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Volume Title: International Dimensions of Monetary Policy

Volume Author/Editor: Jordi Gali and Mark J. Gertler, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-27886-7

Volume URL: http://www.nber.org/books/gert07-1

Conference Date: June 11-13, 2007

Publication Date: February 2010

Chapter Title: International Transmission and Monetary Policy Cooperation

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Chapter URL: http://www.nber.org/chapters/c0513

Chapter pages in book: (157 - 192)

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International Transmission and Monetary Policy Cooperation

Günter Coenen, Giovanni Lombardo, Frank Smets, and Roland Straub

3.1 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." Hamada's seminal paper has spurred a large literature addressing this issue using a variety of models, methodologies, and game-theoretic concepts. The literature of the 1980s (e.g., Canzoneri and Gray 1985; 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 microfoundations 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

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This chapter was prepared for the NBER conference "International Dimensions of Monetary Policy," S'Agaró, Spain, 11–13 June 2007. We thank the organizers of the conference, Mark Gertler and Jordi Galí, the participants to the conference, and in particular our discussant Chris Sims, for their useful comments and suggestions. All remaining errors are our sole responsibility. The views expressed in this chapter do not necessarily reflect those of the European Central Bank.

from cooperation are at best very small. However, Canzoneri, Cumby, and Diba (2002) pointed out that the NOEM literature, per se, does not imply that self-oriented policy-making 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 chapter, we attempt to move in that direction and therefore to close the circle with papers like Oudiz and Sachs (1984)—written 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 European Central Bank (ECB). The NAWM is a two-region dynamic stochastic general equilibrium (DSGE) model that is calibrated to represent the euro area (EA) and U.S. economies. The version used in this chapter is a simplified version of the model presented in Coenen, McAdam, and Straub (2007), which has been recalibrated 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 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, markup, 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 chapter 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, 2004b) and Schmitt-Grohé and Uribe (2004a, 2004b, 2007a). 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, Galí, and Gertler

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.

(2002) and Benigno and Benigno (2003). In the benchmark Cournot-Nash game, we assume that each central bank takes the money growth path of the foreign central bank as given. However, we also discuss alternative choices of instruments and present results based on simple interest rate feedback rules.

Three conclusions of our benchmark analysis are worth highlighting. First, we show that the gains from cooperation are very sensitive to the degree of international economic integration. Given the current degree of openness of the U.S. and euro area economies, and in line with the recent literature, we find that the gains from cooperation are small. 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. Allowing for stronger economic integration between the two regions can bring about sizable gains from cooperation. For example, when the share of import in gross domestic product (GDP) is increased from 10 to 15 percent to about 32 percent in both regions, the gains from cooperation rise to about 1 percent of steady-state consumption. Second, by decomposing the sources of the gains from cooperation with respect to the various shocks, we confirm the findings of Benigno and Benigno (2006) that the markup shocks can bring about larger gains from cooperation. Overall, the gains from cooperation are an order of magnitude larger for the markup 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. 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. It is also 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.

Not surprisingly, the discussion of the results of alternative assumptions regarding the strategy space (i.e., the open-loop Nash game and the simple closed-loop interest rate feedback Nash games) highlights that the size of the gains from cooperation depends very much on the definition of the noncooperative game. However, we argue that for the most reasonable definitions, the conclusions highlighted previously hold.

The rest of the chapter is structured as follows. Section 3.2 lays out the main structure of the two-region DSGE model. Section 3.3 discusses its calibration. Section 3.4 presents the two monetary policy games we study. Section 3.5 discusses the main results. Section 3.6 discusses the gains from cooperation when central banks follow simple feedback rules. Section 3.7 contains the conclusions.

3.2 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 simplified version of the NAWM discussed in Coenen, McAdam, and Straub (2007). In particular, relative to Coenen, McAdam, and Straub (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 markup in the domestic goods market. Furthermore, we also assume incomplete international asset markets in order to 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 that 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.

3.2.1 Households

The preferences of household i are described by the following intertemporal constant relative risk aversion (CRRA) utility function

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

2. The model builds on recent advances in developing microfounded 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, Laxton, and Pesenti 2001) or the Federal Reserve Board's new open economy model named SIGMA (Erceg, Guerrieri, and Gust 2006).

where $C_{i,t}$ is a consumption index, $N_{i,t}$ denotes 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 the 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 in the following). The inverse of the interest rate elasticity of money is denoted by ψ and the weight of money balances in the utility function is denoted by ε^M. The consumption price index (CPI) is P_t, defined later. Following most of the open economy related literature (e.g., Obstfeld and Rogoff 2002) 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:

$$(1 + \tau_t^C)P_tC_{i,t} + P_tI_{i,t} + R_t^{-1}B_{i,t+1} + M_{i,t+1} + ((1 - \Gamma_{B^F}))R_{F,t})^{-1}S_tB^F_{i,t+1}$$
$$= (1 - \tau_t^N)W_{i,t}N_{i,t} + R_{K,t}K_{i,t} + D_{i,t} + T_{i,t} + B_{i,t} + S_tB^F_{i,t} + M_{i,t},$$

where R_t and R_t^F denote the riskless 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). The labor services provided to firms at wage rate $W_{i,t}$ is denoted by $N_{i,t}$, 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 and wage income taxes into the model, denoted by τ_t^c and τ_t^N, respectively.

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 of the single household's position. Finally, it is implicitly assumed that households hold state-contingent securities. These securities are traded among 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 households. As a result, all households 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,

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

where δ is the depreciation rate and $\Gamma_I(\varepsilon_t^I I_{i,t}/I_{i,t-1})$ 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:

$$\frac{\Lambda_{i,t}}{P_t} = \varepsilon_t^C \frac{(C_{i,t} - \kappa C_{i,t-1})^{-\sigma}}{(1 + \tau_t^C)}, \tag{2}$$

$$1 = Q_t\left(1 - \Gamma_I \frac{\varepsilon_t^I I_{i,t}}{I_{i,t-1}} - \Gamma_I' \frac{\varepsilon_t^I I_{i,t}}{I_{i,t-1}} \frac{\varepsilon_t^I I_{i,t}}{I_{i,t-1}}\right) + \beta E_t\left(\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}} Q_{t+1} \Gamma_I' \frac{\varepsilon_{t+1}^I I_{i,t+1}}{I_{i,t}} \frac{\varepsilon_{t+1}^I I_{i,t+1}^2}{I_{i,t}^2}\right),$$

$$Q_t = \beta E_t \frac{\Lambda_{i,t+1} P_t}{\Lambda_{i,t} P_{t+1}}\left((1 - \delta) Q_{t+1} \frac{R_{K,t+1}}{P_{t+1}}\right),$$

$$\beta R_t E_t\left(\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}} \frac{P_t}{P_{t+1}}\right) = 1,$$

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

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

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} stands for a white noise UIP shock.

Wage Setting

Households act as wage setters for their differentiated labor services $N_{i,t}$ 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, 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 $N_t = \int_0^1 N_{i,t} di$.

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

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

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

3.2.2 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 nontradable intermediate good $Q_{f,t}$. All firms are indexed by $f \in [0, 1]$.

Intermediate Goods Firms

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

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

utilizing as inputs homogeneous private capital services, $K_{f,t}$, that are rented from households in fully competitive markets, and labor services, N_t. The productivity processes, z_t and z_t^*, are assumed to follow a symmetric bivariate first-order autoregressive process defining global productivity with cross-correlated innovations, as in Backus and Crucini (2000).

Capital and Labor 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 $R_{K,t}K_{f,t} + W_tN_{f,t}$ 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 markup 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 costs $MC_{f,t}$ are identical across firms; that is, $MC_{f,t} = MC_t$.

Price Setting Each firm f sells its differentiated output $H_{f,t}$ in the domestic markets or to foreign importers (the demand of which 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 its price in a given period t with probability $1 - \xi_H$.

Defining as $P_{H,f,t}$ the price of good f, all firms that receive permission to reset their price contracts in a given period t choose the same price. Those firms that 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 convex combination of past changes in the aggregate price index, $P_{H,t}$, and the steady-state inflation rate, π, where χ_H is a constant indexation weight.

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

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

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

subject to the price indexation scheme 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 product 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:

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

This expression states that in those intermediate good markets in which price contracts are reoptimized, the latter are set so as to equate the firms' discounted sum of expected revenues to the discounted sum of expected marginal cost.

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, $P_{IM,f,t}^D = S_t P_{F,f,t}$, as discussed in Monacelli (2005). Note $P_{IM,f,t}^D$ 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 Economy 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 Goldberg (2002).

In contrast to Monacelli (2005), however, in our setup imported, differentiated intermediate goods are combined at the dock to a composite of imported goods at the dock using a constant elasticity of substitution (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:

$$E_t\left[\sum_{k=0}^{\infty}\xi_{IM}^{k}\Lambda_{t,t+k}\left(\tilde{P}_{IM,t}\left(\frac{P_{t+k-1}}{P_{t-1}}\right)^{\chi_{IM}}\pi^{(1-\chi_{IM})k}-\frac{\theta_{IM}}{\theta_{IM}-1}P_{IM,t}^{D}\right)IM_{f,t+k}\right]=0,$$

where $P_{IM,t}^{D}$ is the price of the composite of the infinite number of imported intermediate 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.

Final Good Firms

The representative final good firm (we neglect the indexation in what follows) produces the nontradable 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,

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

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 measure 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

$$P_t = (\nu(P_{H,t})^{1-\mu} + (1-\nu)P_{IM_t,t}^{1-\mu})^{1/(1-\mu)}.$$

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 indexes of the variables.

3.2.3 Fiscal and Monetary Authorities

The fiscal authority purchases the final good, G_t, and levies lump 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:

$$P_t G_t = T_t + \tau_t^C P_t C_t + \tau_t^N W_t N_t + \tau_t^f D_t.$$

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.

3.2.4 Aggregation and Aggregate Resource Constraint

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

Aggregation

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

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

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

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

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

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

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 $TB_t = P_{H,t} X_t - P_{IM,t}^D IM_t$ 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

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

Overall, the model contains six domestic sources of stochastic shocks in each country: a productivity, an investment, a preference, a labor supply, a markup, and a monetary policy shock. In addition, there is a white-noise exchange rate shock (UIP) that results from variations in the costs of international financial intermediation. As mentioned earlier, the home and foreign productivity shocks are assumed to be partially cross-correlated.

3.3 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 previously. 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 to the extended NAWM as described in Coenen, McAdam, and Straub (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: (a) to replicate the volatility and correlations of some relevant variables such as output, consumption, and investment; and (b) to generate realistic contributions of structural shocks to the variances of key endogenous variables. One benchmark in this respect is de Walque, Smets, and Wouters (2005).

We set the size of the home country to 0.43 corresponding to the size of the euro area's GDP relative to the U.S. GDP. The home bias in the euro area is set to 0.85 and in the United States to 0.9, reflecting the fact that the euro area is relatively more open than the United States. 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 Walque, Smets, and Wouters (2005). The elasticity of labor supply is set to 2.5 in both countries. The inverse of the intertemporal elasticity of substitution σ is set to 2.5 in the euro area and to 2 in the United States, reflecting the observed relatively higher interest rate sensitivity in the United States.

The technology parameter α is set in both countries to 0.36, while the parameters determining the adjustment costs in investment are calibrated

4. In developing the NAWM, a two-track strategy is followed. A relatively large calibrated two-country version is used for policy analysis (as in Coenen, McAdam, and Straub [2007]). A simplified estimated version is used for projections (see Christoffel, Coenen, and Warne [2008]). The estimated version is still in development and treats the foreign block as exogenous and generated by a Vector Autoregression (VAR).

to 1.3 in the euro area and 1.1 in the United States, reflecting the lower investment volatility in the euro area data. At the same time, the parameter shaping the premium on foreign bond holdings 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 the 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 of Schorfheide and Lubik (2005) and de Walque, Smets, and Wouters (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 at 0.1, in both countries.

With regards to the tax rates, we have chosen the values reported, in Coenen, McAdam, and Straub (2007) that are based on Organization for Economic Cooperation and Development (OECD) data. Namely, we set the consumption tax rate at 0.183 in the euro area and at 0.077 in the United States, while labor income tax equals 0.24 in the euro area and 0.22 in the United States. 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 in table 3.1, while table 3.2 compares some of the moments generated by the model with the data for the euro area and the United States. The calibrated model gets the relative standard deviations of real GDP and its components more or less right. However, the standard deviation of inflation generated by the

Table 3.1 **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	0.0055
Productivity foreign	0.0055
Markup home	0.06
Markup foreign	0.06
Labor supply foreign	0.07
Labor supply home	0.06
UIP	0.01

Table 3.2 **Stylized facts of the model**

	Euro area				U.S.	
	Model	Data	Model	Data	Model	Data
Standard deviation						
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	0.53	1.05			0.57	1.20
Real exchange rate			1.98	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			–0.39	–0.51

model is too low (a bit more than half of 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 (2008), 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 macrovariables is reasonable. Tables 3.3 and 3.4 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.[5] 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 markup shocks in the domestic intermediate goods sector are the most important drivers of inflation,

5. See, for example, Smets and Wouters (2003, 2007).

Table 3.3 Variance decomposition

	Euro area				
	Output	Consumption	Investment	Inflation	REX
Euro area shocks					
Technology	55.4	26.3	41.1	27.4	11.6
Labor supply	19.5	6.79	15.7	8.03	9.43
Investment	0.93	0.75	6.06	0.14	0.36
Preferences	2.78	51.7	19.5	4.14	8.38
Markup	5.68	1.39	1.86	52.8	7.55
Monetary policy	1.00	0.41	0.57	1.63	4.48
U.S. shocks					
Technology	14.4	10.9	11.1	4.69	6.79
Labor supply	0.12	0.35	0.28	0.10	10.5
Investment	0.09	0.84	2.93	0.55	6.65
Preferences	0.06	0.28	0.44	0.19	4.06
Markup	0.03	0.12	0.03	0.17	9.02
Monetary policy	0.02	0.09	0.02	0.06	6.69
UIP	0.00	0.09	0.04	0.03	14.5

Table 3.4 Variance decomposition

	United States			
	Output	Consumption	Investment	Inflation
Euro area shocks				
Technology	11.2	10.0	6.38	4.02
Labor supply	0.04	0.15	0.07	0.03
Investment	0.00	0.02	0.06	0.01
Preferences	0.04	0.33	0.17	0.11
Markup	0.01	0.01	0.00	0.07
Monetary policy	0.00	0.04	0.00	0.01
U.S. shocks				
Technology	46.8	27.4	26.9	25.0
Labor supply	22.6	9.78	13.9	9.65
Investment	9.81	11.5	42.7	2.62
Preferences	2.36	38.4	7.05	2.77
Markup	5.34	1.51	1.73	53.1
Monetary policy	1.71	0.80	0.83	2.57
UIP	0.00	0.05	0.01	0.03

followed by technology shocks. The only shocks that have a nonnegligible impact on the variance decomposition of foreign output are the technology shocks. This is a result of the assumption that domestic technology shocks have spillover effects on foreign productivity, as in Backus, Kehoe, and Kydland (1994).

3.4 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.[6] 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 noncooperative 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).[7] The noncooperative 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 in Lombardo and Sutherland (2006), among others.[8] 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.[9] For example, Obstfeld and Rogoff (2002) consider

6. 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 microfounded stylized two-period two-country model. Beetsma and Jensen (2005) discuss the monetary-fiscal interaction in a monetary union in a dynamic two-country model.

7. The open-loop Nash equilibrium implies that each central bank chooses the optimal allocation, taking as given the current and future choices of instrument 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 instruments is known to be dependent on (some of the) other system variables" (Levine, Pearlman, and Pierce 2008, 3341). Benigno and Benigno (2006), Levine, Pearlman, and Pierce (2008), and Clarida, Galí, and Gertler (2002) discuss open-loop equilibria. Feedback-loop (i.e., closed-loop) Nash equilibria have been studied in small models by Obstfeld and Rogoff (2002) and Lombardo and Sutherland (2004). In these models, as in most of the older literature, the distinction between open-loop and closed-loop is irrelevant as the models are essentially static (with preset prices). See Canzoneri and Henderson (1992) for examples of strategic setups in older models.

8. 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.

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

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 chapter, we assume that the central bank is able to control the money supply and we define the strategy space of the noncooperative 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).[10]

For the sake of comparison with the literature, in section 3.5.5 we also briefly consider open-loop Nash equilibria in which CPI and producer price index (PPI) inflation is chosen as the strategic policy variable. However, given that the central bank has a well-defined objective function that includes other variables than inflation, we think that these alternative assumptions regarding the strategy space are unwarranted in our model setup. We prefer to use the central bank's instrument (money supply) as our benchmark case. Nevertheless, it is worth emphasizing again that the size of the gains from cooperation depend, in general, on the particular definition of Nash equilibrium considered.

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

3.5 The Gains from Cooperation: Results

In the next section we report the welfare loss due to noncooperation (i.e., the difference between welfare under cooperation and welfare under noncooperation) 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.[11]

3.5.1 Welfare Decomposition: Baseline Results

Table 3.5 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 noncooperative 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 noncooperative equilibrium, as well

10. 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 saddle-path equilibrium is reestablished. When two such strategies are combined together, they would produce too many unstable roots.

11. Denote Δ^W as the welfare gap produced by following two different monetary policies in a stochastic world. We then solve for λ such that $\Delta^W = (1-\beta)^{-1}\{U((1-\lambda)C_{ss}) - U(C_{ss})\}$.

Table 3.5 **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*
$\mathrm{Var}_{t0}[tot]$	–0.1478	–0.0014	–0.0386	–0.0026	–0.0225	0	–0.0015	–0.0487	–0.0071	–0.0239	–0.0001	–0.0014

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.[12] Moreover, inflation and output volatility may capture the cost from inefficient goods production due to staggered nominal prices. 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 a percentage of their steady-state value. The first column of table 3.5 reports the values for the baseline calibration. The other columns display the values for each type of shock separately. Except for the 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 3.5 a number of observations are worth highlighting. First of all, the first column of table 3.5 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 percent 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).[13] 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 United States are assumed to be traded internationally. This assumption implies that the euro area and the United States are not treated symmetrically in terms of currency-risk hedging options

12. For example, Rogoff (1985), Canzoneri and Gray (1985), and Sachs (1983) on the second point and Woodford (2003) on the first point.

13. 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 U.S. GNP by about 0.5 percent ". . . [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).

(e.g., Devereux and Sutherland 2007) abstracting from the foreign asset return premium, for the U.S. 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 nonzero 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 in the following, the results of broadly symmetric gains across the euro area and the United States do 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 3.5 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 U.S. 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 not by much. Turning to inflation, inflation is 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 3.5 is that the most important source of gains from cooperation are the markup 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 noncooperation 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 markup shocks. This is confirmed by the analysis in table 3.5. The markup shocks explain more than three-fourths of the gains from cooperation. From the variance decomposition in tables 3.3 and 3.4, we know that markup 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 U.S. economies, they do not generate wide discrepancies between the cooperative and the noncooperative 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 markup shocks.

As argued by Canzoneri, Cumby, and Diba (2002), the gains from coop-

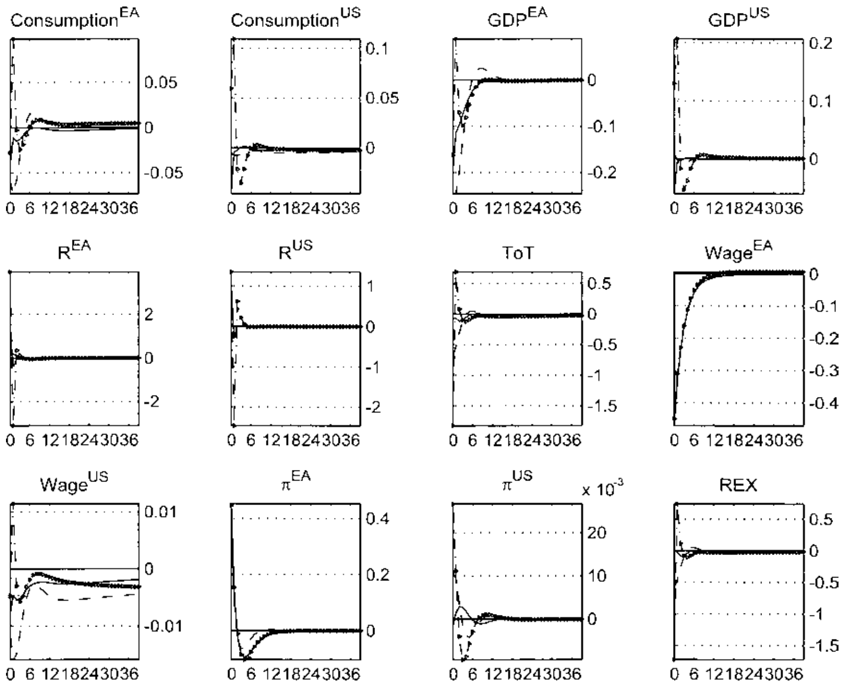

Fig. 3.1 Euro area markup shock: Coop. (solid), Nash (arrowed-dashed), Rule (dashed)

eration are increasing in the size of the policy trade-offs generated by the shocks. Shocks that can be easily offset 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 3.1 and 3.2 compare the response of the euro area and U.S. economy to a markup shock and a productivity shock, respectively, under the cooperative and noncooperative equilibrium and the calibrated monetary policy reaction function. Under the cooperative equilibrium, a positive euro area markup 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 markup shock generates positive comovement between euro area and U.S. GDP. In both countries inflation rises and the real wage falls.

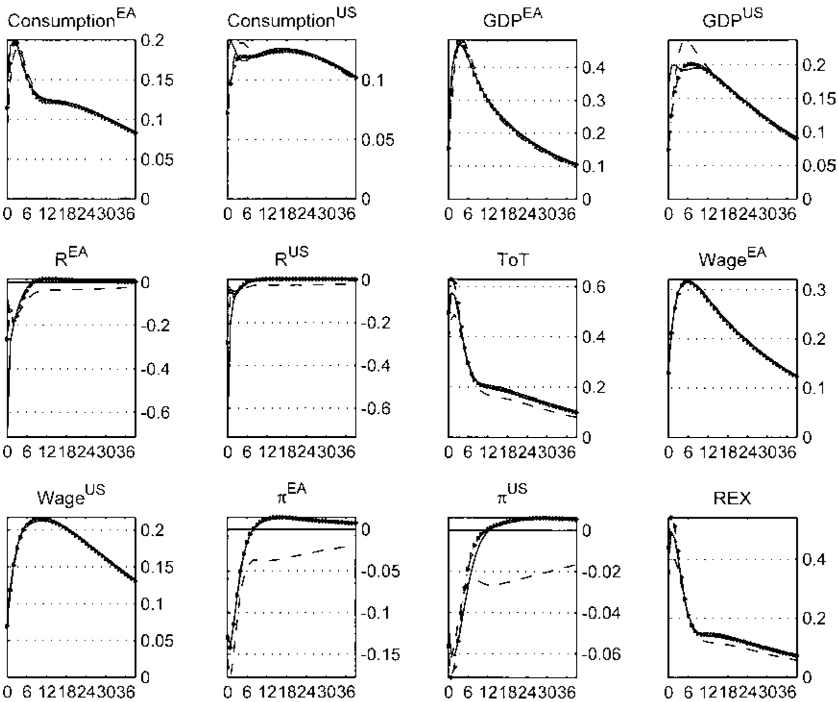

Fig. 3.2 Euro area productivity shock: Coop. (solid), Nash (arrowed-dashed), Rule (dashed)

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 markup shock generates negative comovement 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 model developed by

Benigno and Benigno (2006) if extended with 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 noncooperative 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 United States, 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 3.2 regarding the effects of a productivity shock. In this case, the impulse responses under the cooperative and noncooperative 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 U.S. welfare gains) is the markup shock. We should expect that the randomness in the home markup will partially spillover 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 nonstochastic value. This is true also when we measure the expected home domestic price index relative to the CPI. 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.[14] Each central bank, taken in isolation, will try to increase consumption while reducing labor effort.[15] The policymakers would attempt to do this by affecting the

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

15. 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.

Table 3.6 Welfare decomposition: Nominal rigidities and indexation

Variable	All shocks	mkp^{EA}	mkp^{US}	Σ_{EA} other shocks	Σ_{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

(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.

3.5.2 Sensitivity Analysis with Respect to Nominal Rigidities

While table 3.5 shows the results for the calibrated (benchmark) model, tables 3.6 and 3.7 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 U.S. markup 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 markup shocks a disproportionate effect on output.[16] These results, therefore, should only be taken as indicative of the sensitivity of the wel-

16. For example, the terms of trade would have a standard deviation about seven times larger than in the data. Euro area and U.S. 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, markup shocks would explain between 54 percent (EA) and 45 percent (U.S.) of the volatility of GDP (at twelve quarters).

Table 3.7 Welfare decomposition: Further sensitivity analysis

Variable	All shocks	mkp^{EA}	mkp^{US}	Σ_{EA} other shocks	Σ_{US} other shocks
Unitary intratemporal 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 intratemporal 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 intertemporal 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

fare 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.[17]

We first investigate the role of indexation in the intermediate goods sector (table 3.6). 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: that is, while EA welfare gains increase in their own markup shock and decrease in the U.S. markup shock, the reverse happens in the foreign country. In other words, according to these results the euro area would be

17. 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.

better off not to adopt the cooperative policy if there were only U.S. markup shocks. Turning to the degree of price stickiness in the intermediate goods sector itself, table 3.6 shows the effect of reducing price stickiness by half in the intermediate goods 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 markup 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 3.6, the degree of pass-through is 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 markup shocks reduce the domestic welfare gains while they improve the foreign welfare gains.[18] Notice, furthermore, that the welfare gains associated with markup shocks cease to be symmetric. Table 3.6 shows what happens if import prices are not indexed to domestic CPI inflation. The sign of the contribution of markup 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.

3.5.3 Degree of Openness

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, 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 United States (1982) of between 1.4 and 2.2 percent. While these numbers have increased somewhat since then, they remain relatively small. Our calibration implies that, in the nonstochastic steady state, U.S. exports to the EA

18. 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 markup 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 makes a generalization of them nearly impossible.

are about 8 percent of U.S. GDP while U.S. imports from the EA are about 11 percent of U.S. GDP. The EA exports to the United States are about 14 percent of EA GDP, while EA imports from the United States are about 11 percent of EA GDP. Table 3.7 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 percent for the euro area and 25.3 percent for the United States. Almost all of these gains are due to markup volatility.

Table 3.7 also offers an intermediate case, where the trade shares have been increased to about 32 percent 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 percent of steady-state consumption in the euro area and about 1.0 percent of steady-state consumption for the United States.

3.5.4 Some Other Critical Parameters

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

Inter- and Intratemporal Elasticity of Substitution

Corsetti and Pesenti (2001) show that the cross-country spillover effect of monetary policy crucially depends on the size of the intertemporal elasticity of substitution relative to the intratemporal 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 intratemporal elasticity of substitution relative to the size of the intertemporal 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 spillovers are nil. Nevertheless, even in the latter case, policy spillovers 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 intratemporal elasticity of substitution, the income gains decrease in this elasticity. In the spirit of the "optimum tariff" argument, the lower is the intratemporal elasticity of substitution, and the larger the monopolistic rent that the country can extract internationally.

Table 3.7 shows the welfare decomposition results for different values of the inter- and intratemporal elasticity of substitution. The main result of our chapter 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 intratemporal elasticity of substitution (table 3.7).[19]

Market Completeness

In Obstfeld and Rogoff (2002) the cooperative central banks face a trade-off between stabilization and increased tradable consumption risk-sharing.[20] 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 noncooperative allocations.

Table 3.7 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.

3.5.5 Alternative Assumptions Regarding the Noncooperative Strategy Space

Benigno and Benigno (2006) define the strategy space of the Nash game in terms of the growth rate of the GDP deflator. In our model, we do not see any reason to assume that each central bank should take (any measure of) foreign inflation as given when solving its noncooperative policy problem. On the contrary, in the context of an open-loop noncooperative game, it sounds more reasonable to us to think that each central bank must take as given the choices of the other central bank regarding either the quantity or the price that clears the market in which the other central bank is active. Nevertheless, for the sake of comparison we computed the noncooperative equilibrium under two alternative specifications of the strategy space: in terms of the PPI inflation rates and in terms of the CPI inflation rates.

The Nash equilibrium brought about by the PPI inflation rates in the benchmark calibration is indeterminate, so that we should conclude that the gains from cooperation (in this case) are potentially huge.

In contrast, the Nash equilibrium brought about by the CPI inflation

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

20. In their model the risk-sharing motive is absent when the intertemporal elasticity of substitution is unitary.

rates is saddle-path stable, in the benchmark calibration. The gains from cooperation in this case are larger than those obtained when solving the game in terms of the money supplies. In particular, the gains from cooperation would be 0.32 percent for the euro area and 0.28 percent for the United States. Compared with the results reported in table 3.5, the gains are now one order of magnitude larger.

3.6 Performance of Simple Rules

Monetary policy is often described in terms of interest rate feedback rules of the type used in our calibration. Studying the gains from cooperation when central banks optimally choose the parameters of such feedback rules is not the main focus of our chapter. Nevertheless, in order to gain a sense of how our results would change if the policy problem is described in terms of particular interest rate rules, we have carried out two experiments. In the first, each central bank maximizes its objective function by choosing the coefficients of an inertial interest rate rule that responds to CPI inflation and real GDP, where the degree of inertia is the same as in the calibrated rule. This rule amounts to an inertial Taylor rule (Taylor 1993). This experiment shows that in both the cooperative and noncooperative equilibrium the central banks do not want to respond to output. This result is similar to the findings of Schmitt-Grohé and Uribe (2007a, 2007b), in a closed economy setting. The reason, we conjecture, is that the measure of output used in the model is the actual deviation of output from the steady state. The result would likely differ had we used the deviation of output from its efficient flexible price and wage level.

The second experiment assumes that the (inertial) interest rate rule responds to CPI inflation and wage inflation.[21] This rule is dictated by the results shown in Levin et al. (2006) that the optimal interest rate rule in a closed economy with wage and price stickiness attributes a large weight to wage inflation. This experiment shows that both the cooperative and the noncooperative central banks prefer to respond only to wage inflation.[22] In what follows, we therefore consider a closed-loop Nash game in the simple inertial wage inflation interest rate rules.

Figure 3.3 summarizes the results. The graph shows the contour plot of the EA and U.S. welfare functions (in utility units) in deviation from the steady-state value when the share of import (and export) in GDP is

21. Output is omitted on the basis of the result of the first experiment, thus easing the computational burden.

22. The search of the optimal response coefficients was done by imposing a grid for each parameter. The step size and the range of these grids has been adjusted in order to refine the results to a convincing degree. Given this procedure we cannot exclude that the optimal rule requires to respond to CPI inflation and GDP with very small coefficients. Given the purpose of our experiments we treat these small numbers as zero.

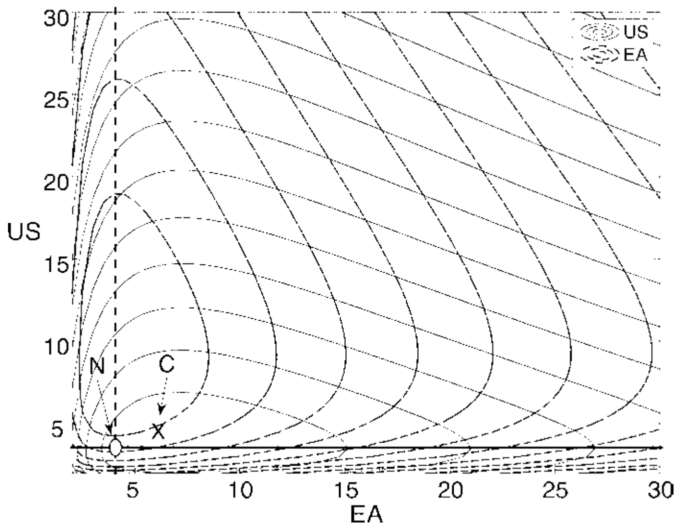

Fig. 3.3 Nash and cooperative equilibria under inertial interest rate rules reacting to wage inflation only

increased to about 32 percent.[23] The figure is reminiscent of the graphical analysis used by Hamada (1976) to derive the noncooperative equilibria in his monetary policy game. On the horizontal axis we have the EA response coefficient to wage inflation, while on the vertical axis we have the U.S. response coefficient. The straight lines crossing the contours represent the reaction functions of each central bank to the other bank's choice of reaction coefficient. As explained by Hamada (1976), the reaction function of the euro area passes through the point of tangency of each EA contour with horizontal lines. The reaction function of the United States passes through the point of tangency of each U.S. contour with vertical lines. The first interesting result is that the reaction functions are perpendicular: the Nash equilibrium involves strictly dominant strategies. This result suggests that, for the strategy space considered here, there is no monetary policy interdependence, although there are international monetary policy spillovers. The second interesting result is that the Nash equilibrium (denoted by "N" in the graph) differs from the cooperative equilibrium (denoted by "C" in the graph): the Nash equilibrium implies a weaker response to wage inflation than the cooperative equilibrium.

For the game described in figure 3.3 the gains from cooperation amount to 0.0013 percent for the euro area and 0.0021 percent for the United States (in consumption units). While these numbers are smaller than those presented in table 3.7 for the same degree of openness but under the open-

23. We consider this case because it makes the graphical analysis more visible.

Table 3.8 Welfare decomposition: Cooperative policy vs. calibrated simple rules

Variable	All shocks	mkp^{EA}	mkp^{US}	Σ_{EA} other shocks	Σ_{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

loop Nash equilibrium, one should notice that the level of welfare obtained under cooperation with this simple rule is lower than that obtained under the Ramsey cooperative allocation. The difference between the former and the latter amounts to –0.4289 percent for the euro area and 0.2287 percent for the United States, making the simple rule suboptimal from the global point of view.

These experiments also confirm that under the benchmark model; that is, with a smaller degree of openness, the gains from cooperation are smaller, amounting to 0.00008 percent for the euro area and –0.00003 percent for the United States.

Finally, table 3.8 shows that the loss incurred in adopting the calibrated rule as opposed to the (Ramsey) optimal cooperative policy are not very large. Levin et al. (2006) in a closed economy model estimated with U.S. 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 percent of steady-state consumption. We find a welfare cost that is about five times smaller.

3.7 Conclusion

In this chapter, we have analyzed the gains from monetary policy cooperation in a quantitative two-region DSGE model for the euro area and the United States. A number of recent papers have revived the debate about the gains from international monetary policy cooperation. None of these, nevertheless, has used large-scale DSGE models to quantify the gains from cooperation. Our chapter is a first attempt to fill this gap. Our analysis shows that the gains from cooperation are very sensitive to the degree of openness of the economies. Given the current degree of openness of the U.S. and euro area economies, and in line with the recent literature, we find that the gains from cooperation are small. 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. As we increase the degree of openness from 10 to 15 percent to about 32 percent, the gains from cooperation rise to a sizable level; that is, about 1 percent of steady-state consumption. Our analysis, therefore, suggests that the recent trends in international economic integration will be accompanied by larger gains from policy cooperation.

Our analysis also shows that markup shocks are the most important source of gains from international monetary policy cooperation. A deeper understanding of the sources of these type of disturbances will therefore be crucial for gauging the need for closer cooperation in the future.

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 markup 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 markup shocks in the labor market and the imported goods sector. Third, we have focused our analysis of the noncooperative 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.

In section 3.6 we have taken a first step in that direction, analyzing closed-loop Nash equilibria in a few simple feedback rules. The results confirm our findings that in the benchmark case the gains from cooperation are small but increasing in the degree of trade integration. However, a more complete analysis using more complicated feedback rules is warranted. Fourth, the importance of markup shocks for the gains from cooperation raises questions about the microfoundations 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 markup shocks.

Appendix

Description of the Solution Method

The cooperative and noncooperative (open-loop Nash) nonlinear 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 policymakers' 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 multipliers of the policy problem. The steady state of the structural equations was solved using a suite of nonlinear 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 multipliers is then obtained by solving a 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).

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Comment Christopher A. Sims

The chapter sets up a state of the art two-country calibrated model in which monetary policy has welfare effects. It uses a second-order expansion to get accurate calculations of these effects, using the model's own agent utility functions, and thereby gives us a prototype of how this analysis should be done. But as the authors acknowledge in various caveats in the text, it is really only a prototype. There are many aspects of the model that are dubious and likely to be important to the conclusion. Most of my comments, therefore, point out questionable aspects of the chapter. At the end, I provide a constructive suggestion.

The Nature of the Game

The chapter models interaction of monetary authorities as a Nash equilibrium, but the nature of such an equilibrium depends crucially on what variables each player treats as given when choosing the player's own moves. The chapter's central case is that each monetary authority takes the entire past and future of the other's money stock as given in optimizing its own money stock choice. This is certainly unrealistic, and the chapter's own sensitivity analyses show that its conclusion that the welfare gains from cooperation are small is sensitive to this choice.

It is perhaps worthwhile to catalog the results of the chapter's sensitivity analysis: if the policy choice variables are the time paths of interest rates, the result is instability—in other words, extremely large welfare losses from noncooperation. The same is true if the policy choice variable is the producer price index (PPI). If the choice variable is consumer price index (CPI) path, the losses from noncooperation are finite, but ten times larger than in the case where the money time path is the choice variable. When the choice variables are the coefficients in a Taylor rule, the losses from noncooperation are minuscule, but "cooperation" in the choice of these coefficients leaves the equilibrium welfare far from the Ramsey optimal solution—by an amount

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This research was supported in part by National Science Foundation (NSF) grant SES-0719055.