Reassessing the gains from monetary policy cooperation

Preliminary and Incomplete

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1 Introduction

A striking finding of the literature on optimal monetary policy in an open economy is that the gains from monetary policy cooperation are small. A comprehensive review of that literature is offered by Corsetti, Dedola, and Leduc (2011). Estimates of gains from cooperation relative to competitive outcomes in the order of 0.001 percent of steady state consumption are not atypical. Much of this literature has focused on stylized settings with technology shocks as the only source of economic fluctuations. As noted by Cole and Obstfeld (1991), movements in the terms of trade are a powerful source of insurance against country-specific technology shocks, independently of the available set of assets. In such settings, wealth effects associated with country-specific shocks tend to be small and do not provide powerful incentives for manipulation of the terms of trade.

As shown in Bodenstein, Erceg, and Guerrieri (2011), wealth effects associated with country-specific oil supply and intensity shocks are quite different from those related to technology shocks. For instance, in response to a foreign oil intensity shock that increases the equilibrium real price of oil, the non-oil terms of trade for the home oil-importing country deteriorate and reinforce the country-specific wealth-effects. In a setting that allows for trade in both oil and non-oil goods, in addition to empirically realistic sources for fluctuations in the real price of oil, we show that the gains from cooperation are multiple orders of magnitude larger than what previously found. Furthermore, we provide the first characterization of how monetary policy should differ depending on whether a country is a net oil importer or a net oil exporter.

Much of the existing analysis of appropriate monetary policy responses to oil price fluctuations under DSGE models has been conducted under the counterfactual premise that the real price of crude oil is exogenous with respect to the U.S. economy (see, e.g., Leduc and Sill 2004; Carlstrom and Fuerst 2006; Dhawan and Jeske 2007; Plante 2009a,b; Winkler 2009; Montoro 2010; Kormilitsina 2011; Natal 2012). Even those DSGE studies that have endogenized the real price of oil have made strong and unrealistic simplifying assumptions about the determination of the price of oil in global markets (see, e.g., Backus and Crucini 1998), have ignored monetary policy (see, e.g., Backus and Crucini 1998; Balke, Brown and Yücel 2010; Bodenstein, Erceg, and Guerrieri 2011; Nakov and Nuño 2011), or have ignored the open economy aspect of the transmission of oil price shocks (see, e.g., Bodenstein, Erceg, and Guerrieri 2008; Nakov and Pescatori 2010a,b). When studying the appropriate monetary policy responses to oil demand and oil supply shocks, it is essential to work with a model that combines all three features.

Bodenstein, Guerrieri, and Kilian (2012) considered a model closely related to the one used in this paper. Whereas the focus of Bodenstein, Guerrieri, and Kilian (2012) was on the optimization of simple instrument rules for the home oil-importing country, having taken the other country's policy rule as given, in the current paper the focus is on the gains from coordination. We present results for both simple instrument rules as well as for targeting rules that solve the Ramsey planner's problem.

We proceed in two steps. First we develop the basic intuition for how oil trade affects the gains from cooperation in a simple model that abstracts from many empirically realistic features. That setting extends the framework used in Bodenstein, Erceg, and Guerrieri

(2009) to encompass an open economy dimension and trade in oil and nonoil goods. We then refine the findings for the simple model by considering the empirically validated model developed by Bodenstein and Guerrieri (2011) and used in Bodenstein, Guerrieri and Kilian (2012).[1]

2 Baseline Monetary Model of Macroeconomic Interdependence with Oil

Our analysis starts by extending the two-country model with two traded goods and sticky prices commonly used in the literature on optimal monetary policy in open economies to incorporate oil use in production and consumption. Abstracting from oil, the model is similar to the ones employed in Clarida, Gali, and Gertler (2002), Benigno and Benigno (2006) and Corsetti, Dedola, and Leduc (2011).

Each country specializes in the production of one good which itself consists of a continuum of differentiated varieties. The two goods are imperfect substitutes in the utility function of households. The differentiated varieties are produced using labor and oil, and each producer of a variety acts under imperfect competition. Prices for varieties are determined by Calvo-Yun contracts and when traded internationally exported varieties are priced in the currency of the producer. Households consume goods, oil, and supply labor. They can also trade in international financial markets by purchasing (a full set of) state-contingent claims. We will also consider the case of financial market incompleteness when a non state-contingent bond is the only internationally traded asset.

For the baseline model without oil, Corsetti, Dedola, and Leduc (2011) distinguish three

[1] We are drawing on a growing literature on monetary policy responses to oil price fluctuations (see Kilian and Lewis 2011; Bodenstein, Guerrieri, Kilian 2012). Our analysis also exploits recent advances in modeling oil markets in the context of the global economy (see Kilian, Rebucci, and Spatafora; Bodenstein, Erceg, and Guerrieri 2011). Finally, our analysis also builds on a recent literature that has stressed the endogeneity of oil prices with respect to macroeconomic aggregates (see Kilian 2008; Bodenstein and Guerrieri 2011).

distortions with which nominally sticky prices interact: the monopolistic competition in product markets, incentives of policymakers to deviate from globally optimal policies through manipulating terms of trade, and – if applicable – frictions in international financial markets.

As customary in the New Keynesian literature, our analysis is conducted in a cashless economy, i.e., the utility component of money is ignored and the monetary policy set the short-term nominal interest rate to achieve its policy goals.

2.1 Specifics of the Baseline Model

As the two countries are symmetric in their economic structure, we only describe the economy of country 1 in detail.

Households The preferences of the representative household are given by:

$$E_t \sum_{j=0}^{\infty} \beta_1^j \left\{ \frac{1}{1-\sigma_1} \left(C_{1,t+j}\right)^{1-\sigma_1} + \frac{\chi_{0,1}}{1-\chi_1} \left(1 - L_{1,t+j}\right)^{1-\chi_1} \right\}. \tag{1}$$

The variables $C_{1,t}$ and $L_{1,t}$ represent consumption and hours worked, respectively.

The time t budget constraint of the household states that:

$$\begin{aligned} & P_{1,t}^c C_{1,t} + \frac{e_{1,t} P_{2,t}^b B_{1,t}}{\phi_{1,t}^b} + \int_S P_{1,t,t+1}^d D_{1,t,t+1} - D_{1,t-1,t} \\ & = W_{1,t} L_{1,t} + \Gamma_{1,t} + P_{1,t}^o Y_{1,t}^o + T_{1,t} + e_{1,t} B_{1,t-1}. \end{aligned} \tag{2}$$

The final consumption $C_{1,t}$ is purchased at the prices $P_{1,t}^c$. The household earns labor income $W_{1,t} L_{1,t}$, receives an aliquot share $\Gamma_{1,t}$ of firm profits, a share of the country's (unrefined) oil endowment $P_{1,t}^o Y_{1,t}^o$, and net transfers of $T_{1,t}$.

Households accumulate financial assets by purchasing state-contingent domestic bonds, and a non state-contingent foreign bond. The state contingent domestic bonds are denoted by $D_{1,t,t+1}$. The term $B_{1,t+1}$ in the budget constraint represents the quantity of the non state-contingent bond purchased by a typical household that pays one unit of foreign currency in the subsequent period, $P_{2,t}^b$ is the foreign currency price of the bond, and $e_{1,t}$ is the exchange rate expressed in units of home currency per unit of foreign currency. $\phi_{1,t}^b$ captures intermediation costs incurred to purchase the foreign bond and render the dynamics of $B_{1,t+1}$ stationary.

If financial markets are complete, as assumed in Clarida, Gali, and Gertler (2002), Benigno and Benigno (2006) and in most of Corsetti, Dedola, and Leduc (2011), the terms

$$\frac{e_{1,t}P_{2,t}^{b}B_{1,t}}{\phi_{1,t}^{b}} - e_{1,t}B_{1,t-1}. \tag{3}$$

in equation (2) are replaced by

$$\int_{S} e_{1,t}P_{2,t,t+1}^{b}B_{1,t,t+1} - e_{1,t}B_{1,t-1,t}. \tag{4}$$

In every period t, the household maximizes the utility functional (1) with respect to consumption, labor supply, and holdings of domestic and foreign bonds, subject the budget constraint (2).

Bundlers of Varieties A continuum of representative bundlers combines differentiated intermediate products into a composite home-produced good $Y_{1,t}$ according to:

$$Y_{1,t}^{d} = \left[\int_{0}^{1} Y_{1,t}\left(i\right)^{\frac{1}{1+\theta_{1,t}^{p}}} di\right]^{1+\theta_{1,t}^{p}}, \tag{5}$$

where $Y_{1,t}^{d}$ is used as the domestic input in producing all final use goods, including exports. One unit of the sectoral output index sells at the price:

$$P_{1,t}^{d} = \left[\int_{0}^{1} P_{1,t}^{d}\left(i\right)^{\frac{-1}{\theta_{1,t}^{p}}} di\right]^{-\theta_{1,t}^{p}}. \tag{6}$$

Under producer currency pricing, the exports sell at the foreign price $P_{2,t}^{m} = P_{1,t}^{d}/e_{1,t}$.

Production of Domestic Intermediate Goods There is also a continuum of differentiated intermediate goods indexed by $i \in [0,1]$, each of which is produced by a single monopolistically competitive firm.

Firm i faces a demand function:

$$Y_{1,t}(i) = \left[\frac{P_{1,t}(i)}{P_{1,t}^{d}}\right]^{-\frac{1+\theta_{1,t}^{p}}{\theta_{1,t}^{p}}} Y_{1,t}^{d}, \tag{7}$$

where $\theta^p_{1,t} > 0$ is time-varying in order to allow for price mark-up shocks as shown in Giannoni (2000).

The production technology combines labor and oil to a variety i. The cost minimization problem is given by:

$$\min_{L_{1,t}(i),O^y_{1,t}(i)} W_{1,t}L_{1,t}(i) + P^o_{1,t}O^y_{1,t}(i) \tag{8}$$

$$s.t.$$

$$Y_{1,t}(i) = \left((\omega^{vy}_1)^{\frac{\rho^o_1}{1+\rho^o_1}} (Z_{1,t}L_{1,t}(i))^{\frac{1}{1+\rho^o_1}} + (\omega^{oy}_1)^{\frac{\rho^o_1}{1+\rho^o_1}} \left(Z^o_{1,t}O^y_{1,t}(i)\right)^{\frac{1}{1+\rho^o_1}} \right)^{1+\rho^o_1}. \tag{9}$$

Utilizing capital labor services $L_{1,t}(i)$ combined with oil $O^y_{1,t}(i)$, firm i produces the domestic nonoil variety $Y_{1,t}(i)$. The term $Z^o_{1,t}$ represents a stochastic process that influences the oil intensity in production while $Z_{1,t}$ represents a technology shock specific to labor.

Sticky Prices The prices of intermediate goods $P_{1,t}(i)$ are determined by Calvo-style staggered contracts, see Calvo (1983) and Yun (1996). with reoptimization probability, $1 - \xi^p_1$. The probabilities are constant and independent across firms, time, and countries. Firms that do not reoptimize their price increase prices with the steady state inflation rate which is set to be zero in this section.

Production of Consumption Goods The consumption basket $C_{1,t}$ that enters the household's budget constraint is produced by perfectly competitive consumption distributors whose production function mirrors the preferences of households over home and foreign nonoil goods and oil:

$$\min_{\substack{C^d_{1,t},M^c_{1,t}\\ C^{ne}_{1,t},O^c_{1,t}}} P^d_{1,t}C^d_{1,t} + P^m_{1,t}M^c_{1,t} + P^o_{1,t}O^c_{1,t} \tag{10}$$

$$s.t.$$

$$C_{1,t} = \left((\omega^{cc}_1)^{\frac{\rho^o_1}{1+\rho^o_1}} \left(C^{ne}_{1,t}\right)^{\frac{1}{1+\rho^o_1}} + (\omega^{oc}_1)^{\frac{\rho^o_1}{1+\rho^o_1}} \left(Z^o_{1,t}O^c_{1,t}\right)^{\frac{1}{1+\rho^o_1}} \right)^{1+\rho^o_1} \tag{11}$$

$$C^{ne}_{1,t} = \left((\omega^c_1)^{\frac{\rho^c_1}{1+\rho^c_1}} \left(C^d_{1,t}\right)^{\frac{1}{1+\rho^c_1}} + (\omega^{mc}_1)^{\frac{\rho^c_1}{1+\rho^c_1}} \left(M^c_{1,t}\right)^{\frac{1}{1+\rho^c_1}} \right)^{1+\rho^c_1}. \tag{12}$$

Each distribution firm produces a nonoil aggregate $C^{ne}_{1,t}$ from the home and foreign intermediate consumption aggregates $C^{d}_{1,t}$ and $M^{c}_{1,t}$, which is then combined with oil $O^{c}_{1,t}$. The same shock $Z^{o}_{1,t}$ that affects oil intensity in production also affects the oil intensity of consumption.

The price of the consumption aggregate $P^{c}_{1,t}$ coincides with the Lagrange multiplier on Equation (11) in the cost minimization problem of a distributor. The price of the nonoil consumption good $C^{ne}_{1,t}$ is referred to as the "core" price level $P^{ne}_{1,t}$.

Oil Market Each period the home and foreign countries are endowed with exogenous supplies of oil $Y^{o}_{1,t}$ and $Y^{o}_{2,t}$, respectively. The two endowments are governed by distinct stochastic processes. With both domestic and foreign oil supply determined exogenously, the oil price $P^{o}_{1,t}$ adjusts endogenously to clear the world oil market:

$$Y^{o}_{1,t} + \frac{1}{\zeta_1} Y^{o}_{2,t} = O_{1,t} + \frac{1}{\zeta_1} O_{2,t}, \tag{13}$$

where $O_{i,t} = O^{y}_{i,t} + O^{c}_{i,t}$.

Resource Constraints for Nonoil Goods and Net Foreign Assets The resource constraint for the nonoil goods sector of the home economy can be written as:

$$Y^{d}_{1,t} = C^{d}_{1,t} + \frac{1}{\zeta_1} \left(M^{c}_{2,t} + M^{i}_{2,t} \right), \tag{14}$$

where $M_{2,t}$ denotes the per capita imports of the foreign country, which accounts for the population scaling factor $\frac{1}{\zeta_1}$.

For the case of incomplete international financial market, the evolution of net foreign assets can be expressed as:

$$\frac{e_{1,t} P^{b}_{2,t} B_{1,t}}{\phi^{b}_{1,t}} = e_{1,t} B_{1,t-1} + \frac{1}{\zeta_1} e_{1,t} P^{m}_{2,t} M_{2,t} - P^{m}_{1,t} M_{1,t} + P^{o}_{1,t} \left(Y^{o}_{1,t} - O_{1,t} \right). \tag{15}$$

Monetary Policy We distinguish two monetary policy regimes. In the first one, subsequently labeled the "Ramsey case," policymakers in the two countries choose joint paths for the policy instruments in the two countries that maximize the joint welfare of the two countries according to:

$$W^R = E_t \sum_{j=0}^{\infty} \beta^j \left\{ \omega U_{1,t+j} + (1-\omega) U_{2,t+j} \right\} \tag{16}$$

with

$$U_{i,t+j} = \frac{1}{1-\sigma_i} \left(C_{i,t+j}\right)^{1-\sigma_i} + \frac{\chi_{0,i}}{1-\chi_i} \left(1 - L_{i,t+j}\right)^{1-\chi_i}. \tag{17}$$

The parameter ω is the weight of country 1 in the welfare function of a fictional global planner/ central bank. While in principle ω can assume any value between 0 and 1, we will set the value of ω in agreement with relative country sizes.

In the second case, policymakers do not cooperate and choose policy paths that maximize welfare of their the households living in their respective country. As a policymaker is assumed to take the path of the other country's policy instrument as exogenous when deciding on her instrument path, we refer to this scenario as the "Nash case." The central bank in country i measures welfare according to:

$$W_i^N = E_t \sum_{j=0}^{\infty} \beta^j U_{i,t+j}. \tag{18}$$

2.2 Equilibrium Conditions and Model Solution

Given a path for policy, the first order conditions of the households' and firms' optimization problems together with the market clearing conditions determine the allocations and prices in the this economy. The full set of these nonlinear conditions is provided in Appendix A.

Let X_{t+j} denote the vector of N endogenous variables excluding the policy instruments, I_{t+j} denote the vector of 2 policy instruments, and $\Xi_t + j$ be the vector of exogenous variables. The N equilibrium conditions of the private sector can be expressed as:

$$\begin{aligned} & F_n \left(X_{t+j-1}, X_{t+j}, X_{t+j+1}, I_{t+j-1}, I_{t+j}, I_{t+j+1}, \Xi_{t+j-1}, \Xi_{t+j}\right) = 0 \\ & \text{for } n = 1, ..., N, \end{aligned} \tag{19}$$

where our notation allows for the first-order leads and lags to appear with the equilibrium conditions associated with time t.

Under the Ramsey case, the fictional global central bank solves:

$$\max_{\{I_{t+j},X_{t+j}\}_{j=0}^{j=\infty}} W^R \tag{20}$$
$$s.t. \text{ constraints in (19) and } I_{t-1}.$$

Splitting I_{t+j} into the set of home and foreign policy instruments $I_{t+j} = \{I_{1,t+j}, I_{2,t+j}\}$, each central bank solves:

$$\max_{\{I_{i,t+j},X_{t+j}\}_{j=0}^{j=\infty}} W_i^N \tag{21}$$
$$s.t. \text{ constraints in (19), } I_{i,t-1}, \text{ and } \{I_{i^-,t+j}\}_{j=-1}^{j=\infty},$$

under the Nash case as a policymaker is assumed to take the other policymaker's policy path as given. i^- denotes the complement to index i in the set of countries.

Policymakers are assumed to commit at time t to their policies for all future periods. The case of discretionary monetary policy is left for future research. In order to apply Taylor series expansions in solving for the optimal policies, both the Ramsey and the Nash case need to produce well-defined deterministic steady states. In addition, meaningful comparisons across models are facilitated if the steady states coincide across models. As pointed out by Benigno and Benigno (2006), adopting the so called timeless perspective (see Woodford (2000)) guarantees that the deterministic steady states exist and coincide across cases.[2]

A popular approach in the optimal monetary policy literature solves for the policy variables in a linear quadratic framework, e.g., Woodford (2003), Gali (2008), and Benigno and Benigno (2006). The equilibrium conditions enter this problem as linear approximations and the welfare functions are expressed as quadratic loss functions. Unfortunately, open economy models quickly reach a degree of complexity that prohibits analytical solutions even for such linear-quadratic frameworks and numerical methods need to be employed.

[2] In principle, the time inconsistency problem of optimal choice first identified by Kydland and Prescott and the concretionary bias discussed in Corsetti and Pesenti (2001) can prevent the two steady states from coinciding.

Although we employ linear approximations of the constraints to facilitate our discussion, we resort to computational methods for solving our model and its extensions. More specifically, we adapt the DYNARE codes developed by Andrew Levin and David Lopez-Salido in Levin and Lopez-Salido (2004) for optimal policy problems in closed economies to our open economy settings. Our augmented Matlab code accesses a DYNARE model file, automatically sets up the Lagrangian problems associated with systems (20) and (21), performs symbolic differentiation with respect to the Lagrange multipliers and the relevant endogenous variables, and finally writes the extended model to a new DYNARE model file. This new nonlinear model can then be solved with DYNARE for the desired degree of approximation.

2.3 Baseline Model without Oil

To place our analysis into the proper theoretical context, we briefly review the results obtained in our model without oil and complete international financial markets. This version of our model yields the same implications as the model presented in Benigno and Benigno (2006).[3]

Log-linearizing the nonlinear equilibrium conditions presented in Appendix A, the structural equations that describe the behavior of firms and households can be reduced to a set of two open-economy Phillips curves, two aggregate demand curves, and a relationship that connects the real exchange rate with relative output across countries. The derivations assume that producers of the intermediate goods receive a constant subsidy that eliminates the monopolistic distortions in the steady state.

[3] The details of the setup in Benigno and Benigno (2006) differ slightly from ours, as they assume that households engage directly into the production of varieties and the assembling of the final consumption good. They model the disutility of labor as $-V(L)$ rather than $+V(1-L)$, allow for positive government consumption, and eliminate home bias. Corsetti, Dedola, and Leduc (2010) deviate from the setup in Benigno and Benigno (2006) by allowing for home bias. None of these differences affect the key results of the optimal policy analysis, however.

The open economy Phillips curves are given by:

$$\pi_{1,t} = \kappa_1 \left[x_{1,t} + \psi_1 \widetilde{rer}_t + u_{1,t}\right] + \beta E_t \pi_{1,t+1} \quad (22)$$

$$\pi_{2,t} = \kappa_2 \left[x_{2,t} - \psi_2 \widetilde{rer}_t + u_{2,t}\right] + \beta E_t \pi_{2,t+1}. \quad (23)$$

The output gap, i.e., the difference between output in the actual sticky price economy and the counterfactual efficient economy with flexible price, is denoted by $x_{i,t}$ for country i. Inflation $\pi_{1,t}$ refers to the changes in the output price deflator and $\widetilde{rer}_t$ measures the difference between the (consumption) real exchange rate in the sticky price economy and the flexible price economy.[4] The variable $u_{i,t}$ is referred to as (price) markup shock and stems from the time-variability of $\theta^p_{i,t}$ in equation (7). As fluctuations in markups drive a wedge between (desired) prices and the marginal costs of production, $u_{i,t}$ is an inefficient shock.

In the closed economy setting, the lack of international trade implies that the coefficient ψ_i assumes the value of zero. Hence, in both the open and the closed economy, current inflation reflects inflation expectations and the current value of the output gap, which measures overall resource utilization in the economy. With the exception of a specific parameter condition, an open economy setting generally implies the parameter ψ_i to differ from zero and inflation will respond to relative price differences. As discussed below, an exception occurs for the case $\sigma\phi = 1$, i.e., if the product of the inverse of the intertemporal elasticity of substitution $\sigma_i = \sigma$ for $i = 1, 2$ and the elasticity of substitution between traded goods $\phi_i = \phi$ for $i = 1, 2$ equals one. In that case $\psi_i = 0$ for $i = 1, 2$ and relative price movements do not affect the equilibrium paths of inflation and the output gaps.

Under complete financial markets, the real exchange rate gap and the output gaps in the two countries are related through the relationship:

$$\widetilde{rer}_t = \frac{\sigma}{1 - (\psi_1 + \psi_2)(\sigma + \varphi)} (x_{1,t} - x_{2,t}). \quad (24)$$

Finally, the so-called aggregate demand equations in the New Keynesian framework for

[4] In this framework, the term of trade and the consumption real exchange rate are proportional to each other.

the two countries satisfy:

$$x_{1,t} = E_t(x_{1,t+1}) - \frac{1}{\sigma}\left(i_{1,t} - E_{t+1}\pi_{1,t+1} - r^n_{1,t}\right) + \psi^*_1 E_t\left(\widetilde{rer}_{t+1} - \widetilde{rer}_t\right) \quad (25)$$

$$x_{2,t} = E_t(x_{2,t+1}) - \frac{1}{\sigma}\left(i_{2,t} - E_{t+1}\pi_{2,t+1} - r^n_{2,t}\right) - \psi^*_2 E_t\left(\widetilde{rer}_{t+1} - \widetilde{rer}_t\right). \quad (26)$$

The nominal interest rate is denoted by $i_{i,t}$ and the natural rate of interest is denoted by $r^n_{i,t}$. The natural rate of interests provide the links between inflation, the output gaps, the exchange rate, and the nominal interest rates on the one hand and – with the exception the markup shock – the underlying shocks to the economy on the other hand. In the present setting domestic and foreign technology shocks lead to fluctuations in both $r^n_{1,t}$ and $r^n_{2,t}$.

Even without the quadratic approximations to the welfare function stated in equation (16), the optimal monetary policy under coordination, i.e., the Ramsey case, can be characterized from equations (22) to (26) when markup shocks are absent. As is the case in the closed economy, the baseline model of the monetary policy prescribes perfect price stabilisation of the GDP price deflators. In turn, output gaps and the gap for the real exchange rate remain closed at all times, whereas the nominal interest rates are set to assume in equilibrium the same values as the respective natural rates of interest. Thus, the optimal policy under cooperation replicates the flexible price outcomes.

The optimality of this policy stems from the fact that inflation induces welfare-costly dispersion among the prices of varieties. Under Calvo-Yun price contracts inflation or deflation distort relative prices between firms that are called upon to adjust their prices and firms that are not leading to higher demand for varieties with a low relative price as stated in equation (7). Heterogeneity in prices and the demand for varieties implies that aggregate output described in equation (5) is not maximised for the given level of labor supply. Absent inflation, all varieties are priced identically and output is maximized for the given level of employment.

The lack of trade-off between inflation, output gaps and the real exchange rate gap is an open economy instance of “divine coincidence” among potentially conflicting objectives.[5]

[5] The term divine coincidence was coined by Blanchard and Gali (2005). They argue that in the closed

The divine coincidence disappears when the economy is subject to markup shocks. Equations (22) to (26) are not satisfied at all times for $\pi_{1,t} = \pi_{2,t} = x_{1,t} = x_{2,t} = \widetilde{rer}_t = 0$ for all t when $u_{i,t} \neq 0$ for $i = 1, 2$ and some t.

2.3.1 Illustration of the Optimal Policy under Cooperation

Figures 1 and 2 illustrate these theoretical implications using the parameterization provided in Table 1 and under the assumption that the steady state is efficient due to a subsidy to the intermediate good producers.

The persistent decline in technology shown in Figure 1 raises both current and future marginal costs of production in the home country. In principle, the following forces are hence set into motion. Firms that adjust prices in a given period would like to raise their nominal (and relative) price which in turn would reduce demand for their goods. Firms that are not adjusting prices would experience additional demand for their goods both from home and foreign consumers, an effect that buffers the output contraction in the sticky price economy relative to the flexible price economy. Hence, a negative technology shock leads to inflation and a positive (welfare-based) output gap, i.e., output in the sticky price economy exceeds output in the (efficient) flexible price economy, and an insufficient appreciation of the home country's real exchange rate.[6] To bring the sticky price economy closer to its flexible price counterpart and reduce welfare losses, monetary policy needs to speed up the adjustment process by raising the nominal and real interest rate. Through such actions, the central bank narrows the output gap, keeps prices stable, and induces a stronger appreciation of the home country's real exchange rate. In line with equations (25) and (26), the optimal Ramsey policy calls for pushing up interest rates in the two countries just enough to counter the increase in the respective natural rates of interest that was triggered by the decline in

economy New Keynesian model the gap between flexible price level of output and efficient (first-best) level of output is constant and invariant to shocks. Stabilizing the gap between actual and flexible output and actual and efficient output are therefore equivalent absent markup shocks which in turn stabilises prices.

[6]The flexible price economy is efficient in our case due to the assumption of a price subsidy to producers in the steady state. Price markups are removed and are unaffected by the technology shock.

technology.

The ability of the global central bank to replicate the first best outcomes after a technology shock stems from the fact that raising the interest rate moves all variables closer to their first best outcomes. When the economy experiences a markup shock, this is no longer true and the policymaker faces a trade-off between output gap, inflation, and international prices. Figure 2 analyses the case of a transitory decrease in price markups in the home counter.

Prices in the home country fall on impact and output expands as the reduction in markups acts like similar to a reduction in marginal costs. The real exchange rate depreciates. To limit the decline in prices, the central bank opts to further fuel the expansion in output by lowering the nominal interest rate. As advocated in the closed economy literature, see for example Gali (2008), the global central bank simultaneously commits to stimulating the home country's economy in future periods by keeping the interest rate below its steady state level although the decline in markups is purely transitory.

The transmission of the shock to the foreign country depends on the value of the trade elasticity of substitution ϕ relative to the inverse of the intertemporal elasticity of substitution σ. If $\sigma\phi < 1$, the parameter ψ_2 in the foreign country's New Keynesian Phillips curve, equation (23), is negative and the real depreciation of the home country relative to the foreign country acts like decline in the foreign country's markups. The movements in foreign output, inflation, and nominal interest rate thus behave qualitatively similar to their home country counterparts. If home and foreign goods are substitutes and $\sigma\phi > 1$, the parameter ψ_2 is positive and the real exchange rate depreciation of the home country act like an increase in the foreign country's markups, i.e., an increase in $u_{2,t}$. In the special case of $\sigma\phi = 1$, the real exchange rate vanishes from equation (23) and the foreign country is insulated from the events abroad by lowering the nominal interest rate to perfectly offset the impact of the real exchange rate depreciation in the aggregate demand, equation (26).

2.3.2 Nash Gaps and the Gain from Cooperation

When policymakers do not cooperate and set policies without taking into account of the path of policies in the other country, welfare losses may occur. Absent cooperation, each country has an incentive to manipulate its terms of trade. The optimal direction and magnitude of the manipulation under open-loop Nash strategies depends again on the relationship between the inverse of intertemporal elasticity of substitution and the trade elasticity.

To facilitate the discussion, we plot the outcomes under the Nash case in deviation from the Ramsey case for a persistent contraction in domestic technology – Figure 3 – and a reduction in domestic markups – Figure 4. A positive value for a variable thus indicates that its outcome under the Nash case exceeds its outcome in the Ramsey case. As most vigorously argued in Obstfeld and Rogoff (2002), the gains from cooperation are very small for plausible parameter choices in simple models. Both for technology and markup shocks the Nash Gaps appear to be larger for higher values of the trade elasticity.

The gains from cooperation disappear altogether for a technology shock under the special case $\sigma\phi = 1$. If real exchange rate movements are absent from the Phillips Curves, the incentive to manipulate international relative prices is no longer present. Albeit a knife-edge case, the mere existence of a case for which nationally oriented policies have no negative global implications casts doubt on the strength the motive to manipulate the terms of trade. When goods are substitutable, $\sigma\phi > 1$, policymakers in the home country try to reduce the real appreciation that is induced by the technology shock; and when goods are complements, $\sigma\phi < 1$, the home country engineers an even larger appreciation of the real exchange rate.

2.4 Baseline Model with Oil

As a first departure from the baseline model, we introduce oil in production and consumption. Oil is freely traded across borders at flexible prices in international markets, i.e., the law of one price applies for oil. For the purpose of macroeconomic modelling, the chief characteristics of oil are its low substitutability with other factors of production and the skewed distribution of oil ownership across countries.[7]

The Ramsey Case Figures 5 and 6 revisit the optimal monetary policy under cooperation in a model with oil. The underlying parameterization of the model, summarized inTable 1, follows the baseline model with some changes to incorporate oil trade. In particular, the elasticity between oil and labor in the production function $\frac{1+\rho_o}{\rho_o}$ is set equal to 0.4 (high elasticity) or 0.05 (low elasticity). The share of oil in total output is kept at 5%. Only the foreign country has a positive endowment with oil. The trade elasticity $\frac{1+\rho_c}{\rho_c}$ is kept as 2 throughout the following illustrations.

A contraction in foreign oil supply displayed in Figure 5 pushes up the real price of oil, contracts output worldwide. The onslaught of inflation is prevented by increases in interest rates in both countries under the optimal monetary policy. The rise in foreign policy interest rates induces even a mild deflation in the foreign country and allows foreign output to drop below its counterpart under flexible prices, causing the foreign output gap to turn negative. In the home country, the process of pushing the outcomes in the actual economy closer to their flexible price counterparts is delayed and the output gap remains positive for the first few periods.

Although the departures of the model outcomes under sticky prices from the first-best are small, the small change of introducing oil into the baseline model do cause the divine coincidence to break down even for a shock that is considered "efficient shocks" in the New Keynesian literature. This finding carries over to other efficient shocks such as oil intensity shocks, i.e., shocks that change the amount of oil needed to produce one unit of output, and standard technology shocks, here in the form of shocks to labor productivity. Figure 6 shows

[7] Although other commodities feature similar characteristics from a modelling perspective, we focus on oil for three reasons. First, in contrast to other commodities, oil is not only used in the production of goods, but it is also directly used by consumers. Hence, changes in oil prices have a direct impact on consumer prices and therefore monetary policy. Second, ever since the 1970 oil supply shocks, oil has received considerable attention in the macroeconomics literature. Third, when assessing the implications of trade in oil on the gains of international monetary policy cooperation in a fully-fledged general equilibrium model, we can employ the estimated model by Bodenstein and Guerrieri (2011).

the departures from the divine coincidence for efficient and inefficient shocks and different values of the oil elasticities. The undesirability to match the flexible price outcomes at all times becomes more apparent for low oil elasticities.

Gains from Cooperation When policymakers fail to cooperate the deviation of the actual economy for its flexible counterpart become more pronounced. Figure 7 plots the differences between the Nash case and the Ramsey case for a foreign oil supply shock and two values of the oil elasticity, $\frac{1+\rho_o}{\rho_o}$ equal to 0.4 and 0.05, respectively.

Compared to the Ramsey case, nominal interest rates are kept lower under the Nash case as countries try to create more favorable international relative prices for themselves. The relatively lower level of nominal interest rates buffers the decline in output at the expense of higher inflation when countries do not cooperate on policies.

3 Towards a Full Quantitative Model

Quantitative models of the international business cycle incorporate additional features to bridge the gap between macroeconomic time-series and stylized models. In this section, we introduce step-by-step nominally sticky wages, and incomplete international financial markets. The subsequent section then introduces capital, investment, and real rigidities such as consumption habits and investment adjustment costs. The resulting general equilibrium equilibrium model is then parameterized using the estimates reported in Bodenstein and Guerrieri (2011).

3.1 Sticky Wages

At least since Christiano, Eichenbaum and Evans (2004), the New Keynesian literature has accepted the outsized importance of nominally sticky wages relative to sticky prices as a source of nominal rigidities. To incorporate sticky wages into our framework, we follow Erceg, Henderson and Levin (2000) and adapt the monopolistic competition framework in product markets to the labor market.

Households supply their homogenous labor to intermediate labor unions. These unions introduce distinguishing characteristics on the labor services and resell them to intermediate labor bundlers. The unions use Calvo contracts to set the wages charged to the intermediate bundlers. In turn, firms purchase a labor bundle $L_{1,t}^d$ from the labor bundlers.

The labor bundle demanded by firms takes the from:

$$L_{1,t}^d = \left[\int_0^1 L_{1,t}(h)^{\frac{1}{1+\theta_{1,t}^w}} dh \right]^{1+\theta_{1,t}^w}, \tag{27}$$

where $\theta_{1,t}^w$ is time-varying reflecting shocks to the wage markup.

The labor bundlers buy the labor services $L_{1,t}(h)$ from unions, combine them to obtain $L_{1,t}^d$, and resell them to the intermediate goods producers at wage $W_{1,t}$. In a perfectly competitive environment, profit maximization by the bundlers implies:

$$L_{1,t}(h) = \left[\frac{W_{1,t}(h)}{W_{1,t}} \right]^{-\frac{1+\theta_{1,t}^w}{\theta_{1,t}^w}} L_{1,t}^d, \tag{28}$$

and the zero-profit condition yields:

$$W_{1,t} = \left[\int_0^1 W_{1,t}(h)^{-\frac{1}{\theta_{1,t}^w}} dh \right]^{-\theta_{1,t}^w}. \tag{29}$$

Labor bundlers purchase labor from the unions that intermediate between the households and the labor bundlers. The unions allocate and differentiate the labor services from the households and choose a wage subject to the labor demand equation. Labor unions take the real wage desired by the household, $W_{1,t+j}^f / P_{1,t+j}$, as the cost of labor services. In the spirit of Calvo, a union can readjust a wage with probability $1 - \xi_1^w$ in each period. For those unions which cannot adjust wages in a given period, wages grow the steady state wage inflation rate which equals the overall steady state inflation rate. The problem of a union h

is given by:

$$\max_{W_t(h)} E_t \sum_{j=0}^{\infty} (\xi_1^w)^j \psi_{t,t+j} \left[(1+\tau_1^w)\omega_{t,j}^l W_t(h) L_{t+j}(h) - W_{t+j}^f L_{t+j}(h) \right] \tag{30}$$

$s.t.$

$$L_{1,t}(h) = \left[\frac{W_{1,t}(h)}{W_{1,t}} \right]^{-\frac{1+\theta_{1,t}^w}{\theta_{1,t}^w}} L_{1,t}^d, \tag{31}$$

$$\omega_{t,j}^l = \prod_{s=1}^{j} \pi^*. \tag{32}$$

The subsidy τ_1^w is set to guarantee the efficient level of labor supply in the steady state.

To assess the importance of sticky wages the model parameters assume again the values reported in Table 1. The probability of adjusting wages $1 - \xi^w$ is set to 0.25 implying an average duration of a wage contract of 4 quarters. The average contract duration for prices is also fixed at 4 quarters. The parameter choices for the oil sector of the economy follow the previous section.

Focussing on the gains of monetary policy cooperation, Figure 8 shows the difference between the outcomes of the Nash case relative to the Ramsey case for a negative oil supply shock under sticky and flexible wages, respectively. The deviations between the Nash and Ramsey cases under sticky wages dwarf the differences in the flexible wage economy.

The differences between the assumptions on monetary policy are also pronounced for other types of shocks. Particularly striking are the large differences for technology shocks in Figure 9.

3.2 Baseline Model with Incomplete Financial Markets

To be added.

4 Optimal Monetary Policy in a Quantitative Model of Oil

To measure the possible magnitude of gains from international monetary policy cooperation in a more realistic model, we incorporate capital accumulation and real rigidities into the model of the previous sections to obtain the general equilibrium model estimated in Bodenstein and Guerrieri (2011). Tables 2, 3, and 4 provide details on the parameter values and the stochastic shock processes. A full description of the model is provided in a separate Appendix B. In the following, we refer to the home country as the United States.

4.1 The Effects of a Foreign Oil Intensity Shock

To understand the fundamental policy trade-offs in the full model, we start by assessing the effects of a foreign oil intensity shock under both the Ramsey policy and the Taylor-type instrument rule estimated in Bodenstein and Guerrieri (2011).[8]

In Figure 10, foreign oil intensity increase through a change in $Z^o_{2,t}$.[9] As foreign oil demand expands, the real price of oil in US. consumption units increases. Upon impact, the price rises 14%. The half life of the response is close to 5 years. Home oil demand contracts as both households and firms substitute away from the more expensive oil input. Since the oil price elasticity of demand in the model is estimated close to -0.4, the decline in demand is also approximately 40% of the price increase.[10]

[8]The estimated instrument rule, the central banks impose substantial interest rate smoothing and respond to inflation only by raising the nominal interest rate with the weight on core inflation equal to 2. Bodenstein and Guerrieri (2011) found the weight on the output gap to be zero and an interest rate smoothing parameter of 0.65.

[9]When the oil substitution elasticity is less than 1, an increase in foreign oil intensity is brought about through a decline in $Z^o_{2,t}$.

[10]It is still widely believed that the short-run price elasticity of oil demand is close to zero. This consensus is based on reduced-form regression estimates that are known to be biased toward zero. These traditional estimates are invalid. Recently, a number of studies have provided properly identified estimates of the

Eventually, lower oil use leads to a fall in the current and future marginal product of capital, causing investment, consumption, and gross output to fall. However, in the short run, the adjustment is delayed in particular under the estimated rule. Real rigidities prevent both consumption and investment from adjusting immediately, as can be inferred from the response of domestic absorption. Furthermore, the response of net nonoil exports, as well as the role of nominal rigidities and monetary policy need to be taken into account.

Focusing on trade, for a net oil importer such as the United States with a demand elasticity well below unity, an oil price increase results in a marked deterioration of the oil trade balance. With incomplete international financial markets, the deterioration in the oil trade balance is linked to substantial differences in wealth effects across countries. Because the negative wealth effect is relatively larger for the oil importer, the home nonoil terms of trade worsen and induce an expansion in nonoil net exports.[11]

Apart from net exports, nominal rigidities and monetary policy also play an important role in shaping the short-term response. In Figure 10, under the estimated rule the output contraction is delayed relative to the optimal policy under cooperation, i.e. the Ramsey policy. The differences in the responses show through in the behaviour of real interest rates. In the presence of pronounced real rigidities that make the economy relative insensitive to movements in the real interest rate in the short run, very large swings in the real interest rate occur in the first best economy (the dashed dotted line) in order to curb domestic absorption. The Ramsey policy implements such drastic swings in the real rate whereas the smoothing component of the estimated historical monetary policy rule generates a gradual

short-run price elasticity of oil demand from structural econometric models. The latter studies, regardless of methododolgy, yield much higher elasticity estimates that are similar in magnitude to our estimate in this paper (see, e.g., Kilian and Murphy (2010) and the references therein).

[11]For each country, we define the non oil terms of trade as the price of imports over the price of exports, expressed in a common currency; accordingly, an upward movement in Figure 10 denotes a worsening of the terms of trade for the home country. We define the exchange rate as the price of the home consumption basket over the price of the foreign consumption basket, expressed in a common currency; accordingly, an upward movement in Figure 10 denotes a depreciation for the home country.

increase in real rates only. The relative movements of output under the optimal policy and the estimated rule mirror those of the interest rate movements. With respect to inflation, the Ramsey policy stabilizes both wages and (core) prices more effectively than the estimated policy rule through its increase in real interest rate. This feature of the optimal policy hints towards the general importance of stabilizing wage inflation in New Keynesian models.[12]

4.2 Gains from Cooperation

Finally, Figures 11, 12, and 13 plot the differences in responses between the Nash and Ramsey cases in the full quantitative model for various shocks. In contrast to the previous sections, the shocks follow now Bodenstein and Guerrieri (2011) with respect to their statistical features. Nevertheless, the key observations form the baseline model survive. The largest differences between the Nash and Ramsey case occur for wage markup shocks (Figure 13), but also the so-called efficient shocks lead to sizeable differences.

Furthermore, the differences between policy regimes and the possible gains from international policy cooperation are depend on the presence of wage stickiness, real rigidities, and oil. Whereas the role of nominal and real rigidities in amplifying the differences between the Nash and Ramsey outcomes is not surprising, the importance of oil is a novel insight. Removing oil from the full model not only eliminates oil shocks as possible sources for instability, but also affects the transmission of other shocks. With respect to the possible gains from coordination, the differences between Nash and Ramsey outcomes are cut by about half when removing oil from the picture.

4.3 Gains from Cooperation and Consumption Gains

To be added.

[12] As shown in Bodenstein, Guerrieri, Kilian (2012) a simple instrument rule that responds to wage inflation without interest rate smoothing is close to optimal within the class of simple instrument rules.

5 Conclusion

We show that introducing oil into the baseline monetary model of macroeconomic interdependence eliminates the divine coincidence of monetary policy even if the steady state of the model is efficient and only so called efficient shocks are considered.

To assess the gains from international monetary policy cooperation we compute both Ramsey and Nash policies in a standard two country DSGE model that incorporates trade in oil as discussed in Bodenstein and Guerrieri (2011). Sticky wages and real rigidities play a possibly important role in observing large differences between the outcomes under full cooperation (Ramsey case) and purely nationally oriented policies (Nash case). Surprisingly, though so does oil.

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Table 1: Parameters for Baseline Model

Parameter	**Used to Determine**	**Parameter**	**Used to Determine**
Parameters common across countries			
$\beta = 0.99$	discount factor	$\sigma = 1$	intertemporal consumption elasticity
$\chi = 3$	Determines Lab. Supply El. $(\frac{1}{2\chi})$	$\frac{1+\rho^o}{\rho^o} = 0.4$	Oil Subst. Elasticity
$\frac{1+\rho^c}{\rho^c} = 2$	Trade Subst. Elasticity	$\xi^p = 0.75$	Calvo Price Parameter
$\xi^w = 0.75$	Calvo Wage Parameter	$N_{ss} = 0.33$	steady state labor share to fix χ_0
$\omega_{oy} = 0.05$	weight on oil in production	$\omega_{oc} = 0.05$	weight on oil in consumption
Country specific parameters			
$\zeta = 1$	relative size of home country	$\frac{Y^1_{O ss}}{O^1_{Y ss}+O^1_{C ss}} = 0$	steady state ratio oil prod. to cons. (home)

Table 2: Steady State Ratios and Parameters

Parameter	Used to Determine	Parameter	Used to Determine
Parameters common across countries			
$\beta = 0.99$	discount factor	$\sigma = 1$	intertemporal consumption elasticity
$\kappa = 0.30^{**}$	habits in consumption	$\chi = 59.5^{*}$	Determines Lab. Supply El. ($\frac{1}{2\chi}$)
$\delta = 0.025$	depreciation rate of capital	$\rho_v = -2$	K-L sub. elasticity (0.5)
$\psi^i = 3.5^{*}$	Investment Adjustment Cost	$\bar{\pi}^{core} = 1.011^{*}$	Steady State Inflation (gross)
$\frac{1+\rho^o}{\rho^o} = 0.42^{*}$	Oil Subst. Elasticity	$\frac{1+\rho^c}{\rho^c} = 1.75^{*}$	Trade Subst. Elasticity
$\xi^p = 0.81^{*}$	Calvo Price Parameter	$\xi^w = 0.89^{*}$	Calvo Wage Parameter
$\iota^p = 0.00^{*}$	Lagged Price Indexation	$\iota^w = 0.00^{*}$	Lagged Wage Indexation
$g = 0.18$	steady state gov. cons. share of GDP	$N_{ss} = 0.33$	steady state labor share to fix χ_0
$\mu_z = 1.0058^{*}$	Growth Rate of Technology (gross)	$\mu_o = 1.0026$	trend growth in oil supply (gross)
Parameters not common across countries			
$\omega_{k,1} = 1.54$	parameter on K in value added (home)	$\omega_{k,2} = 1.60$	parameter on K in value added (foreign)
$\omega_{oy,1} = 0.026$	weight on oil in production (home)	$\omega_{oy,2} = 0.057$	weight on oil in production (foreign)
$\omega_{oc,1} = 0.021$	weight on oil in consumption (home)	$\omega_{oc,2} = 0.041$	weight on oil in consumption (foreign)
$\omega_{mc,1} = 0.068$	weight on imports in consumption (home)	$\omega_{mc,2} = 0.039$	weight on imports in consumption (foreign)
$\omega_{mi,1} = 0.40$	weight on imports in investment (home)	$\omega_{mi,2} = 0.25$	weight on imports in investment (foreign)
Parameters specific to home country			
$\zeta = 1/2$	relative size of home country	$\frac{Y^1_{Oss}}{O^1_{Yss}+O^1_{Css}} = 0.3$	steady state ratio oil prod. to cons. (home)
$\phi_b = 0.0001$	curvature of bond intermed. cost		

Values carrying the superscript "*" are taken from the estimation exercise reported in Bodenstein and Guerrieri (2011). "**" indicates that the value used for κ in our simulations deviates from its estimated value of 0.65 in that paper to guarantee existence of the equilibrium under Ramsey and Nash policies.

Table 3: Shocks and Parameterization

Shock	**Stochastic Process**
Home Shocks	
neutral technology	$ln(Z_{1,t}) = (1+\rho_1^z - \rho_2^z)ln(Z_{1,t-1}) - \rho_1^z ln(Z_{1,t-2}) + \sigma_1^z \varepsilon_{1,t}^z$
investment	$ln(Z_{1,t}^i) = \rho_1^{zi} ln(Z_{1,t-1}^i) + \sigma_1^{zi} \varepsilon_{1,t}^z$
consumption	$ln(Z_{1,t}^c) = \rho_1^{zc} ln(Z_{1,t-1}^c) + \sigma_1^{zc} \varepsilon_{1,t}^z$
spending	$ln(Z_{1,t}^g) = \rho_1^{zg} ln(Z_{1,t-1}^g) + \sigma_1^{zg} \varepsilon_{1,t}^z$
price markup	$\hat{\theta}_{1,t}^p = \rho_1^p \hat{\theta}_{1,t-1}^p + \sigma_1^p \varepsilon_{1,t}^p$
wage markup	$\hat{\theta}_{1,t}^w = \rho_1^w \hat{\theta}_{1,t-1}^w + \sigma_1^w \varepsilon_{1,t}^w$
Oil Shocks	
home oil supply	$ln(Y_{1,t}^o) = (1+\rho_{11}^{yo} - \rho_{21}^{yo})ln(Y_{1,t-1}^o) - \rho_{11}^{yo} ln(Y_{j,t-2}^o) + \sigma_1^{yo} \varepsilon_{1,t}^{yo}$
foreign oil supply	$ln(Y_{2,t}^o) = (1+\rho_{12}^{yo} - \rho_{22}^{yo})ln(Y_{2,t-1}^o) - \rho_{12}^{yo} ln(Y_{2,t-2}^o) + \sigma_2^{yo} \varepsilon_{2,t}^{yo}$
home oil intensity	$ln(Z_{1,t}^o) = (1+\rho_1^{zo} - \rho_2^{zo})ln(Z_{1,t-1}^o) - \rho_1^{zo} ln(Z_{1,t-2}^o) + \sigma_1^{zo} \varepsilon_{1,t}^{zo}$
for. oil intensity	$ln(Z_{2,t}^o) = (1+\rho_1^{zo} - \rho_2^{zo})ln(Z_{2,t-1}^o) - \rho_1^{zo} ln(Z_{2,t-2}^o) + \sigma_2^{zo} \varepsilon_{2,t}^{zo}$
Other Open-Economy Shocks	
for. neutral tech.	$ln(Z_{2,t}) = (1+\rho_1^z - \rho_2^z)ln(Z_{2,t-1}) - \rho_1^z ln(Z_{2,t-2}) + \sigma_2^z \varepsilon_{2,t}^z$
home import	$ln(Z_{1,t}^m) = (1+\rho_1^{zm} - \rho_2^{zm})ln(Z_{1,t-1}^m) - \rho_1^{zm} ln(Z_{1,t-2}^m) + \sigma_1^{zm} \varepsilon_{1,t}^{zm}$
foreign import	$ln(Z_{2,t}^m) = (1+\rho_1^{zm} - \rho_2^{zm})ln(Z_{2,t-1}^m) - \rho_1^{zm} ln(Z_{2,t-2}^m) + \sigma_2^{zm} \varepsilon_{2,t}^{zm}$
foreign consumption	$ln(Z_{2,t}^c) = \rho^{zc} ln(Z_{2,t-1}^c) + \sigma_2^{zc} \varepsilon_{2,t}^z$

For shocks that occur in both countries, we impose that the autoregressive coefficients are identical except in the case of oil supply shocks.

Table 4: Estimation Results

	Estimate		Estimate
ρ_1^z, Technology, growth AR coef.	0.2163	ρ_2^z, Technology, level error corr. coef.	0.0001
σ_1^z, U.S. Technology, st. dev. of innov.	0.0066	σ_2^z, For. Technology, st. dev. of innov.	0.0108
ρ_1^{zi}, U.S. Investment Technology, AR coef.	0.9059	σ_1^{zi}, U.S. Inv. Tech. st. dev. of innov.	0.0269
ρ_1^{zc}, Consumption Shock, AR(1) coef.	0.9188	σ_1^{zc}, U.S. Consumption, st. dev. of innov.	0.6484
σ_2^{zc}, For. Consumption, st. dev. of innov.	0.7174		
ρ_1^{zg}, U.S. Government Expenditure, AR coef.	0.9980	σ_1^{zg}, U.S. Gov. Exp. st. dev. of innov.	0.0246
ρ_1^p, U.S. Price Markup, AR(1) coef.	0.7401	σ_1^p, U.S. Price Markup, st. dev. of innov.	0.4774
ρ_1^w, U.S. Wage Markup, AR(1) coef.	0.9768	σ_1^w, U.S. Wage Markup, st. dev. of innov.	3.6988
ρ_{11}^{yo}, U.S. Oil Supply, growth AR coef.	0.1236	ρ_{21}^{yo}, U.S. Oil Supply, level error corr. coef.	0.0001
σ_1^{yo}, U.S. Oil Supply, st. dev. of innov.	0.0253		
ρ_{12}^{yo}, For. Oil Supply, growth AR coef.	0.0001	ρ_{22}^{yo}, For. Oil Supply, level error corr. coef.	0.0378
σ_1^{yo}, For. Oil Supply, st. dev. of innov.	0.0181		
ρ_{11}^{zo}, Oil Efficiency, growth AR coef.	0.0001	ρ_{21}^{zo}, Oil Efficiency, level error corr. coef.	0.0145
σ_1^{zo}, U.S. Oil Efficiency, st. dev. of innov.	0.0470	σ_2^{zo}, For. Oil Efficiency, st. dev. of innov.	0.1269
ρ_1^{zm}, Import, growth AR coef.	0.0001	ρ_1^{zm}, Import, level error corr. coef.	0.0019
σ_1^{zm}, U.S. Import, st. dev. of innov.	0.0263	σ_2^{zm}, For. Import, st. dev. of innov.	0.0412

Parameters were estimated in Bodenstein and Guerrieri (2011). For details on the estimations and confidence intervals the interested reader is referred to the latest version of that paper.

Figure 1: Optimal Monetary Policy under Cooperation – Negative Technology Shock and Divine Coincidence

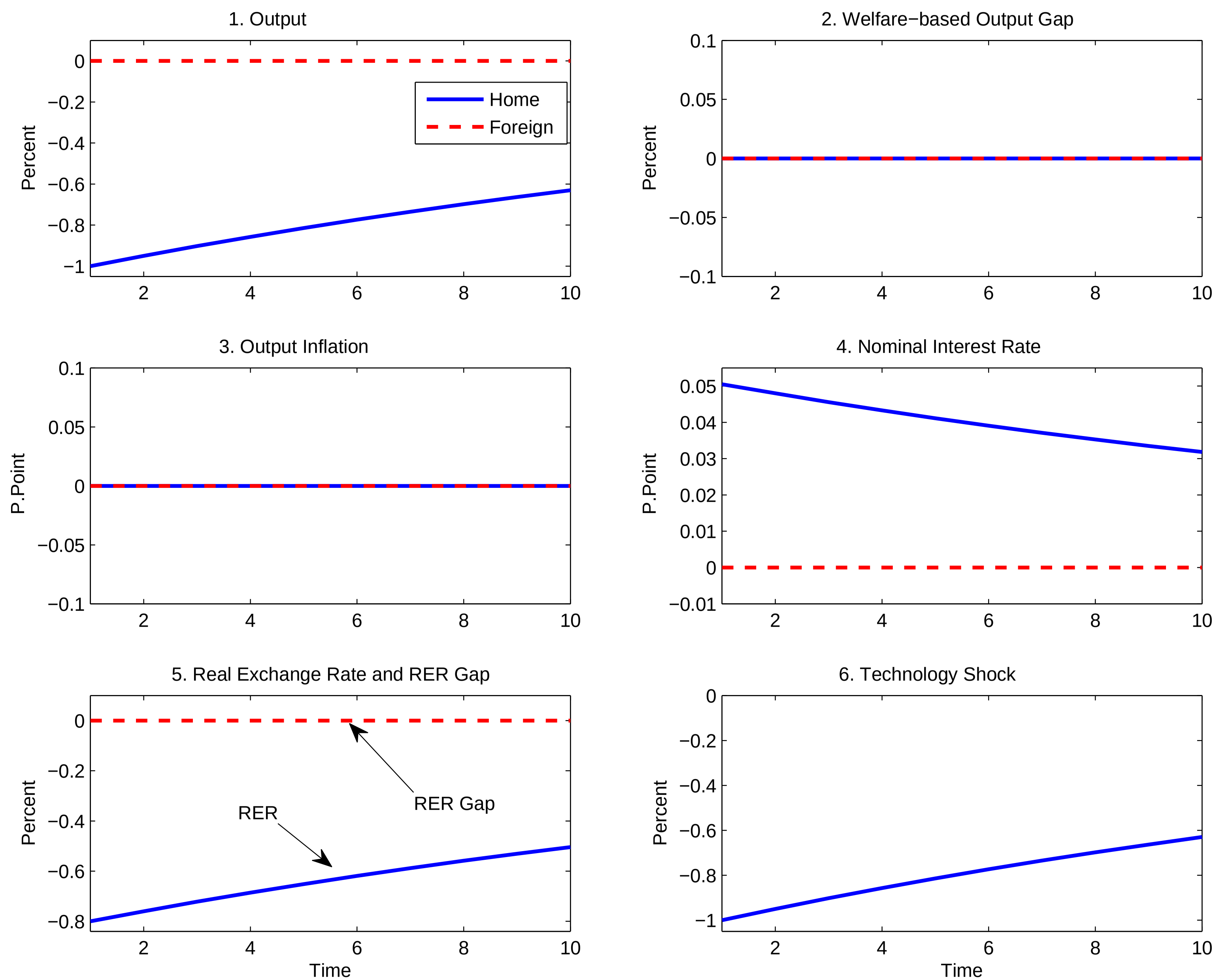

Figure 2: Optimal Monetary Policy under Cooperation – Negative Markup Shock and Trade Elasticity

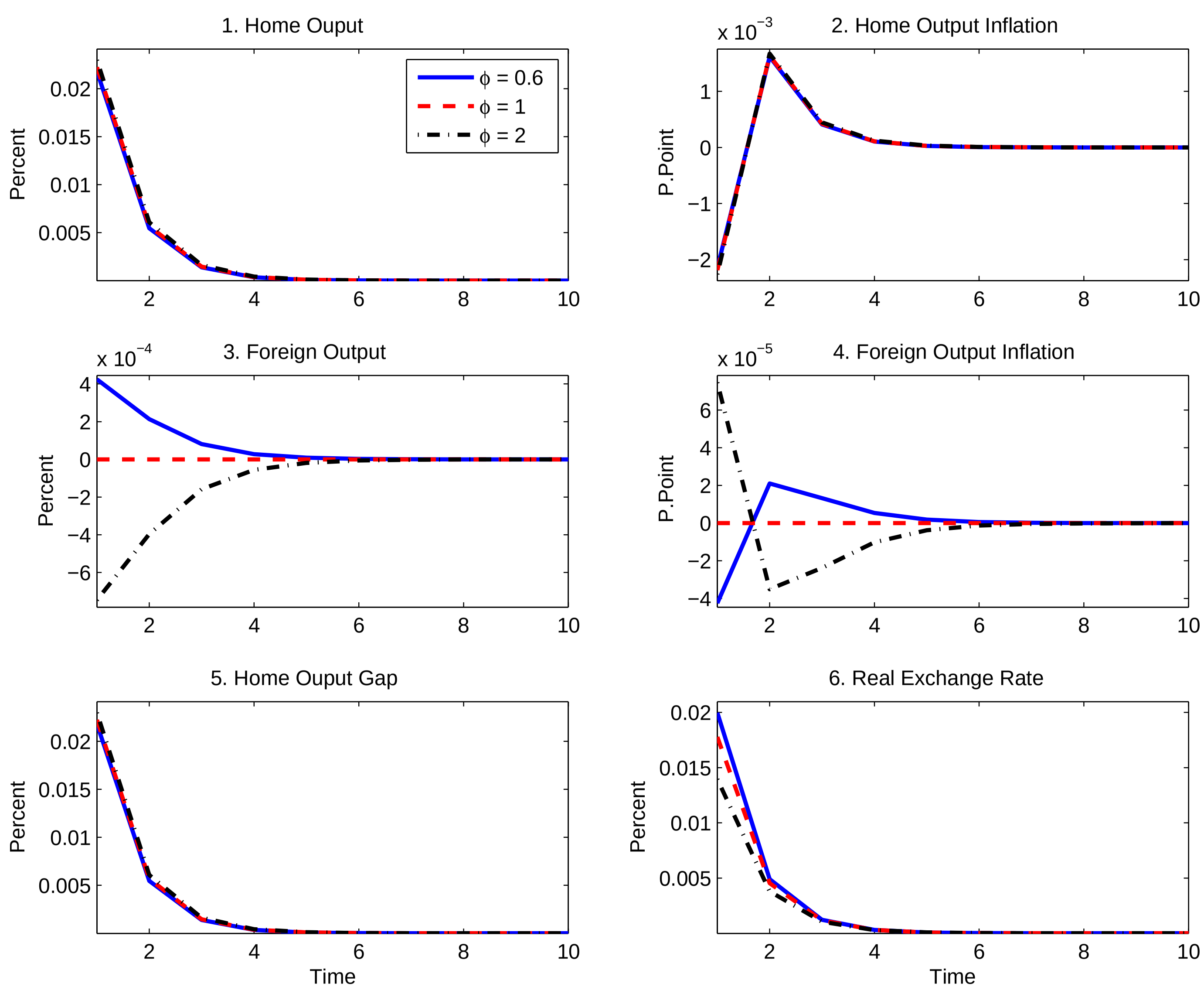

Figure 3: Nash Gaps and Gains from Cooperation – Negative Technology Shock

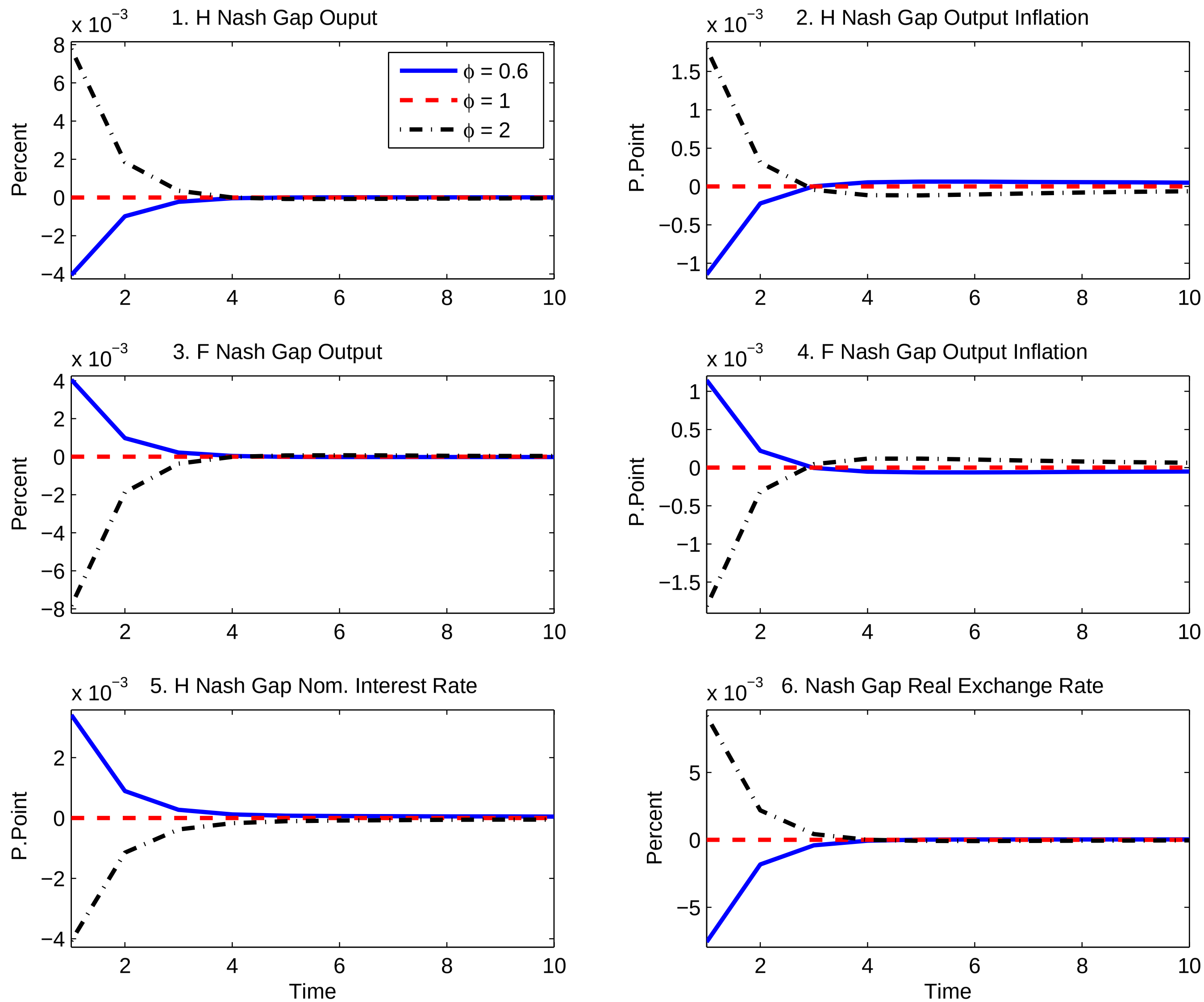

Figure 4: Nash Gaps and Gains from Cooperation – Negative Markup Shock

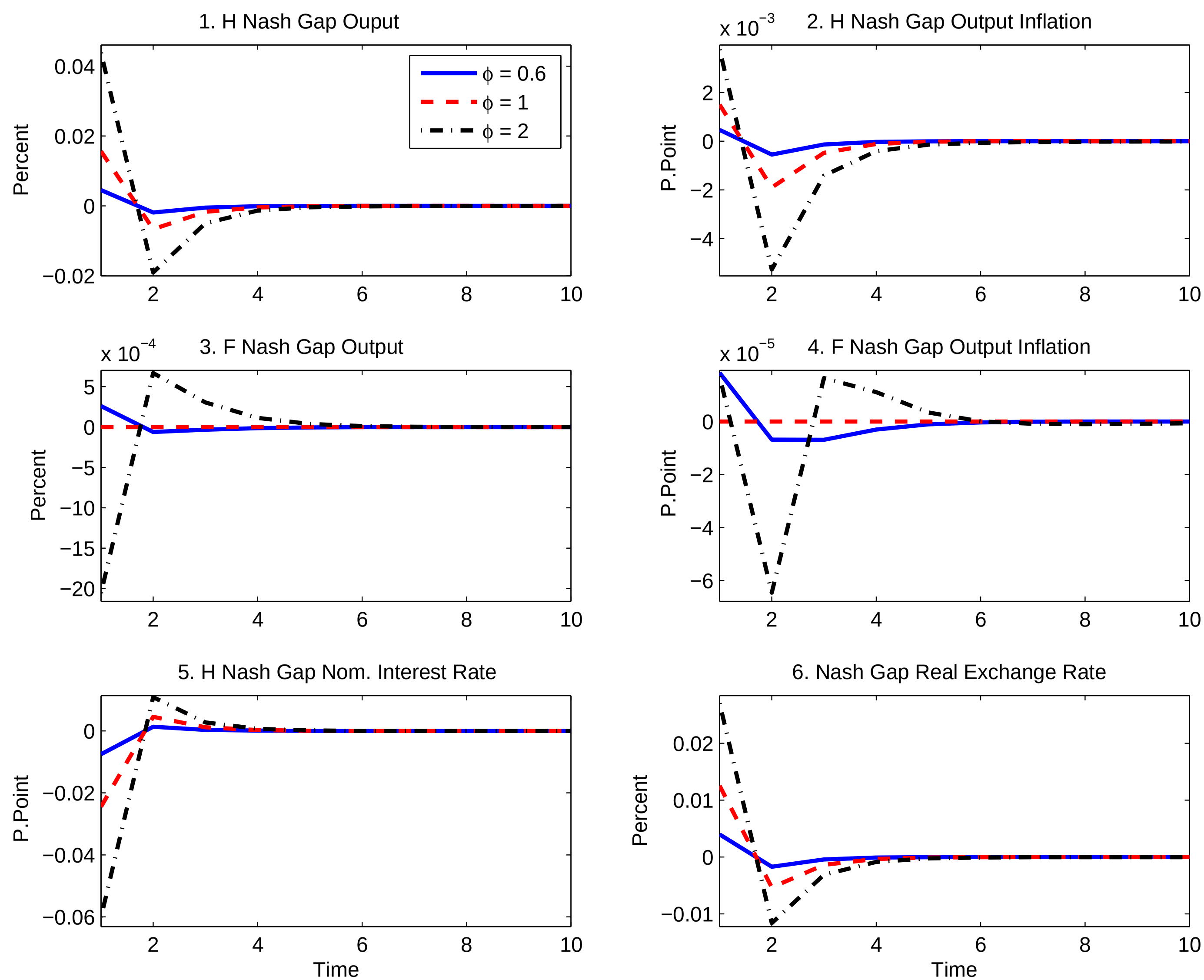

Figure 5: Optimal Monetary Policy under Cooperation – Foreign Oil Supply Shock

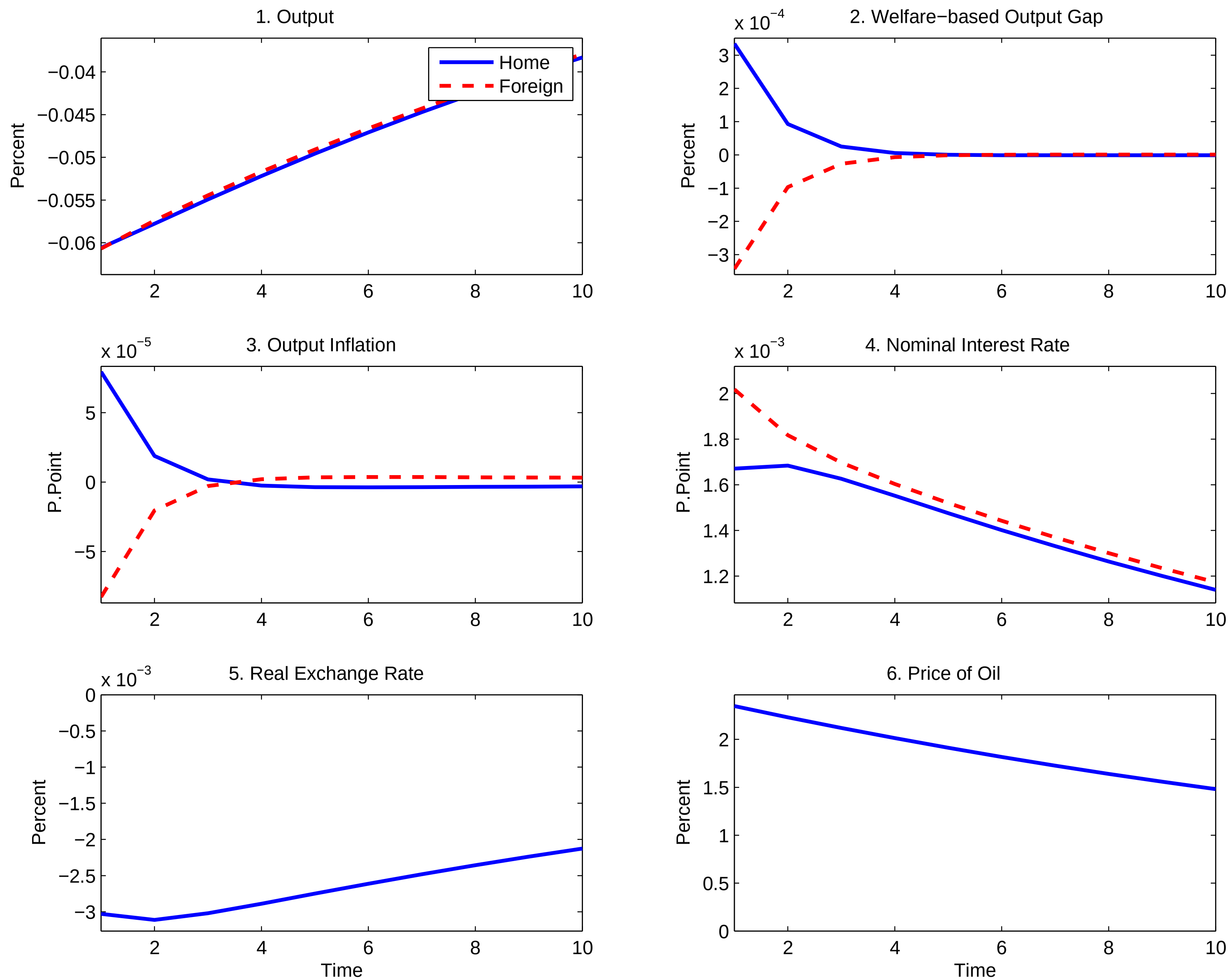

Figure 6: Optimal Monetary Policy under Cooperation in a Model with Oil – Comparison of Shocks

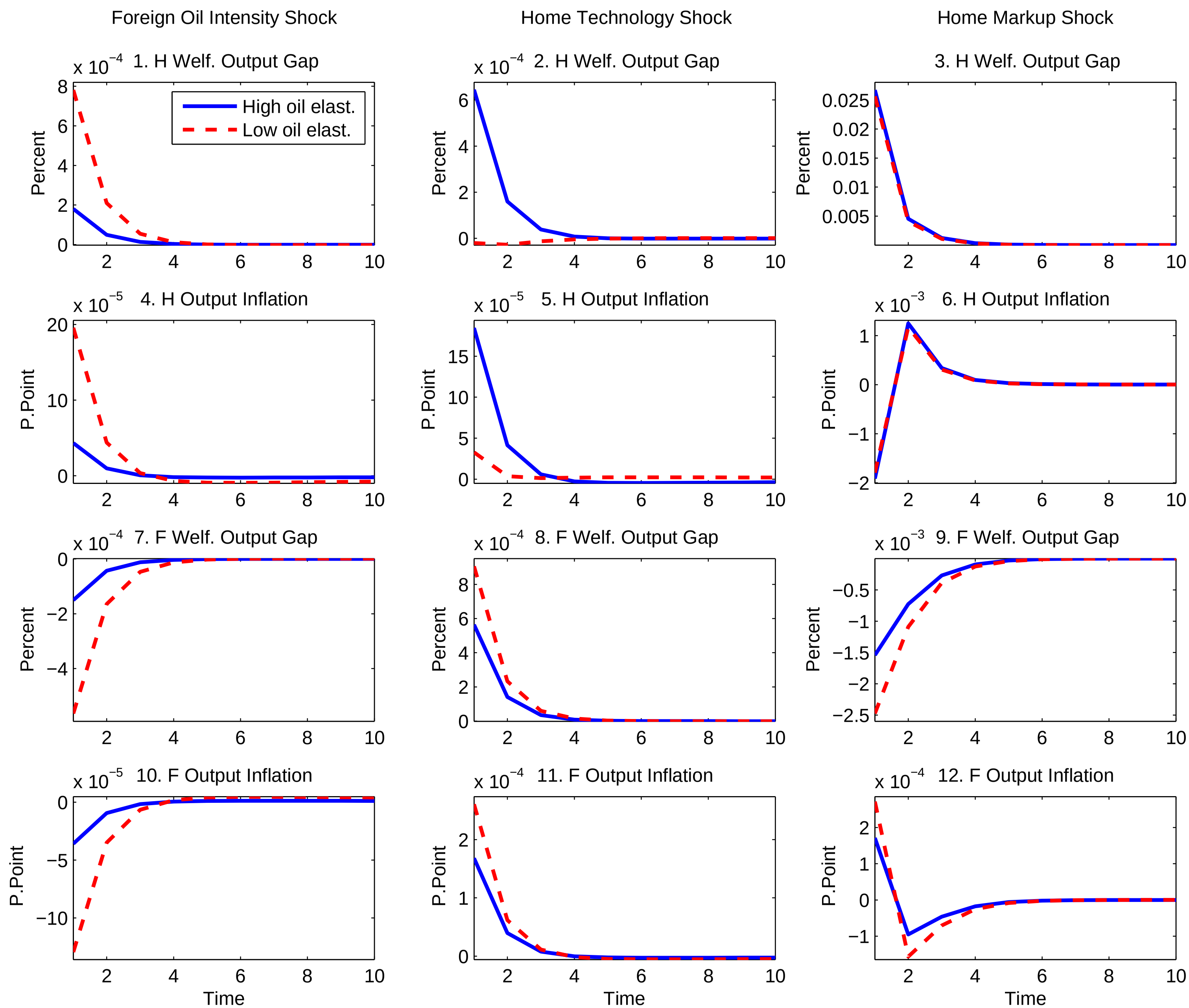

Figure 7: Nash Gaps and Gains from Cooperation – Foreign Oil Supply Shock

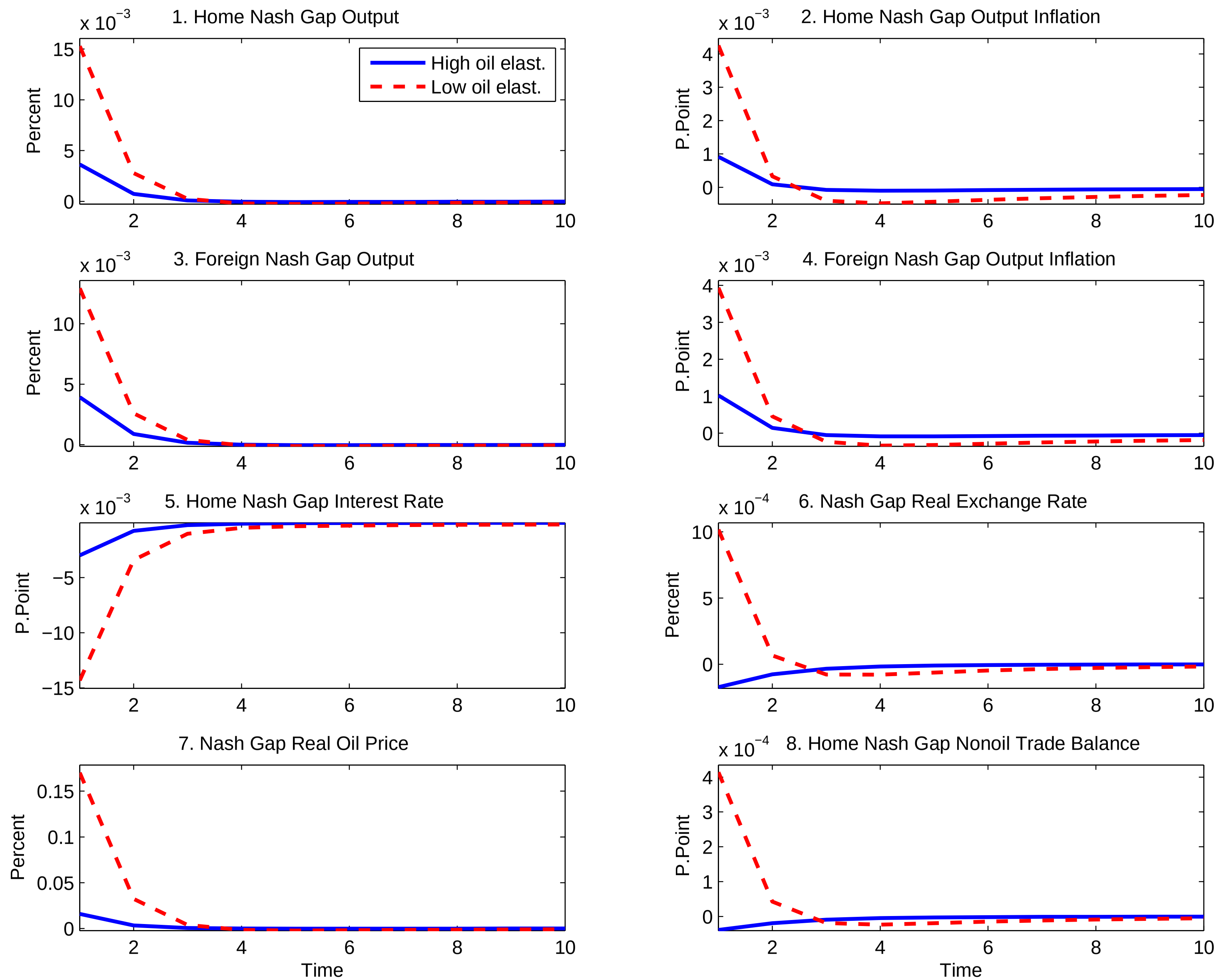

Figure 8: Nash Gaps and Gains from Cooperation with Sticky Wages – Foreign Oil Supply Shock

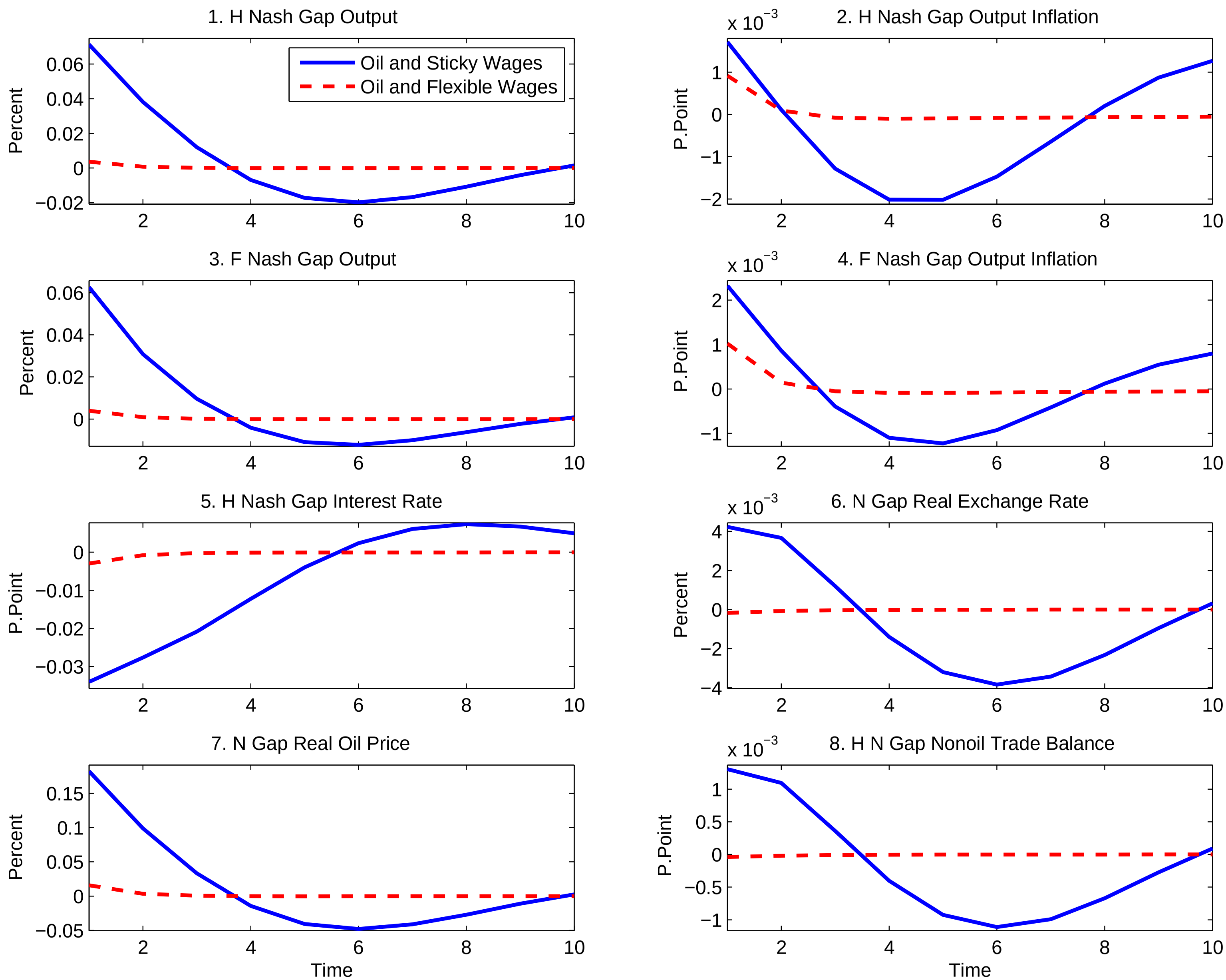

Figure 9: Nash Gaps and Gains from Cooperation with Sticky Wages – Comparison of Shocks

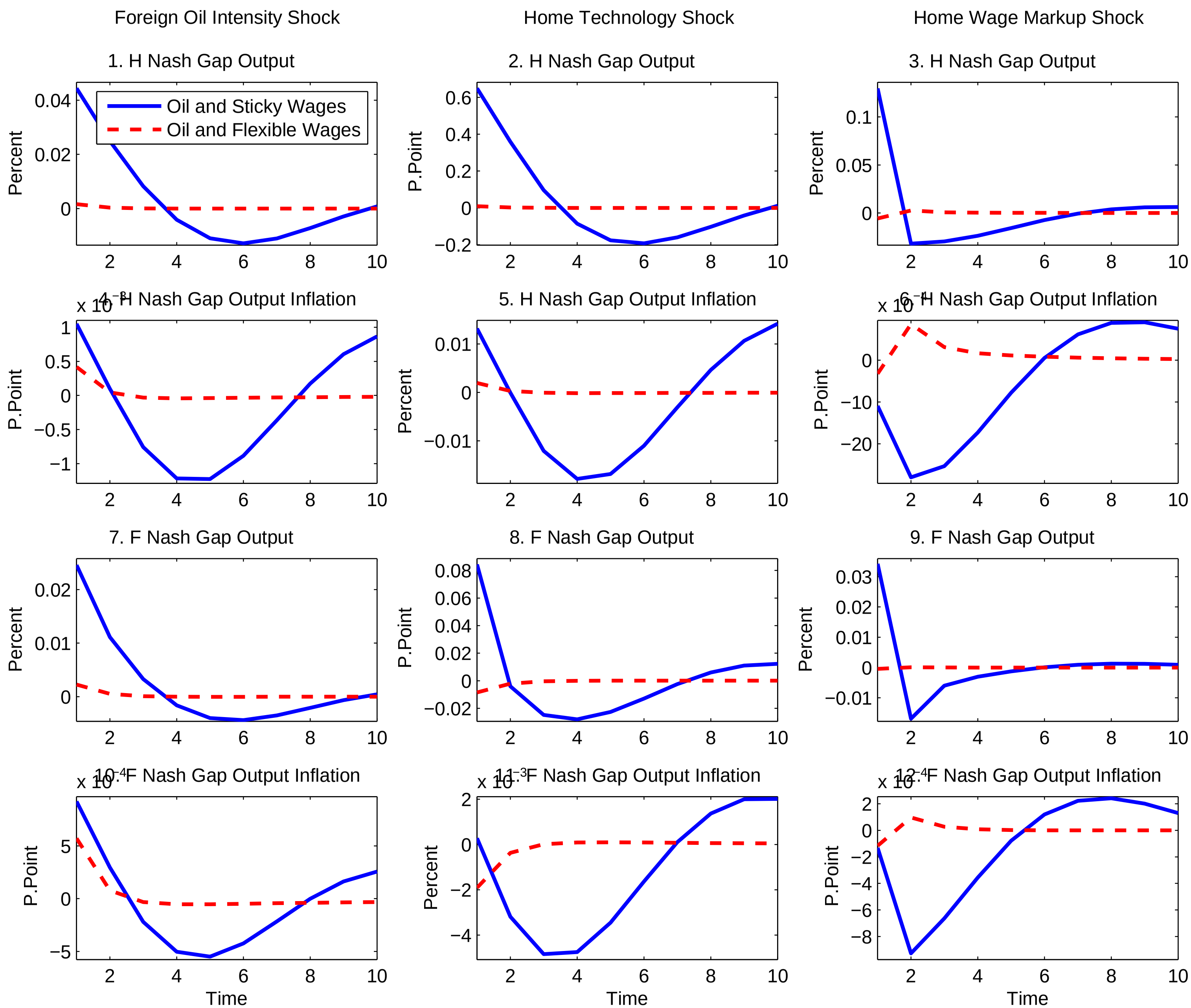

Figure 10: Optimal Monetary Policy under Cooperation in a Empirical Model with Oil – Home Country Responses to Foreign Oil Intensity Shocks

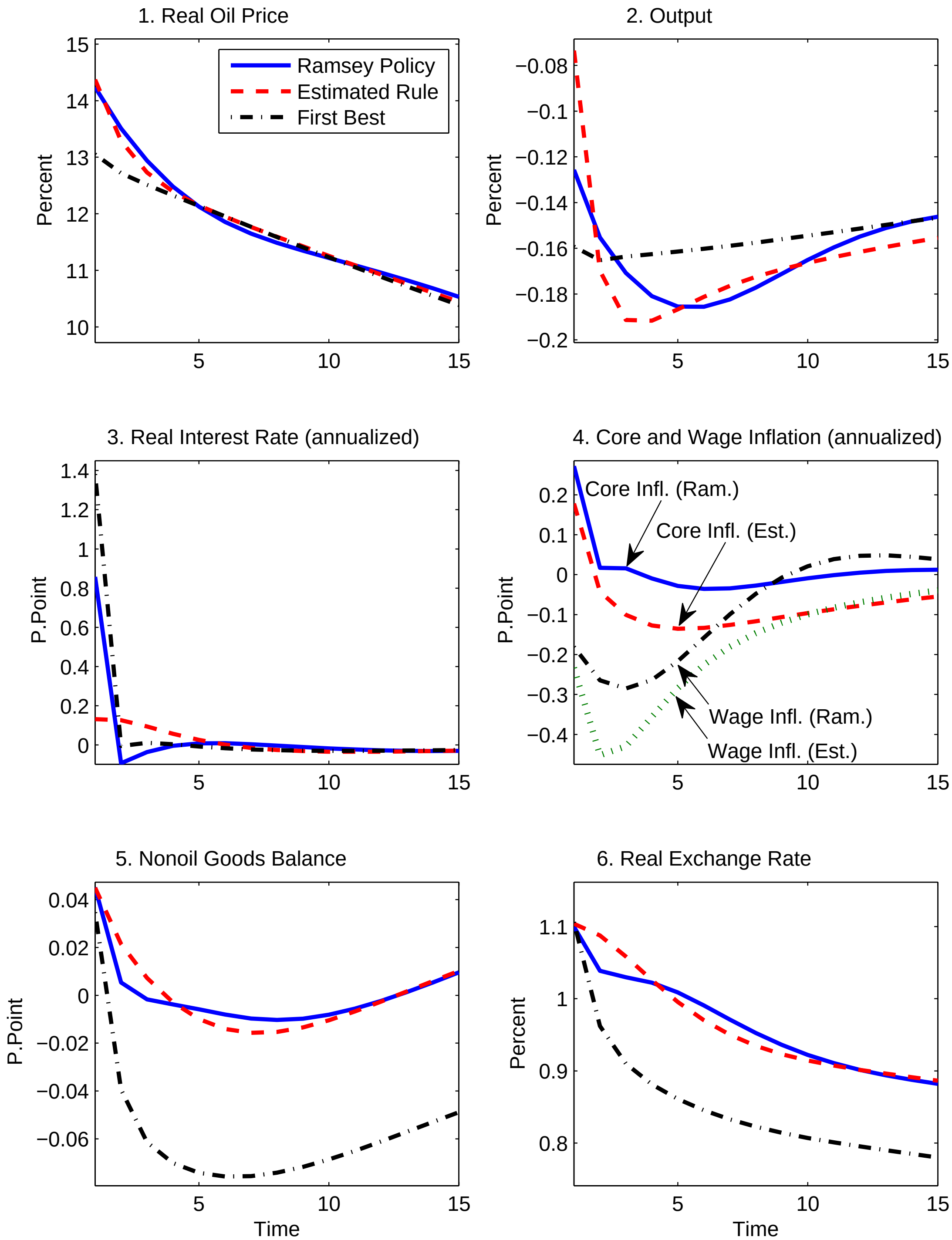

Figure 11: Nash Gaps in a Empirical Model with Oil – Technology Shocks

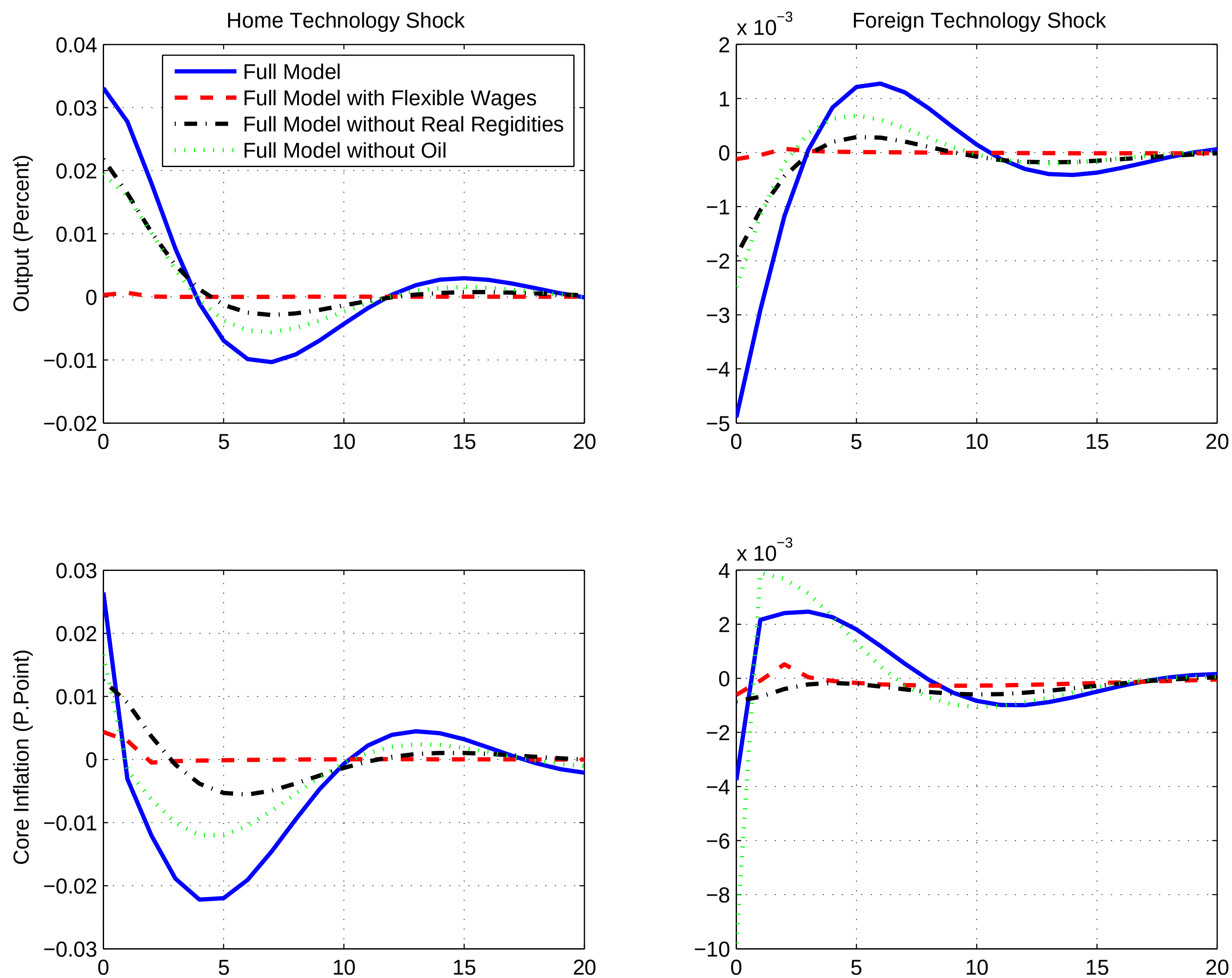

Figure 12: Nash Gaps in a Empirical Model with Oil – Foreign Oil Shocks

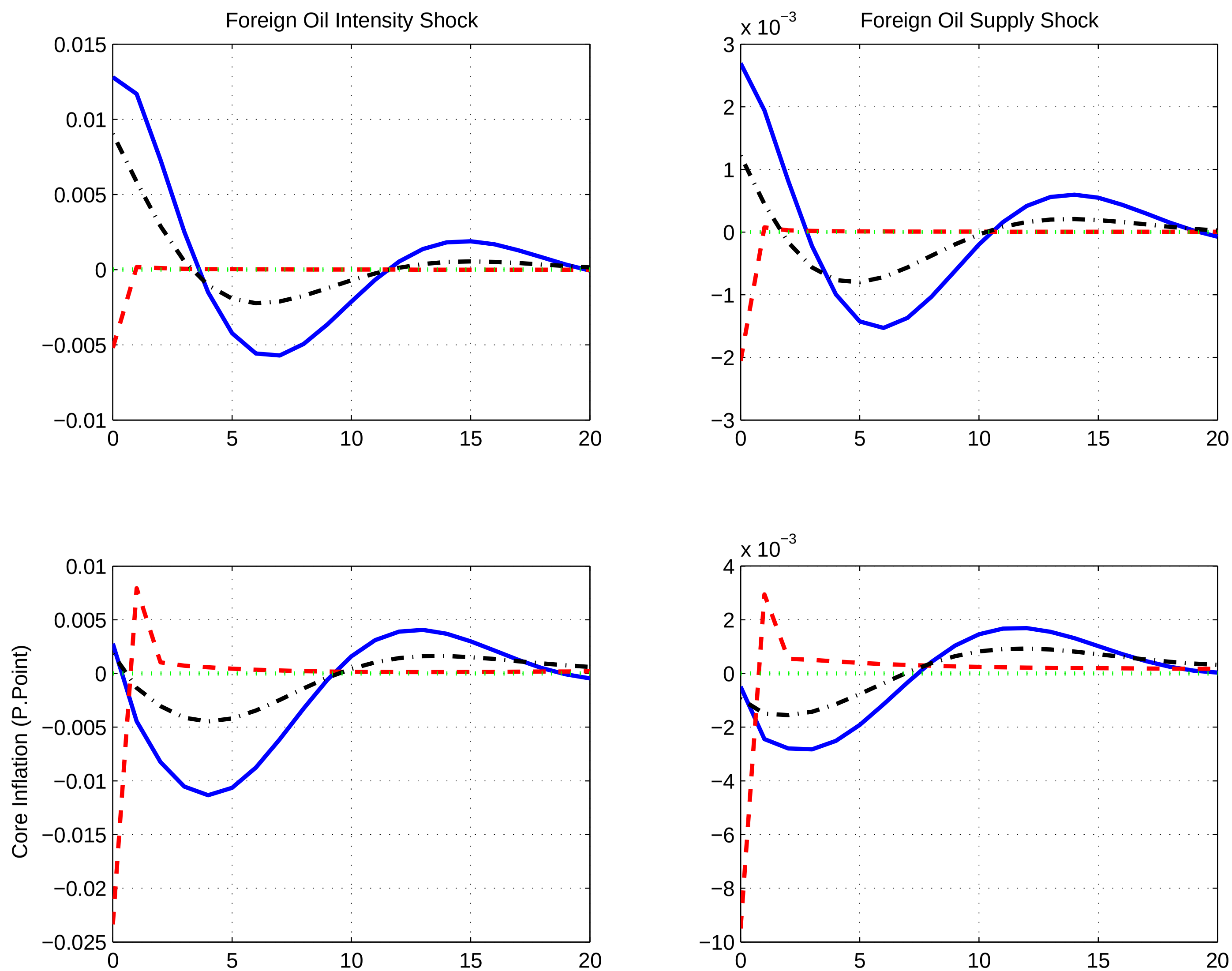

Figure 13: Nash Gaps in a Empirical Model with Oil – Markup Shocks