA}	$pref^{EA}$	mkp^{US}	$prod^{US}$	lab^{US}	inv^{US}	$pref^{US}$
$E_{t0}[Welf^{EA}]$	0.0272	0.0015	0.0141	0.0016	0.0006	0	0.0001	0.0065	-0.0001	0.0021	0.0008	0
$E_{t0}[Welf^{US}]$	0.0294	0.003	0.0072	0.0002	0.0017	0	0.0002	0.014	0.0018	0.0012	-0.0001	0.0002
$E_{t0}[Cons^{EA}]$	0.0392	0.0012	0.0203	0.0024	0.0017	0	0.0003	0.0082	0.0007	0.0037	0.0006	0.0002
$Var_{t0}[Cons^{EA}]$	-0.0006	0	-0.0001	0.0003	-0.0002	0	0	-0.0004	0.0001	-0.0002	0	0
$E_{t0}[Cons^{US}]$	0.0415	0.002	0.0085	0.0009	0.0028	0	0.0004	0.0231	0.0026	0.0006	0.0003	0.0003
$Var_{t0}[Cons^{US}]$	-0.0003	-0.0001	-0.0002	0.0003	0	0	0	0	0.0003	-0.0007	0	0
$E_{t0}[Lab^{EA}]$	0.0491	0.0005	0.0221	0.0026	-0.0026	0	0.0005	0.0203	0.0006	0.0052	-0.0004	0.0003
$Var_{t0}[Lab^{EA}]$	-0.009	-0.0003	0.0002	-0.0018	-0.0034	0	0.0001	-0.004	-0.0001	0.0001	0	0.0001
$E_{t0}[Lab^{US}]$	0.0212	0.0009	0.0086	-0.0004	0.001	0	0.0002	0.0187	0.0016	-0.0103	0.0011	0
$Var_{t0}[Lab^{US}]$	-0.0093	-0.0005	-0.0015	-0.0001	0.0006	0	0.0001	0.001	-0.0009	-0.0079	0	0
$E_{t0}[Infl^{EA}]$	-0.0712	-0.0006	-0.0117	-0.0017	-0.0178	-0.0001	-0.0036	-0.0123	-0.0044	-0.016	-0.0003	-0.0026
$Var_{t0}[Infl^{EA}]$	-0.0003	0	-0.0001	0	-0.0001	0	0	-0.0001	0	0	0	0
$E_{t0}[Infl^{US}]$	-0.0528	-0.0003	-0.0038	-0.0029	-0.0125	0	-0.003	-0.0097	-0.0021	-0.0153	-0.0009	-0.0023
$Var_{t0}[Infl^{US}]$	-0.0002	0	0	0	0	0	0	0	0	-0.0002	0	0
$E_{t0}[GDP^{EA}]$	0.1099	0.0009	0.055	0.0052	0.0035	0.0001	0.0008	0.0299	0.002	0.0117	0.0002	0.0007
$Var_{t0}[GDP^{EA}]$	-0.0019	-0.0001	0.0001	0.0006	-0.0015	0	0.0001	-0.0016	0.0005	0.0001	0	0
$E_{t0}[GDP^{US}]$	0.0701	0.0013	0.0153	0.0005	0.0035	0	0.0005	0.0502	0.0034	-0.0056	0.0008	0.0002
$Var_{t0}[GDP^{US}]$	-0.003	-0.0002	-0.0006	0.0006	0.0002	0	0	0.0004	0.0003	-0.0037	0	0
$E_{t0}[tot]$	-0.0589	-0.0065	-0.0624	0.0067	-0.0096	0.0003	-0.0003	0.0059	-0.0007	0.0118	-0.0046	0.0003
$Var_{t0}[tot]$	-0.1478	-0.0014	-0.0386	-0.0026	-0.0225	0	-0.0015	-0.0487	-0.0071	-0.0239	-0.0001	-0.0014

Table 6: Welfare Decomposition: Nominal rigidities and indexation

Variable	All shocks	mkp^{EA}	mkp^{US}	$\sum_{EA}$ other shocks	$\sum_{US}$ other shocks
Lower price rigidity in intermediate-goods sector (Calvo pr. = 0.35)					
$E_{t0}[Welf^{EA}]$	10.9639	6.1409	5.397	0.1241	0.1271
$E_{t0}[Welf^{US}]$	18.0099	8.2732	11.0678	0.2592	0.2412
Higher exchange-rate pass through (Calvo pr. = 0.35)					
$E_{t0}[Welf^{EA}]$	0.0353	-0.011	0.0456	0.0003	0.0004
$E_{t0}[Welf^{US}]$	-0.0001	0.0251	-0.0266	0.0011	0.0003
Lower wage rigidity (Calvo pr. = 0.35)					
$E_{t0}[Welf^{EA}]$	0.0181	0.0078	0.0022	0.004	0.0041
$E_{t0}[Welf^{US}]$	0.0207	0.0046	0.0093	0.004	0.0028
No indexation of prices in intermediate-goods sector					
$E_{t0}[Welf^{EA}]$	0.0376	0.051	-0.0236	0.0058	0.0045
$E_{t0}[Welf^{US}]$	0.0549	-0.0217	0.0629	0.008	0.0058
No indexation of import prices					
$E_{t0}[Welf^{EA}]$	0.0438	-0.0115	0.0486	0.0034	0.0033
$E_{t0}[Welf^{US}]$	0.0433	0.0487	-0.0136	0.0053	0.003
No indexation of wages					
$E_{t0}[Welf^{EA}]$	0.0271	0.0152	0.0052	0.004	0.0028
$E_{t0}[Welf^{US}]$	0.0294	0.0058	0.0149	0.0053	0.0034

Table 7: Welfare Decomposition: Further sensitivity analysis

Variable	All shocks	mkp^{EA}	mkp^{US}	$\sum_{EA}$ other shocks	$\sum_{US}$ other shocks
Unitary intra-temporal elasticity of substitution					
$E_{t0}[Welf^{EA}]$	0.0086	0.0061	-0.0009	0.0017	0.0018
$E_{t0}[Welf^{US}]$	0.0065	-0.001	0.0052	0.0015	0.0007
Higher intra-temporal elasticity of substitution (1.7)					
$E_{t0}[Welf^{EA}]$	0.0031	0.0013	0.0005	0.0005	0.0008
$E_{t0}[Welf^{US}]$	0.0037	0.0007	0.0016	0.0009	0.0005
Equal intra- and inter-temporal elasticities (0.7)					
$E_{t0}[Welf^{EA}]$	0.0016	-0.0007	-0.0029	0.0031	0.0021
$E_{t0}[Welf^{US}]$	0.0422	0.0148	0.0178	0.0074	0.0022
Equal country size and no home bias					
$E_{t0}[Welf^{EA}]$	21.5074	11.2688	10.0618	3.106	1.4399
$E_{t0}[Welf^{US}]$	24.8622	11.2348	13.0827	3.556	1.7581
Equal size and lower home bias (0.65)					
$E_{t0}[Welf^{EA}]$	0.7382	0.3876	0.1818	0.1384	0.0348
$E_{t0}[Welf^{US}]$	0.961	0.2237	0.5004	0.175	0.068
Complete markets (benchmark calibration)					
$E_{t0}[Welf^{EA}]$	0.0044	0.0026	-0.0008	0.0017	0.0009
$E_{t0}[Welf^{US}]$	0.0024	0.0005	0.0022	-0.0002	-0.0001
Complete markets, equal size and lower home bias (0.65)					
$E_{t0}[Welf^{EA}]$	0.0269	0.0096	0.0158	0.0013	0.0002
$E_{t0}[Welf^{US}]$	0.0381	0.0219	0.0136	0.0016	0.001

Table 8: Welfare Decomposition: Cooperative policy vs. calibrated simple rules

Variable	All shocks	mkp^{EA}	mkp^{US}	$\sum_{EA}$ other shocks	$\sum_{US}$ other shocks
$E_{t0}[Welf^{EA}]$	0.1366	0.0145	0.0248	0.055	0.0424
$E_{t0}[Welf^{US}]$	0.1067	-0.0088	-0.0161	0.0224	0.1092

Figures

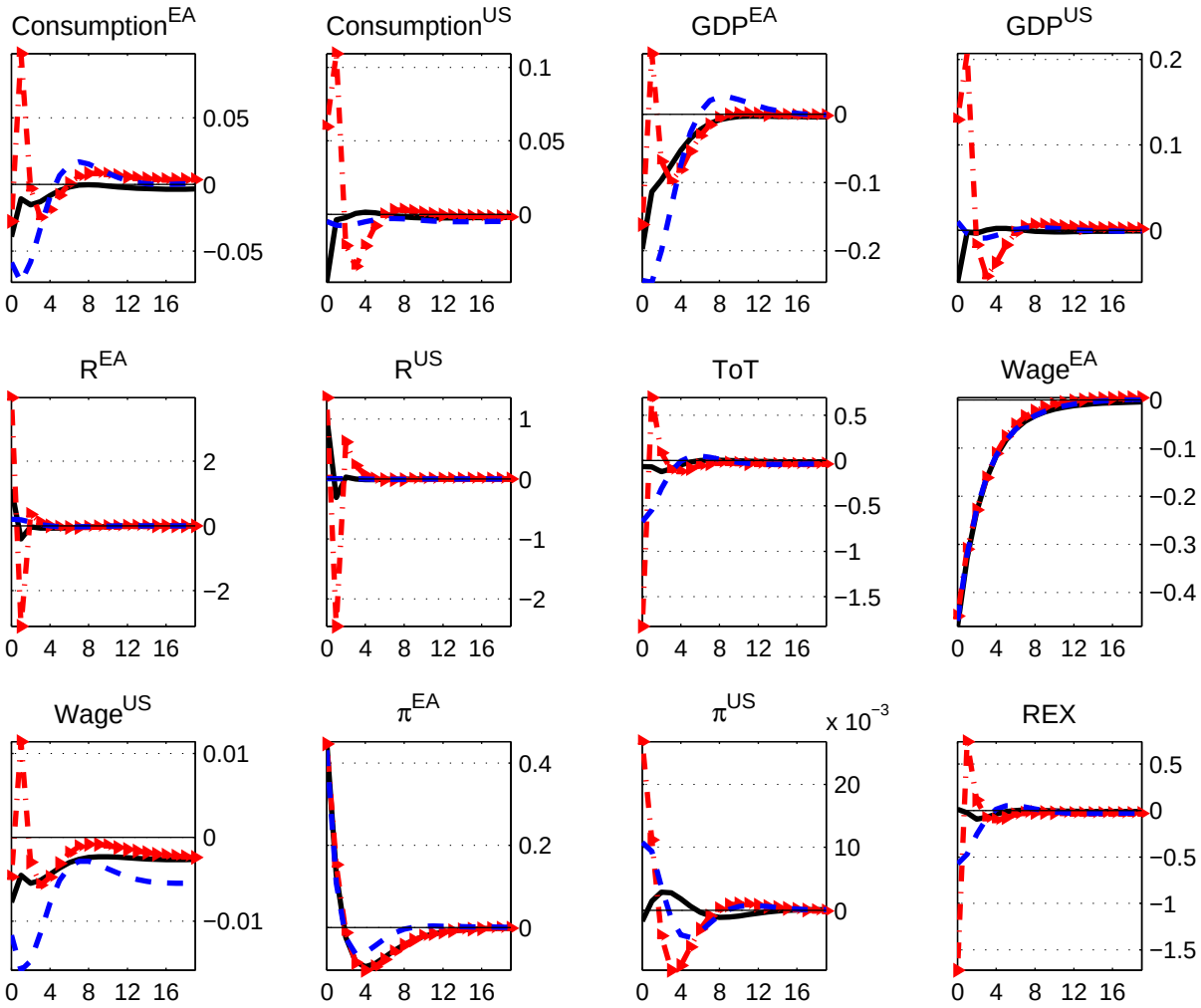


Figure 1: EA mark-up shock: Coop. (solid), Nash (arrowed-dashed), Rule (dashed)

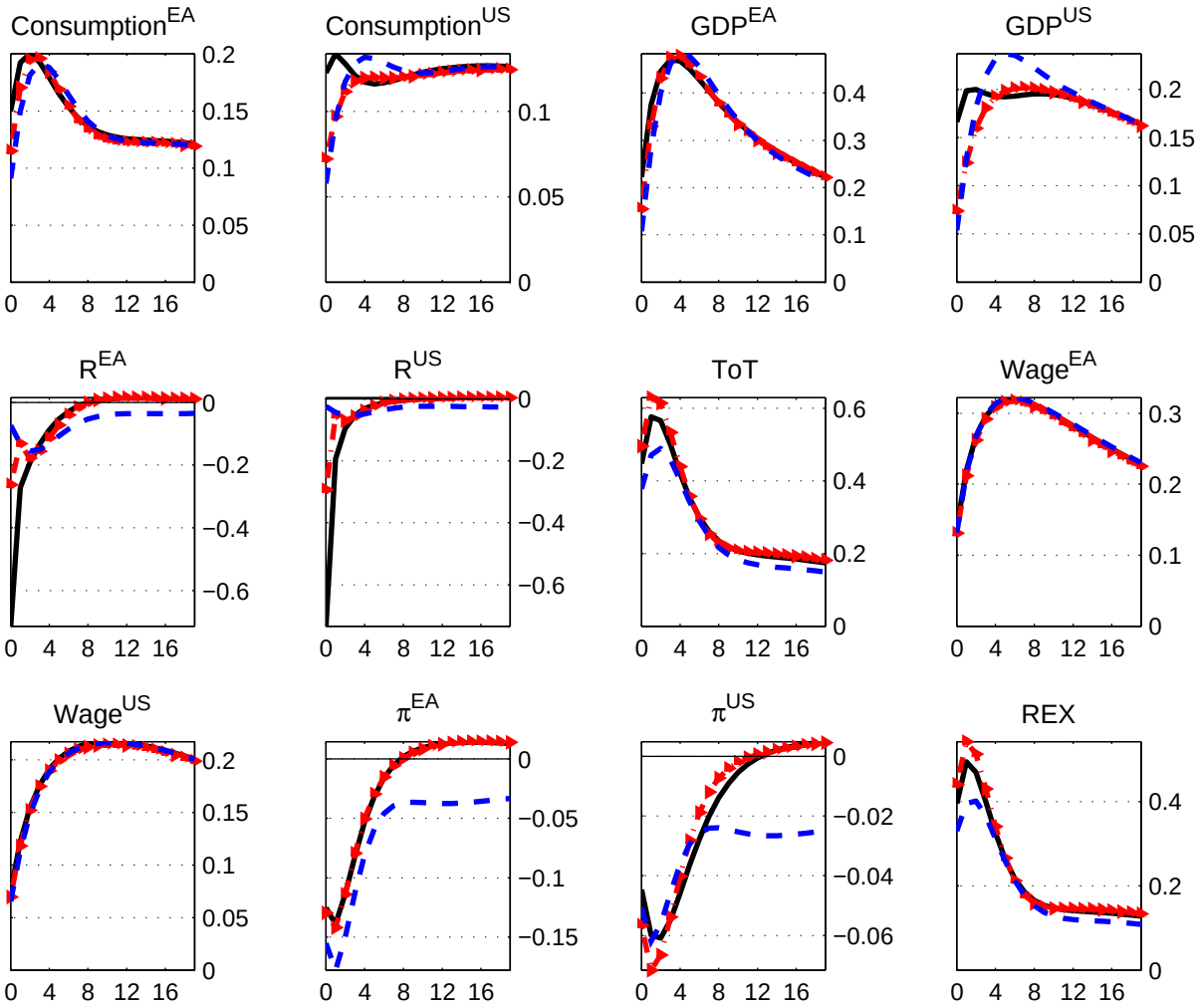


Figure 2: EA productivity shock: Coop. (solid), Nash (arrowed-dashed), Rule (dashed)

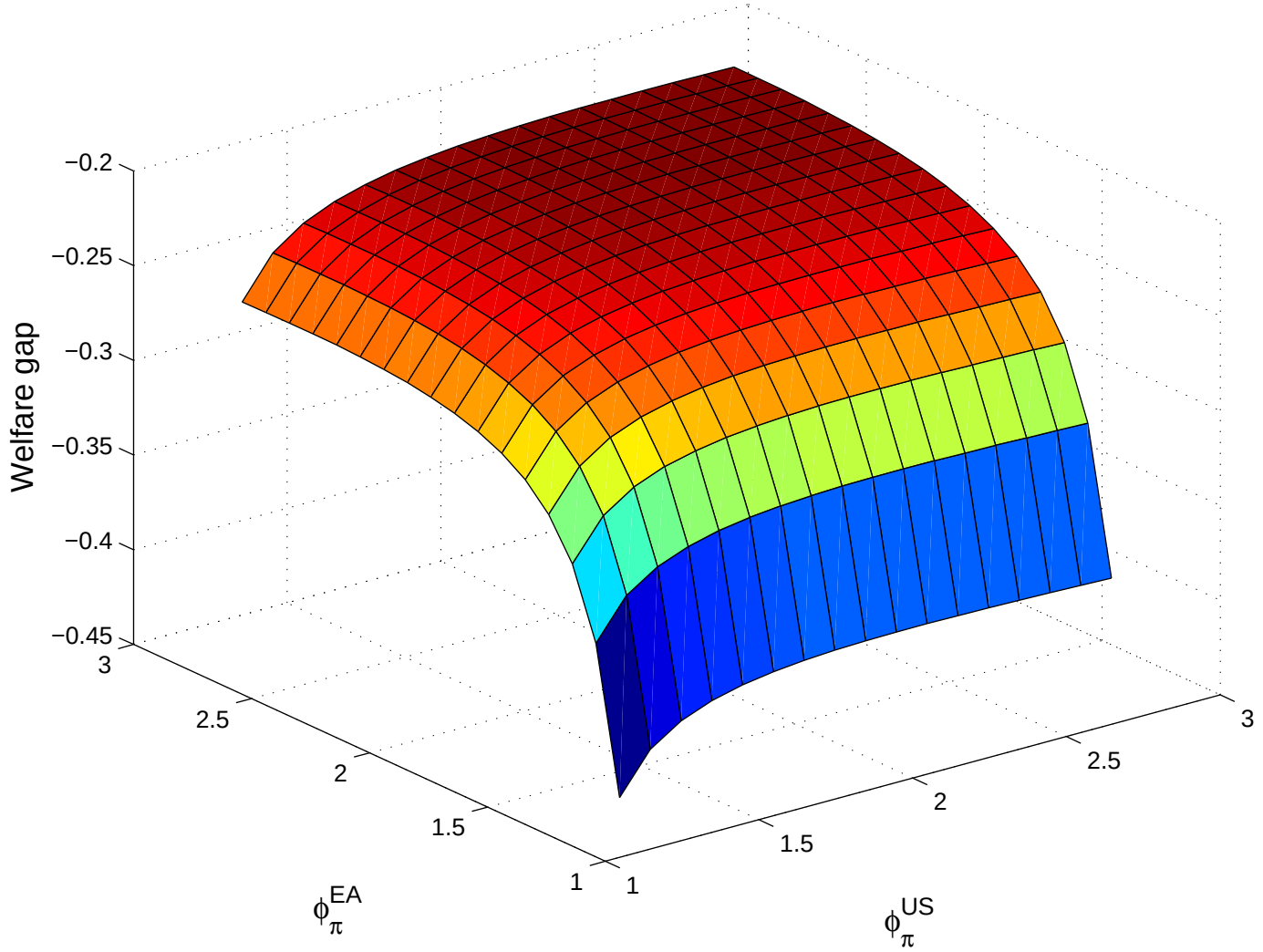


Figure 3: Global welfare under the simple rule in deviation from cooperative optimum (consumption equivalent units)

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