Expectations and Exchange Rate Dynamics: A State-Dependent Pricing Approach[*]

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Abstract

We introduce elements of state-dependent pricing and strategic complementarity into an otherwise standard New Open Economy Macroeconomics (NOEM) model. Relative to previous NOEM work, there are striking new implications for the dynamics of real and nominal economic activity: complementarity in the timing of price adjustment dramatically alters an open economy's response to monetary disturbances. Using a two-country Producer-Currency-Pricing environment, our framework replicates key international features following a domestic monetary expansion: (i) a high international output correlation relative to consumption correlation, (ii) a delayed overshooting of exchange rates, (iii) a J-curve dynamic in the domestic trade balance, and (iv) a delayed surge in inflation across countries. Overall, the model is consistent with many empirical aspects of international economic fluctuations, while stressing pricing behavior and exchange rate effects highlighted in the traditional work of Mundell, Fleming, and Dornbusch.

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1 Introduction

The Mundell-Fleming-Dornbusch (MFD) model remains the dominant workhorse for international policy analysis. At its core is the intuitive notion that exchange rate changes redirect global expenditure in the presence of price rigidity. Dornbusch (1987), Krugman (1991), and Obstfeld and Rogoff (2000) provide empirical evidence that the expenditure switching effect of exchange rate changes is alive and well among industrial countries. In a similar spirit, Figure 1 displays annual changes in nominal exchange rate series versus annual changes in exports for France, Germany, Japan and the United Kingdom to the United States since 1991. The strong correlations between changes in currency value and changes in export demand suggest that exchange rate movements remains an important determinant of trade flows.

Like the MFD approach, recent work on the New Open Economy Macroeconomics (NOEM) builds in pricing frictions and studies their implications for the dynamics of exchange rates, trade balances, and other macroeconomic variables. However, while introducing better microeconomic foundations, the NOEM literature has not successfully incorporated the basic notions and predictions found in the MFD approach: the canonical NOEM model has marginal expenditure-switching effect and has many other empirical predictions that differ sharply from the observed empirical evidence. Furthermore, both the MFD and NOEM models have been criticized because of ad hoc pricing elements. The MFD framework keeps prices fixed for the duration of the analysis or adopts mechanical price adjustment rules. In the NOEM literature, optimizing price-setters can only change the magnitude, but not the timing of adjustments.

We introduce elements of state-dependent pricing and strategic complementarity into an otherwise standard NOEM model. Relative to previous NOEM work, there are striking new implications for the dynamics of real and nominal economic activity: complementarity in the timing of price adjustment dramatically alters an open economy's response to monetary disturbances. Under a traditional Producer-Currency-Pricing environment, our framework replicates key international features following a domestic monetary expansion: (i) a delayed surge in inflation across countries, (ii) a delayed overshooting of exchange rates,

(iii) a J-curve dynamic in the domestic trade balance, and (iv) a high international output correlation relative to consumption correlation. Overall, our open economy macroeconomic model is consistent with many empirical aspects of international economic fluctuations, while stressing pricing behavior and exchange rate effects highlighted in the Keynesian tradition. In addition, our model emphasizes the expenditure-switching effect as an important channel of international monetary policy transmission and consequently keeps the spirit of Mundell (1963), Fleming (1962), and Dornbusch (1976) within the confines of the microfounded dynamic general equilibrium approach.

The similarities between our model and the MFD approach comes from the interaction of state-depedent pricing and strategic complementarity. As opposed to the NOEM literature where the timing of price adjustment is fixed, the interaction of state-dependent pricing and strategic complementarity implies that firms can coordinate their actions by paying a fixed menu cost. On the one hand, forward looking price-setting firms would prefer to raise their prices in light of a monetary expansion. On the other hand, firms know that they have the possibility to reset their prices at any time in the future, and would rather do so than lose market share by pricing high relative to their competitors. This behavior leads to price responses that are initially nonexistant and therefore closed to those engineered in IS-LM models. On aggregate, this implies a gradual transmission of monetary shocks to prices, and ultimately to aggregate economic activities: delayed inflation and exchange rate responses lead to desired movements in output, consumption, and trade balances.

The remainder of the paper is organized as follows. Section 2 recalls some standard views on the international transmission of monetary policy. Section 3 describes our open economy macroeconomic model. Section 4 discusses the model's implications using a hypothetical two-country framework. In this section, we analyze the endogenous evolution of price distributions in response to a expansionary monetary policy shock, describe the way these distributions influence international economic activity, and contrast the implications of our model with its corresponding time-dependent counterpart which is used as a reference case because of its popularity in the current literature. To clear ideas, Section 5 provides an agnostic empirical exercise aimed at understanding the model's hits and misses. Finally,

section 6 concludes.

2   International Priors: The Standard Views

The following standard views form our priors on the international transmission of monetary policy shocks and guide us in building our open economy macroeconomic model.

1. **Exchange rate changes redirect global expenditure through the price of imports.** Dornbusch (1987), Krugman (1991), Obstfeld and Rogoff (2000), and Obstfeld (2002) emphasize and document the role of nominal exchange rate changes: a country with a depreciating currency experiences a fall in the relative price of its exports redirecting world expenditure in favor of its product.

2. **Monetary policy expansions stimulate world aggregate demand.** Empirical studies concerning the transmission of monetary policy shocks in open economies generally reinforce the standard view that a US monetary expansion has a positive spillover effect on other developed economies by stimulating world aggregate demand (Sims (1992), Kim (2001), and Faust and Rogers (2003) among others).

3. **The trade balance displays a J-curve dynamic following a domestic monetary expansion.** Kim (2001) find that US monetary policy expansions generate a dynamic pattern in the domestic trade balance similar to the famous J-curve effect: a domestic monetary expansion leads to a short-term worsening followed by a long-run improvement of the trade balance similar to the notion of income-absorption and expenditure-switching effects of Keynesian models.

4. **The exchange rate overshoots its long-run value following a monetary policy shock.** Empirical research has struggled to support the impact change of nominal exchange rate following monetary disturbances predicted by Dornbusch's (1976) famous exchange rate overshooting hypothesis. For example, Eichenbaum and Evans (1995) find delayed overshooting in exchange rates up to three years. Although reaching the

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same qualitative conclusion about delayed overshooting of exchange rates, Kim and Roubini (2000), Faust and Rogers (2003), and Scholl and Uhlig (2005) note much quicker responses.

5. **The quantity puzzle: international output correlations are higher than international consumption correlations.** A well documented characteristic of international business cycles is the high cross-country output correlation relative to consumption correlation. This feature of the data has been documented by Backus et al. (1995) and Baxter (1995) as stylized facts that the international business cycle program should aim to capture. Obstfeld and Rogoff (2000) revisit the issue and concluded that the relation between cross-country correlation of output and consumption remains a puzzle to existing open economy macroeconomics models. Ambler et al. (2004) note that replicating the cross-country correlations of consumption remains a significant challenge for dynamic stochastic general equilibrium models, especially when those models assume a high degree of international risk sharing.

3 Structure of the Model

The NOEM builds small scale dynamic general equilibrium models for open economy macroeconomics and is the departure point for our work.[1] The world economy consists of two countries each having (i) a representative infinitely lived household, (ii) a continuum of firms indexed on the unit interval, and (iii) a monetary authority. In what follows, each variable is represented by a country-specific subscript (i.e.: 1 and 2 for Country 1 and Country 2 respectively). When three subscripts are attached to a single variable, the first and second denote the country of production and the country of consumption respectively, and the third subscript denotes time.

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[1]Examples include Betts and Devereux (2000), Chari et al. (2002), Kollmann (2001), Bergin and Feenstra (2001), and Obstfeld and Rogoff (1995, 2000).

3.1 The Households

Households are identical across countries except for the local bias introduced in consumption. They demand consumption goods produced in both countries and supply factors of production on a competitive basis. Households in both countries maximize the following time separable objective function defined over consumption goods (c) and leisure $(1 - n)$:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(u\left(c_t\right) - v\left(n_t\right) \right) \tag{1}$$

where β is the subjective discount factor and $u\left(c_t, n_t\right)$ is the momentary utility function with characteristics $u_c > 0$, $u_{cc} < 0$, $v_n > 0$, and $v_{nn} > 0$. These characteristics imply that $u(c)$ is increasing and concave, and that $v(n)$ is increasing and convex. Concavity of $u(c)$ indicates diminishing marginal utility of consumption, while convexity of $v(n)$ suggests increasing marginal disutility from labor supply. More specifically, our momentary utility function, separable in consumption and leisure, has the following form, where σ governs the intertemporal elasticity of substitution and η governs the elasticity of labor supply:

$$u\left(c_t\right) - v\left(n_t\right) = \frac{1}{1 - \sigma} c_t^{1-\sigma} - \frac{\chi}{1 + \eta} n_t^{1+\eta} \tag{2}$$

We assume that households prefer to consume locally produced goods. This feature generates movements in relative prices and reinforces the terms of trade as an important channel through which country-specific output movements affect welfare: following a decline in imported good prices, households do not fully substitute domestic for imported goods in their consumption basket. Instead, households consume a relatively fixed basket with a fraction $(1 - \theta)$ of domestic goods, and the remaining θ of foreign goods. This specification is consistent with the data since the ratios of imports to GDP are relatively stable in the long-run. We let the parameter θ determines the degree of openness in the steady-state, and ς the elasticity of substitution between domestic and imported goods. The consumption

indices for both countries are defined as:

$$c_{1,t} = \left((1-\theta_1)^{\frac{1}{\varsigma}} c_{1,1,t}^{\frac{1-\varsigma}{\varsigma}} + \theta_1^{\frac{1}{\varsigma}} c_{2,1,t}^{\frac{1-\varsigma}{\varsigma}} \right)^{\frac{\varsigma}{1-\varsigma}} \tag{3}$$

$$c_{2,t} = \left((1-\theta_2)^{\frac{1}{\varsigma}} c_{2,2,t}^{\frac{1-\varsigma}{\varsigma}} + \theta_2^{\frac{1}{\varsigma}} c_{1,2,t}^{\frac{1-\varsigma}{\varsigma}} \right)^{\frac{\varsigma}{1-\varsigma}}$$

In this context, the following equations define the optimal allocations between domestic and imported consumption

$$c_{1,1,t} = (1-\theta_1) \left(\frac{P_{1,t}^P}{P_{1,t}^C} \right)^{-\varsigma} c_{1,t} \qquad c_{2,1,t} = \theta_1 \left(\frac{S_t P_{2,t}^P}{P_{1,t}^C} \right)^{-\varsigma} c_{1,t} \tag{4}$$

$$c_{2,2,t} = (1-\theta_2) \left(\frac{P_{2,t}^P}{P_{2,t}^C} \right)^{-\varsigma} c_{2,t} \qquad c_{1,2,t} = \theta_2 \left(\frac{P_{1,t}^P}{S_t P_{2,t}^C} \right)^{-\varsigma} c_{2,t}$$

which depend on overall consumption, domestic and imported producer price indices (hereafter PPIs) denoted by P^P, overall consumer price indices (hereafter CPIs) denoted by P^C, and on the nominal exchange rate S defined as the price of one unit of foreign currency in terms of the domestic currency.

Our benchmark economy evolves under complete domestic and international financial markets. This implies that households can freely reallocate risk through a complete set of state-contingent nominal bonds b and corresponding stochastic discount factor D, such that $E_t[D_{t+1}b_{t+1}] = \sum_{s_{t+1}} \rho(s_{t+1}|s_t) D(s_{t+1}|s_t) b(s_{t+1})$ where $\rho(s_{t+1}|s_t)$ denotes the probability of the state of nature s_{t+1} given s_t. The households also receive nominal wages W from labor services, and a series of dividend payments Z from firms. The sequence of intertemporal budget constraints can be represented in terms of aggregates as:

$$P_{1,t}^C c_{1,t} + E_t[D_{t+1}b_{1,t+1}] \leq b_{1,t} + W_{1,t}n_{1,t} + Z_{1,t} \tag{5}$$

$$P_{2,t}^C c_{2,t} + E_t[D_{t+1}b_{2,t+1}] \leq b_{2,t} + W_{2,t}n_{2,t} + Z_{2,t}$$

We assume that prices are set in the currency of the producer and that there is no impediment to trade so that the law of one price holds. In this environment, households choose an amounts consumption, labor, and portfolio holdings to maximize their lifetime

utility (1) subject to a sequence of intertemporal budget constraints (5) and allocation of time. The maximization problem implies the following risk sharing condition with the real exchange rate defined as $q_t = S_t \cdot \left(P_{2,t}^C / P_{1,t}^C \right)$ and a constant reflecting initial wealth differences κ:

$$q_t = \kappa \cdot \frac{\lambda_{2,t}}{\lambda_{1,t}} \tag{6}$$

That is, the existence of complete financial markets implies that the ratios of marginal utilities of consumption λ are equalized across countries such that the levels of consumption defined in (3) differ only to the extent that the real exchange rate deviates from its steady-state value.[2] Finally, the level of nominal aggregate demand is governed by a money demand relationship of the form $M_t / P_t^C = c_t$ along with country-specific monetary policies.

3.2 Strategic Complementarity and Demand Functions

We introduce strategic complementarity through the demand functions as suggested by Kimball (1995). That is, strategic complementarity among individual firms arises by allowing for variable demand elasticity. In this context, it is easier for a firm to lose customers by raising its price than it is to gain customers by lowering its price relative to the average price charged by other firms. This approach is consistent with microeconomic evidence suggesting that competitors' actions play a central role in the behavior of price adjustments:[3] when setting their prices, firms are influenced by other firms with which they must compete.[4] This concept has also been introduced by Stiglitz (1979) and Ball and Romer (1990), and more recently within the NOEM literature by Bergin and Feenstra (2001) and Bouakez (2005). However, as opposed to the NOEM literature where the timing of price adjustment is fixed, the interaction of strategic complementarity and state-dependent pricing implies that firms can coordinate their actions by paying a fixed menu cost. Hence, in contrast to time-dependent

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[2]Deviations in the real exchange rate are allowed by the local consumption bias introduced in preferences.

[3]Examples include Amirault, Kwan, and Wilkinson (2004) for Canada, Bills and Klenow (2004), Klenow and Krystov (2005), and Blinder (1994) for the United States, as well as papers presented at the "Inflation Persistence in the Euro Area" at the European Central Bank in 2004 for Europe.

[4]The literature typically assume that firms face a constant elasticity of demand. This assumption implies that the optimal price-setting rule is a constant markup over marginal cost. Therefore, cost considerations become central to a firm's price setting decision leaving little room for interactions between competitors. The constant elasticity counterpart is exploited in Landry (2003, 2004).

models, high inflation episodes correspond to more frequent price adjustment by firms.

3.2.1 Demand Aggregators and Firm's Relative Demand

We follow the approach outlined by Kimball (1995) and consider the following general expenditure minimization problem for each country:

$$\min_{d(z)} \int_0^1 P(z)d(z)\,dz \qquad \text{subject to} \qquad \int_0^1 \Gamma\left(d(z)/d\right)dz = 1 \tag{7}$$

where d represents a country-specific aggregate demand for goods which is implicitly defined by a demand aggregator Γ such that an aggregate producer price index P^P holds for each country. In this environment, each firm produces a differentiated product such that $P(z)$ identifies the price of the good charged by an individual firm z with corresponding relative demand $d(z)/d$. Moreover, our specific aggregator Γ is an increasing and concave function reflecting diminishing demand elasticity, and is defined over the parameters φ and γ which govern the curvature of the demand function:[5]

$$\Gamma\left(d(z)/d\right) = \frac{1}{(1+\varphi)\gamma}\left[(1+\varphi)\left(d(z)/d\right)-\varphi\right]^\gamma - \left[1+\frac{1}{(1+\varphi)\gamma}\right] \tag{8}$$

This demand aggregator implicitly defines firm's relative demand as the ratio of firm z in a country-specific aggregate demand d, and is a function of individual and aggregate prices:

$$\frac{d_t(z)}{d_t} = f\left(\frac{P(z)}{P^P},\varphi,\gamma\right) \tag{9}$$

Derivation of the above equations are provided in Appendix B.

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[5]A nice property of this specification is that the Dixit and Stiglitz aggregator is a special case represented by $\varphi = 0$.

3.2.2 Price Indices

The PPIs are given as a weighted sum of prices over individual firm ratios

$$
\begin{aligned}
P_t^P &= \int_0^1 P_t(z) \left(d_{1,t}(z)/d_{1,t}\right) dz \\
P_t^P &= \int_0^1 P_t(z) \left(d_{2,t}(z)/d_{2,t}\right) dz
\end{aligned}
\tag{10}
$$

and the CPIs follow a weighted sum of domestic and imported good prices

$$
\begin{aligned}
P_{1,t}^C &= \left((1-\theta_1)(P_{1,t}^P)^{1-\varsigma} + \theta_1 \left(S_t P_{2,t}^P\right)^{1-\varsigma}\right)^{\frac{1}{1-\varsigma}} \\
P_{2,t}^C &= \left((1-\theta_2)(P_{2,t}^P)^{1-\varsigma} + \theta_2 \left(P_{1,t}^P/S_t\right)^{1-\varsigma}\right)^{\frac{1}{1-\varsigma}}
\end{aligned}
\tag{11}
$$

As in the Mundell-Fleming-Dornbusch model, the expenditure-switching effect arises as movements in the nominal exchange rate alter the price of imports faced by consumers, and in turn the composition of CPIs.

3.3   The Firms

There exists a continuum of monopolistically competitive firms located on the unit interval and indexed by z in each country. At any date t, a firm is identified by its current price $P(z)$, and its current menu cost of price adjustment $\xi_t(z) \in \left[0, \overline{B}\right]$. The menu cost is denominated in labor hours and drawn from a time-invariant distribution $G(\xi)$ that is common across all country-specific firms. Since the indices z are uncorrelated over time, and there are no other state variables attached to individual firms, all country-specific price-adjusting firms choose the same optimal price $\widehat{P}$. We restrict ourselves to environments with positive steady-state inflation rates so that the benefit of price adjustment becomes infinitely large as the number of periods for which the price has been fixed grows. Given that the support of the distribution $G(\xi)$ is finite, there exist finite fractions of firms sharing a common price in each country denoted by J_1 and J_2 and defined as vintages.

3.3.1 Production and Demand

In this environment, labor used for price adjustment is denoted $n^a(z)$ and labor used for production is denoted $n^y(z)$. The total amount of labor is thus $n^a(z) + n^y(z) = n(z)$. Technology is linear in labor, and firms are subject to a common country-specific stochastic total factor productivity a such that production by an individual firm is represented by $y_t(z) = a_t n_t^y(z)$.

Using (4), aggregate demand d is determined by domestic and exported consumption

$$
\begin{aligned}
d_{1,t} &= (1-\theta_1)\left(\frac{P_{1,t}^P}{P_{1,t}^C}\right)^{-\varsigma} c_{1,t} + \theta_2 \left(\frac{P_{1,t}^P}{S_t P_{2,t}^C}\right)^{-\varsigma} c_{2,t} \\
d_{2,t} &= (1-\theta_2)\left(\frac{P_{2,t}^P}{P_{2,t}^C}\right)^{-\varsigma} c_{2,t} + \theta_1 \left(\frac{S_t P_{2,t}^P}{P_{1,t}^C}\right)^{-\varsigma} c_{1,t}
\end{aligned}
\tag{12}
$$

such that production by an individual firm corresponds to a fraction of its country aggregate demand

$$
\begin{aligned}
y_{1,t}(z) &= f\left(\frac{P_{1,t}(z)}{P_{1,t}^P}, \varphi, \gamma\right) \cdot d_{1,t} \\
y_{2,t}(z) &= f\left(\frac{P_{2,t}(z)}{P_{2,t}^P}, \varphi, \gamma\right) \cdot d_{2,t}
\end{aligned}
\tag{13}
$$

Equation (13) illustrates that production by an individual firm depends on its price relative to other domestic firms (PPI), and on its country-specific aggregate demand (12) which is determined by the degree of openness, the elasticity of substitution between domestic and imported goods, the currency adjusted PPI to CPI ratios, and aggregate domestic and foreign consumption.

3.3.2 Pricing Policy

In both state- and time-dependent pricing frameworks, the firm's optimal decision can be represented using a dynamic programming approach: given the level of technology, demand (13), the current menu cost of price adjustment $\xi(z)$, the current real price $p^C(z)$, and the

prevailing real wage rate w, individual firms decide whether or not to adjust their prices with respect to a state vector s. Accordingly, each individual firm has a real value function of the form:

$$v\left(p_{jt}^C, \xi_t | s_t\right) = \max \left\{ \begin{array}{l} v_{jt} = \pi\left(p_{jt}^C | s_t\right) + \beta E_t \Lambda_{t,t+1} v\left(p_{j+1,t+1}^C, \xi_{t+1} | s_{t+1}\right), \\ v_{0t} = \max_{\widehat{p}_t^C} \pi\left(\widehat{p}_t^C | s_t\right) + \beta E_t \Lambda_{t,t+1} v\left(\widehat{p}_{t+1}^C, \xi_{t+1} | s_{t+1}\right) - w_t \xi_t \end{array} \right\} \quad (14)$$

with the value if the individual firm does (v_{0t}) or does not (v_{jt}) adjust, and real profits π defined as

$$\pi\left(p_{jt}^C | s_t\right) = \left(p_{jt}^C - \psi_t\right) \cdot y_{jt} \quad (15)$$

where $\widehat{p}^C$ is the optimal price chosen by the country-specific adjusting firms. Both, the optimal $\widehat{p}^C$ and current real price $p^C(z)$ are relative to domestic CPI such that $\widehat{p}^C = \widehat{P}(z)/P^C$ and $p^C(z) = P(z)/P^C$ which are the appropriate prices in the firm's decision making.

In these functions, $\Lambda_{t,t+1} = \lambda_{t+1}/\lambda_t$ denotes the ratio of future to current marginal utility and is the appropriate discount factor for future real profits, and ψ_t represents real marginal cost which is equal to $\psi_t = w_t/a_t$. Equation (14) shows that the firm must weight the current and future benefits of adjusting its price versus the status-quo. Firms that decide to adjust set prices optimally and choose cost-minimizing levels of input. Firms that decide not to adjust prices take their output as given and simply choose input to minimize cost. In this environment, the country-specific endogenous adjustment fractions $\alpha_{j,t}$ are determined by the menu cost of the marginal firms being just equal to the value gained such that

$$\xi\left(\alpha_{j,t}\right) \cdot w\left(s_t\right) = v_{0,t}(s_t) - v_{j,t}(s_t). \quad (16)$$

Finally, the dynamic program (14) implies that the optimal price satisfies an Euler equation that involves balancing pricing effects on current and expected future profits. That is, as part of an optimal plan, price-adjusting firms choose prices that satisfy

$$0 = \frac{\partial \pi\left(\widehat{p}_t^C | s_t\right)}{\partial \widehat{p}_t^C} + \beta E_t \left[\Lambda_{t,t+1} \cdot \frac{\partial v\left(\widehat{p}_t^C, \xi_{t+1} | s_{t+1}\right)}{\partial \widehat{p}_t^C}\right]. \quad (17)$$

Iterating the Euler equation (17) forward, the country-specific firm nominal optimal prices $\widehat{P}$ can be expressed as an explicit function of current and expected future variables:

$$
\begin{aligned}
\widehat{P}_{1,t} &= \frac{\sum_{j=0}^{J_1-1} \beta^j E_t \left[\Omega_{1,j,t,t+j} \cdot \Lambda_{1,t,t+j} \cdot \epsilon_{1,j,t+j} \cdot \psi_{1,t+j} \cdot P_{1,t+j}^P \cdot d_{1,j,t+j}\right]}{\sum_{j=0}^{J_1-1} \beta^j E_t \left[\Omega_{1,j,t,t+j} \cdot \Lambda_{1,t,t+j} \cdot (\epsilon_{1,j,t+j} - 1) \cdot \left(P_{1,t+j}^P / P_{1,t+j}^C\right) \cdot d_{1,j,t+j}\right]} \\
\widehat{P}_{2,t} &= \frac{\sum_{j=0}^{J_2-1} \beta^j E_t \left[\Omega_{2,j,t,t+j} \cdot \Lambda_{2,t,t+j} \cdot \epsilon_{2,j,t+j} \cdot \psi_{2,t+j} \cdot P_{2,t+j}^P \cdot d_{2,j,t+j}\right]}{\sum_{j=0}^{J_2-1} \beta^j E_t \left[\Omega_{2,j,t,t+j} \cdot \Lambda_{2,t,t+j} \cdot (\epsilon_{2,j,t+j} - 1) \cdot \left(P_{2,t+j}^P / P_{2,t+j}^C\right) \cdot d_{2,j,t+j}\right]}
\end{aligned}
$$

$$(18)$$

where $\Omega_{j,t,t+j}$ represents the probability of non-adjustment from t to $t+j$,[6] and $\epsilon_{j,t+j}$ denotes the elasticity of demand facing the individual firm. Accordingly, the optimal price is a fixed markup over real marginal cost if the demand elasticities, the price levels, and real marginal cost are expected to be constant over time.

The optimal pricing rules (18) are generalizations of the types derived in NOEM models with exogenous probabilities (for examples see Obstfeld and Rogoff (1995) and Bouakez (2005)). They also represent an open economy version of the closed economy state-dependent pricing rules of Dotsey, King, and Wolman (1999), and Dotsey and King (2005). However, in contrast to their closed economy counterparts, foreign economic conditions and the nominal exchange rate enter the decision of the value maximizing firms and henceforth influence the endogenous adjustment probabilities. The pricing rules illustrate that optimal prices vary with adjustment probabilities, discount factors, demand elasticities, real marginal costs, domestic PPIs and CPIs, and current and expected future demand (which includes global consumption, domestic and foreign CPIs, domestic PPIs, and the nominal exchange rate). In this environment, firms are forward-looking when choosing an optimal price because price changes are costly. Therefore, (i) if firms expect future global demand or domestic CPI to be high, they will set a higher price so that near future inflation leaves the optimal price closer to maximizing static profit, (ii) if firms expect future real marginal costs to be high, they will similarly set a higher price so that they do not sell at a loss immediately after the price adjustment, (iii) elasticities of demand are introduced in a time-varying manner

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[6] That is $\Omega_{t,t+j} = (1 - \alpha_{j,t+j}) \cdot (1 - \alpha_{j-1,t+j-1}) \cdot \ldots \cdot (1 - \alpha_{1,t+1})$.

and depend on the state of the economy such that the price-setting firm must foresee itself at different positions on the demand curve, and finally (iv) adjustment probabilities also enter in the optimal pricing rules in a time-varying manner and depend on the state of the economy. In particular, these adjustment probabilities modify the discount factors such that if the price-setting firms expect future adjustment probabilities to be high, they will weight more heavily their beliefs of current economic conditions.

3.4 Monetary Policies

The monetary policy rules are specified as exogenous money supply rules.[7] More specifically, the nominal money supply growth follows an autoregressive process in both countries

$$
\begin{aligned}
\Delta M_{1,t} &= \rho_1 \Delta M_{1,t-1} + \vartheta_1 \Delta M_{2,t} + \nu_{1,t} \\
\Delta M_{2,t} &= \rho_2 \Delta M_{2,t-1} + \vartheta_2 \Delta M_{1,t} + \nu_{2,t}
\end{aligned}
\tag{19}
$$

where ρ describes the coefficients of autocorrelation, ϑ admits for the possibility of monetary policy comovements, and ν_t are independently and identically distributed zero-mean disturbances.

3.5 General Equilibrium

In this environment, the aggregate state of the economy at time t is a vector $s_t = (M_{1,t}, M_{2,t}, \Theta_{1,t}, \Theta_{2,t})$, where M represents the exogenous state variables, and Θ represents the evolution of producer prices within each country (country's specific vector of prices and corresponding density distribution of firms across prices). Given the aggregate state, a general equilibrium for the economy is a collection of sequences satisfying a set of equilibrium conditions: a collection of allocations for consumers $c_{1,t}, n_{1,t}, b_{1,t+1}$ and $c_{2,t}, n_{2,t}, b_{2,t+1}$, a collection of allocations and price for firms $y_{1,t}(z), n_{1,t}(z), P(z)$ and $y_{2,t}(z), n_{2,t}(z), P(z)$, and a collection of prices $P_{1,t}^P, P_{1,t}^C, W_{1,t}, D_{1,t+1}$ and $P_{2,t}^P, P_{2,t}^C, W_{2,t}, D_{2,t+1}$ such that (i) consumers maximize their

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[7]This choice is arbitrary but consistent with recent reseach in open economy macroeconomics. The model can easily accomodate other monetary policy rules.

utilities, (ii) firms maximize their values, and (iii) aggregate consistency conditions hold. These aggregate consistency conditions include market clearing conditions in the goods and labor markets, and consistency for the time-varying distributions of firms in each country.

4 Hypothetical Economy

4.1 Solution and Benchmark Parameterization

4.1.1 Solution

We use numerical methods to solve the model and study its behavior. First, we compute separately the steady state equilibrium of each country by imposing trade account balance to the long-run behavior of the model.[8] The steady-state equilibrium for this economy involves the lowest values of vintages that generates unconditional adjustment by all firms in each country. Second, we take a linear approximation of the behavioral equations around the steady state equilibrium and compute the resulting linear rational expectations equilibrium using an algorithm developed by King and Watson (1998).

4.1.2 Benchmark Parameterization

To better understand the model and its implications, we first build our intuition using a hypothetical symmetric two-country economy. The hypothetical parametrization of our two-country system is presented in Table 1. We use parameter values generally accepted in the macroeconomic and open economy literatures. A time period of the model corresponds to a quarter of a year. The subjective discount factors β imply annual real rate of returns of 4.1 percent. We choose preference parameter values that produce a low elasticity of marginal cost with respect to real output by setting the parameters governing the degrees of risk aversion σ to 0.25 and the parameters governing the elasticities of labor supply η to 0.05.

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[8]In the case of PCP, the steady-state nominal exchange rate isolates each country from their trading partners' levels of inflation. Therefore, the aggregate consistency condition in the goods market is equivalent to its closed economy counterpart. This result does not hold in the case of a Pricing-to-Market structure where the levels of inflation rate differ. The implications of such pricing structure is explored in Landry (2004).

Those parameters generate elasticities of marginal cost of approximately 0.3.[9] Agents work 20 percent of their time endowment. Country 1 and 2 are of equal sizes and have degrees of openness of 20 percent (those correspond to the shares of imports in consumption). We set the elasticities of substitution between domestic and imported consumption goods ς to unity. Bergin (2004) offers empirical evidence from macro-level data which supports this common practice in the literature. The two countries share similar levels of productivity a equal to 1. Finally, we set steady-state money growth rates μ to 0.01 which correspond to growth rates of 4 percent on an annual basis, and the autocorrelations of the money growth processes ρ to 0.5.

4.1.3 Demand Structure and Price Distributions

The variable elasticity demand curves are parametrized by choosing values of φ so that demand curves have elasticities of 10 at $d(z)/d = 1$. Restricting γ to take values of 1.02 implies that a 1 percent increase in price decreases demand by 13 percent, which is somewhere between the response assumed Kimball (1995), and Bergin and Feenstra (2001).

The remaining parameters involve the distributions of adjustment costs which, alongside the demand functions, determine the timing and distributions of prices. Table 2 displays the steady-state fractions of price-adjusting firms as well as the population densities associated with the parametrized model for both countries.[10] The chosen adjustment costs structure leads to a steady-state hazard function that is roughly quadratic in the log relative price deviation as suggested by Caballero and Engle (1993). It implies an average age of prices of less then 2.72 quarters, and an expected price duration of 4 quarters under the steady-state inflation rate of 4 percent. Together, the demand and adjustment costs specifications provide a good approximation of the main features governing the pattern of price adjustments and pricing policies observed in empirical studies on pricing behavior in developed economies.

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[9]Given that the households efficiency condition is $w_t = c_t^\sigma n^\eta$, and that consumption and labor are approximately equal to output, the elasticities of marginal cost are approximately equal to $\sigma + \eta$.

[10]Choice of the adjustment costs parameters are detailed in Appendix C.

4.2 Understanding the Model and its Implications

In this subsection, we analyze the model's responses to a monetary policy shock and contrast these responses with those from a time-dependent variant more closely related to standard NOEM work. We subject Country 1 to a monetary policy shock in which the money stock increases by 1 percent on impact with a long-run response approaching 2 percent above its initial level. Figures 2-5 display the impulse response of microeconomic and macroeconomic aggregates over horizons of 16 quarters. The solid lines represent our state-dependent version of the model, while the dashed lines represent its time-dependent counterpart. The time-dependent counterpart is calibrated so that the fractions of price-adjusting firms are held fixed at steady-state values. To get a better understanding of the mechanism through which money affects international economic activity, we start by exploring the reaction of individual firms to the monetary policy shock and then turn to the aggregate implications.

4.2.1 Firms' Reactions to a Monetary Shock

Firms' Adjusting Fractions Figure 2 displays firms' reactions following the monetary shock. Relative to similar experiments in the NOEM literature, a novel feature of the state-dependent pricing open economy model is the evolving distribution of price-adjusting firms across countries. Looking at the top row of the figure, we observe that the fraction of price-adjusting firms is increasing in Country 1: raising product demand generated by the monetary policy shock increases the value of price-adjusting firms, and consequently induces a larger fraction of firms to reset their prices. In contrast, the fraction of price-adjusting firms is decreasing in Country 2: the monetary shock generates an appreciation of the foreign currency and lowers product demand. In turn, the value of price-adjusting firms decreases and a smaller fraction of firms opt to adjust prices.

Notice that movements in adjusting fractions arise slowly: the introduction of variable elasticity demand curves within a state-dependent pricing framework coordinates the actions of individual firms and consequently does not allow for immediate deviations in the fractions of price-adjusting firms.[11] Initially, the monetary shock translates very little to

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[11]This is in sharp contrast with a Dixit and Stiglitz demand specification exploited in Landry (2003, 2004).

individual and aggregate prices because firms are not willing to act differently from one another. However, rising aggregate prices enforce the extent of adjustment of individual firms and consequently result into increasing deviations in fractions of price-adjusting firms across countries. Altogether, these smooth movements in the distributions of price-adjusting firms heavily influence the dynamics of aggregate prices and are responsible for the novel responses of aggregate economic activity: in sharp contrast to the NOEM literature, initially, movements in aggregate prices are almost absent and therefore much closer to the MFD pricing framework.

Firms' Optimal Prices   Associated with movements in adjusting fractions are the optimal prices depicted in the bottom row of Figure 2. In contrast to its time-dependent counterpart, optimal prices in a state-dependent environment react very slowly to the monetary shock with initial price responses being almost absent. On the one hand, the forward looking price-setting firm would prefer to raise its price in light of the monetary policy shock. On the other hand, the firm knows that it has the possibility to reset its prices at any time in the future, and would rather do so than lose market share by pricing high relative to its competitors. This is in sharp contrast with time-dependent models in which individual firms do not have any control over the timing of price adjustments, and must therefore incorporate their inability to reset prices in their pricing policy.

Although the initial responses of optimal prices are relatively small, responses at longer horizons become important. Those large swings are explained by the gravity among firms' optimal pricing that occurs following a monetary policy shock. For instance, we observe the following: (i) an overshooting of the optimal price in Country 1 peaking almost 11 quarters after the shock. The larger fraction of price-adjusting firms increases the level of aggregate prices above their long-run values and consequently induces price-adjusting firms to price high, and (ii) an oscillation dynamic of the optimal price in Country 2. At first, the optimal price decreases as the country faces a lower demand for its products but as domestic demand increases the optimal price surges to positive territory. These overshooting and oscillating dynamics are absent in the time-dependent counterpart but will be revealed to

be important in explaining international economic fluctuations in the context of our state-dependent model.

4.2.2 Aggregate Implications of a Monetary Shock

Output, Consumption, and Inflation Dynamics We now turn to the aggregate implications of our model. Figure 3 displays the responses of output, consumption, and CPI inflation rates. First, the domestic monetary shock generates a hump-shaped response in output and consumption across countries. In Country 1, peak responses of output and consumption arise contemporaneously 2 quarters after the monetary policy shock. In Country 2, output responds first, peaking 3 quarters after the monetary policy shock, while the peak response of consumption is delayed to the 5th quarter. The dynamics of output and consumption in Country 2 arise as follows: output responds to an increase in export demand followed by an increase in domestic demand, while consumption rises later as CPI attains a through.

In relation to Figure 3, the model generates a high cross-country output correlation relative to consumption correlation: the cross-correlation of output is 0.55 while the cross-correlation of consumption is 0.32. This is in sharp contrast with correlation numbers obtained in the time-dependent counterpart: the cross-correlation of output is 0.96 while the cross-correlation of consumption is 0.92. This result is impressive given that (i) the model embodies international risk-sharing, and (ii) the model does not rely on international market segmentation to induce discrepancies in consumption aggregates.[12] The simple introduction of strategic complementarity and state-dependent pricing generates the desired outcome. We explore in further detail the components of foreign output and consumption below.

Output and consumption aggregates in both economies also display oscillating cycles

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[12]Recently, an increasing amount of research have relied on international market segmentation, or so-called Pricing-to-Market models, to generate consistent international movements in output and consumption. Among others, Betts and Devereux (2000) assume market segmentation for a fraction of firms and show how this specification can be used to attain the observed consumption correlation moments. Instead, Chari et al. (2002) impose market segmentation for all firms and rely on monetary policy endogeneity to obtain the desired correlation. In their model, international market segmentation is necessary to cleave the relation between output and consumption, while cross-correlated monetary shocks are needed to provide a consumption expansion abroad.

associated with movements in aggregate prices. The stimulation of economic activity lasts roughly 7 and 12 quarters for the domestic and foreign economies respectively, followed by a period of real contractions. Although real contractions in economic activity last for a substantial amount of time, they do not undo the initial stimulations generated by the monetary expansion in either countries. Altogether, the output and consumption aggregates return to their pre-shock level in both countries after roughly four years.

Fluctuations in output and consumption are induced by corresponding movements in price indices. An important strength of the model is its ability to generate delayed responses in CPI inflations. The bottom row of Figure 3 displays CPI inflation dynamics. In Country 1, CPI inflation peaks 5 quarters after the monetary shock. In Country 2, CPI inflation responds negatively on impact as the domestic exchange rate depreciation feeds through the foreign CPI. However, as Country 2's demand increases, CPI inflation surges into positive territory to peaks 12 quarters after the monetary policy shock. These delayed responses of CPI inflation rates observed in our model are generated by corresponding movements in CPIs, and consequently can mostly be understood alongside country-specific optimal prices charged by adjusting firms, which increase at a faster rate during high inflation periods.

Delayed Overshooting of the Nominal Exchange Rate and Trade Movements in the nominal exchange rate can be understood by looking at the dynamic behavior of its components which are displayed in the top row of Figure 4. The monetary shock induces a significant and persistent depreciation in the nominal exchange rate, and displays the delayed overshooting effect stressed by Eichenbaum and Evans (1995) empirical study on the effects of US monetary policy shocks on exchange rates. The bottom row of Figure 4 displays the relative contribution of nominal exchange components: initially, the nominal exchange rate responds to the raising real exchange rate but become primarily driven by Country 1's consumer prices a few quarters after the shock. This figure aknowledges that the model failed to generate real and nominal exchange rate movements that are as highly correlated as in the data. However, this problem is common to our approach and to the NOEM literature: the high correlation between real and nominal exchange rate often found in the

NOEM literature results from simultaneous front loading aspects of prices and consumption common to time-dependent models.

Figure 5 shows the nominal exchange rate, displays the trade balance for Country 1, and decomposes Country 2's output and consumption aggregates into their domestic and foreign components. This figure emphasizes the expenditure-switching effect as an important channel of international adjustment: trade is the only channel of monetary policy transmission across economies in our experiment. From the perspective of Country 1, movements related to trade can be explained by looking at the trade balance. Following the monetary policy shock, the trade balance displays a J-curve dynamic: it worsens within a year, then starts to improve and becomes positive after 7 quarters. The trade improvement is quite persistent, peaking 10 quarters after the shock before returning to its long-run value. On impact, the increase in income raises the demand for imports, and explains the short-run worsening of the trade balance, which represents an income-absorption effect. However, the slow depreciation of the nominal exchange rate generates a deterioration of the terms of trade with some delays, and leads to a medium- to long-run improvement in the trade balance, which represents an expenditure-switching effect[13]. In particular, the expenditure-switching effect corresponds to the overshooting response of the nominal exchange rate: goods produced in Country 1 become relatively competitive on the global market.

From the perspective of Country 2, real economic activity and trade dynamics are best understood by undertaking decompositions of output and consumption into their domestic and foreign components. The expansion of output falls in two phases: initially, rising exports demand launches output (which is associated with the income-absorption effect present in Country 1), later the accumulation of wealth generated by the production boom translates into rising domestic consumption which further fuels output. On the consumption side: initially, the appreciation of Country 2's currency generates an expenditure-switching effect in favor of foreign goods. This increases the level of competition among firms in Country 2, and leads to declining producer prices which further propels the consumption boom.[14]

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[13]Kim (2001) found similar trade dynamics in documenting the international transmission of U.S. monetary shocks.

[14]To compete in the domestic and foreign markets, some producers in Country 2 decrease their optimal

5 International Dynamics

5.1 Econometric Methodology

To clear ideas on the international priors used to developed our open economy macroeconomics model, we estimate a Vector Autoregression (VAR) that generates impulse responses consistent with the standard views. This agnostic exercise permits us to illustrate the model's plausibility and to capture its crucial elements. In other words, the VAR methodology offers an alternative in understanding international economic activity: given a minimal set of identifying assumptions, structural VARs allow us to investigate the likely international relationships resulting from a US monetary policy shock and their empirical estimates provide a natural way to assess the empirical plausibility of our dynamic general equilibrium model.

We follow the general recursive framework of Eichenbaum and Evans (1995) and Christiano et al. (2005) and consider the dynamic response of key macroeconomic variables for the US economy and for an aggregate of the non-US G5 economies (G4 Economy) to a US monetary policy shock.

$$FFR_t = f\left(\Upsilon_t\right) + \varepsilon_t \tag{20}$$

Characterization of US monetary policy is given by equation (20) where FFR_t represents the monetary instrument, f is a linear function of the information included in Υ_t, and ε_t represents the monetary policy shock. The identifying assumption relies on ε_t being orthogonal to the elements of Υ_t. Let Y_t denote the vector of variables included in Υ_t.

$$Y_t = [Y_{1t}, FFR_t, Y_{2t}]' \tag{21}$$

The recursive causal ordering assumes that the vector Y_{1t} contains variables whose values at time t do not respond contemporaneously to a monetary policy shock while its counterpart Y_{2t} consists of all other variables included in Υ_t. The variables in Y_{1t} are per capita US real gross domestic product, per capita US real personal expenditure, per capita G4 real gross domestic product, per capita G4 real personal expenditure, US personal expenditure deflator,

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prices while others delay their price adjustment. In turn this decreases Country 2's PPI.

G4 personal expenditure deflator, and per capita US real trade balance. The variables in Y_{2t} are the growth rate of per capita US real M1 and the nominal exchange rate. The decision to include aggregates of output, consumption, inflation, and trade balance in Y_{1t} reflects a long standing view that those macroeconomic variables do not respond contemporaneously to policy shocks. Finally, we measure the monetary instrument FFR_t using the Federal Funds Rate which is the preferred policy instrument of Bernanke and Blinder (1992), Bernanke and Mihov (1998), and Christiano et al. (1999, 2005) among others.[15]

The quarterly data cover the period from 1974Q1 to 2004Q4 and when necessary are expressed in 2000 US dollars at purchasing-power-parity. The data sources and aggregation are described in Appendix A. The VAR contains two lags of each variable. To compare the given empirical estimates with our business cycle model, variables in Y_t have been logged and filtered using a one-sided Band-Pass filter with business cycle periodicity[16] except for the deflators and the monetary instrument.

When the constant term is ignored, the VAR takes the following representation:

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + Ce_t \tag{22}$$

where C is a 10×10 lower triangular matrix, and e_t is a ten-dimensional vector of zero-mean serially uncorrelated shocks. We estimate the parameters A_i, $i = 1, 2$, C, and the variance of the elements of e_t with standard least-square methods. Using these estimates, we compute the dynamic path of Y_t. To maintain consistency with the model presented, we consider an innovation in the Federal Funds Rate that corresponds to a 1 percent increase in the growth rate of the monetary aggregate.

The impulse response functions are displayed in Figure 6. The straight lines correspond to the estimated average while the dotted lines represent their 95 percent confidence intervals

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[15] Bernanke and Blinder (1992) argued that the Federal Funds Rate is a better measure of US monetary policy stance than quantity-based measures since quantity-based measures are more likely to reflect endogenous changes in money demand rather than monetary policy actions.

[16] The data have been filtered using a Band-Pass filters with periodicity between 6 and 32 quarters using 12 lags as suggested by Baxter and King (1999). Consequently, the effective sample period ranges from 1977Q1 to 2004Q4. Similar properties are found using a one-sided HP filter.

about the point estimates evaluated using Bootstrap methods. Our VAR results generally agree with the standard view and consequently pave the way to the estimation of the model.

5.2 Minimum Distance Estimation of the Structural Parameters

We calibrate a primary set of parameters and estimate the remainders. The calibrated parameters are presented in Table 3. As in the previous exercise, the discount factors β are 0.99, households work 20 percent of their time endowment and the total factor productivities are 1. The US Economy is characterized by a degree of openness of 2.5 percent and represents 1/2 of the world's GDP. The former corresponds roughly to the US share of import to GDP traded with the G4 Economy, while the latter corresponds to the ratio of the US Economy to G4 Economy GDP. Finally, we set steady-state country-specific money growth rates to the average inflation rates observed in the sample period estimated, which correspond to 4 percent for the US Economy and 3.8 percent for the G4 Economy.

Our estimation strategy involves selecting the remaining structural parameters that minimize the distance between the estimated empirical impulse responses and the model-based impulse responses. For the purpose of our monetary model, the relevance of this estimation strategy holds in estimating parameters of the model by matching conditional dynamics induced by a monetary shock. Formally, we consider a set of structural parameters $\psi = (\sigma_1, \sigma_2, \eta_1, \eta_2, \varsigma_1, \varsigma_2, \gamma_1, \gamma_2, \epsilon_1, \epsilon_2, \rho_1)$, a vector containing the empirical estimates $\widehat{\Psi}$, and a mapping from ψ to the model based impulse response functions $\Psi(\psi)$. To avoid non existence or multiplicity of equilibria, our structural parameters ψ are evaluated at a subset of solutions in the neighborhood of the parameter values explored by Dotsey and King (2005). Our estimator of ψ is the solution to

$$J = \min_{\psi} \left[\widehat{\Psi} - \Psi(\psi)\right]' W \left[\widehat{\Psi} - \Psi(\psi)\right] \tag{23}$$

where W is the identity matrix.[17]

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[17]Following Boivin and Gianoni (2003) and Christiano et al (2005), we have also estimated the parameters using W as a diagonal matrix with the inverse of each impulse response's variances along the diagonal. Although this weighting matrix accounts for the fact that some points of the impulse response functions

To keep consistency between the empirical estimates and the model, (i) we consider the empirical impulse responses that range from the 2nd to the 18th quarters: we discard the first two point estimates from the estimation procedure since our benchmark model does not incorporate frictions that could capture the slow transmission of monetary policy or other rigidities, such as contracts, that could explain the puzzling nature of the first estimated points in the empirical impulse response functions,[18] and (ii) we exploit all impulse response functions that share long-run behavior similar to the model impulse response functions. Hence, we do not consider the empirical nominal exchange rate impulse responses in estimating the model since its long-run behavior appears stationary while the long-run property of the model implies a permanent shift anchored to the money stock (i.e.: a monetary expansion requires that the price level increases and that the nominal exchange rate depreciates in equal proportion to preserve the real equilibrium).

The estimated parameters are shown in Table 4. Following Ireland (2004), we express the standard errors of our estimates as the square root of the diagonal elements of the matrix $V \equiv \left(\left[\partial g\left(\psi \right) / \partial \psi \right]' W \left[\partial g\left(\psi \right) / \partial \psi \right] \right)^{-1} / T$, where $g\left(\psi \right) = \left(\widehat{\Psi} - \Psi\left(\psi \right) \right)$ and T is the number of impulse responses used in the estimation. Given the complexity of the current structure and the difficulties existing in extracting information useful to evaluate our model, we should be reassured yet cautious of drawing any strong conclusions about parameter values. Although we believe that estimating the parameters of our model by matching the conditional dynamics resulting from a monetary policy shock makes sense, important identification and specification issues arise in the estimation of dynamic stochastic general equilibrium models. Canova and Sala (2005) offer an informative discussion on the problematics associated with our estimation strategy.

The parameters governing preferences produce a low elasticity of marginal cost with respect to real output of approximately 0.3. The elasticity of substitution between domestic and imported consumption goods are in between the unitary elasticity of substitution

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are less precisely estimated than others and hence garantees that $\Psi\left(\psi \right)$ lies as much as possible inside the confidence intervals, the relatively small confidence intervals arround the nominal variables of the impulse response functions bias the results by giving too much weight to inflation processes.

[18]To some instance, we also minimize the impact of the VAR identification in the estimation of our model.

defended by Bergin (2005) and the numbers brought by Backus et al. (1992). The demand functions' parameters are estimated such that the elasticities of demand ϵ hold at $d(z)/d = 1$. Together, with the estimated values of γ, this implies that a 1 percent increase in prices decreases demand by roughly 11 percent in the United States and 12 percent in the G4 Economy.

Finally, we estimated the coefficient governing the US autocorrelation of money growth to be a little higher than one half, in line with the related literature. Although some researchers evoke the possibility of policy endogeneity, we find no substantial endogenous reactions or comovements by OECD monetary authorities from US monetary shocks both from an inspection of the data and from estimation of a joint stochastic process.[19] In a related paper, Landry (2005) offers further insights into contemporaneous monetary policy comovements by exploring the implications of a US monetary policy shock for the Canadian economy.

Table 5 displays the steady-state fractions of price-adjusting firms as well as the population densities associated with the estimated model for both countries. The estimated parameters imply an average age of prices of less then 2.75 quarters and an expected price duration of 4.02 quarters for the United States, and an average age of prices of less then 2.78 quarters and an expected price duration of 4.13 quarters for the G4 Economy. Together, the demand and adjustment cost specifications provide a reasonable approximation of the main features governing the pattern of price adjustments and pricing policies observed in those economies.

5.3   Hits and Misses

Figure 7 displays the estimated state-dependent model impulse response functions alongside the VAR impulse response functions. In line with both the standard views and with the empirical estimates, our estimated model replicates some key macroeconomic comovements. Following a US monetary expansion:

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[19]In the context of our work, results from the VAR suggest that foreign monetary policy interventions are not contemporaneous since peak timings of foreign output and consumption are not contemporaneous with the domestic economy and that the delayed responses of foreign variables are too long to be tought as being directly affected by a contemoraneous foreign monetary policy shock.

- Domestic output and consumption expand and display hump-shaped responses.

- Foreign output expands first followed by foreign consumption.

- Monetary policy has a delayed and gradual effect on domestic and foreign inflations.

- On impact, domestic monetary policy has a deflationary effect on foreign inflation.

- The US trade balance displays a J-curve dynamic.

- The nominal exchange rate overshoots its long-run value.

Although the model based impulse responses functions are consistent with most international priors, two questions are worth asking: (i) how well does the model perform in matching the moments generated by our dataset, and (ii) how well does the model perform in replicating the impulse responses generated by our international VAR? To answer the first question, Table 6 displays the unconditional moments and the moments conditional on our monetary policy shock which are based on Bootstrap methods. The state-dependent model appears to do better than its time-dependent counterpart in terms of matching moments of interest. In particular, domestic and cross-country model moments associated with output, consumption, and CPI inflation are much closer to those observed in the data.

How well does the model perform in replicating the impulse responses generated by our international VAR? On the domestic front, the model does fairly well in replicating the implied output and consumption responses while the inflation process implied by the model is not as nearly persistent as the one implied by the empirical estimates. On the foreign front, the model is able to replicate the shapes of output, consumption and inflation, but has some difficulties matching their amplitudes. As for the inflation process, there appears to be a world component to inflation probably transmitted through commodity prices' reaction to shocks as suggested by Sims (1992). Moreover, the model's nominal exchange rate movements are different than their empirical counterparts for reasons discussed earlier. Introduction of monetary policy rules and other structural features can potentially solve these problems. Finally, the model does fairly well in replicating both the shape and amplitude of the observed deviations in the US trade balance.

6 Conclusion

The expenditure-switching role of exchange rate adjustments is alive and well among industrial countries. Using elements of state-dependent pricing and strategic complementarity, this paper builts a modern NOEM model consistent with many empirical aspects of international economic fluctuations. In contrast with previous NOEM work, the introduction of state-depedent pricing and strategic complementarity implies a gradual transmission of monetary policy actions to aggregate economic activity and highlights the expenditure-switching role of exchange rate adjustments.

By replicating key fluctuations in real and nominal economic activity, our model offers a new framework in which to address different issues. For example, the delayed response of inflation offers a templates in which to incorporate endogenous monetary policies. The J-curve dynamics found in the domestic trade balance offers an interesting channel for investment dynamics. Finally, the high international output correlation relative to consumption correlation could be use to study the patterns of rish sharing over the business cycles.

7 Appendices

7.1 Appendix A: Data

The data were acquired from FRED II and the OECD databases. Definition of the series used are listed below:

Source: FRED II

- Quarterly Real Gross Domestic Product

- Quarterly Real Personal Consumption Expenditure

- Quarterly Personal Consumption Expenditure Price Index

- Monthly Effective Federal Funds Rate

- Monthly M1 Money Stock

- Monthly Trade Weighted Exchange Index - Major Currencies[20]

Domestic real trade balance was aggregated from the following series:

- Monthly Exports/Imports to/from Japan

- Monthly Exports/Imports to/from Germany

- Monthly Exports/Imports to/from United Kingdom

- Monthly Exports/Imports to/from France

Source: OECD Economic Outlook

For each Non-US G5 Economies:

- Quarterly Gross Domestic Product, Volume, Market Prices

- Quarterly Private Final Consumption Expenditure, Volume

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[20]Consumption weighted exchange rate with Non-US G5 economies gives similar results.

- Quarterly Gross Domestic Product, Deflator, Market Prices

- Quarterly Private Final Consumption Expenditure, Deflator

- Annual Purchasing Power Parity in US dollars

For all G5 Economies:

- Working-age Population

All data are seasonally adjusted except for exports and imports data.

Aggregation of Non-US G5 Economies

Monthly data were transformed to quarterly data using end of quarters. G4 aggregates were built using working population weights and translated to US dollars using a 3 quarters moving average transformation of the annualized purchasing power parity figures.

7.2 Appendix B: Demand Aggregators

We consider the following general expenditure minimization problem for each country:

$$\min_{d(z)} \int_0^1 P(z)d(z)\, dz \quad\text{subject to}\quad \int_0^1 \Gamma\left(d(z)/d\right) dz = 1 \tag{B.1}$$

The country-specific aggregate demands d for goods are implicitly defined by a demand aggregator Γ such that an aggregate producer price index P^P holds for each country. The first order condition of the expenditure minimization problem yields:

$$P(z) = Z \cdot \Gamma'\left(\frac{d(z)}{d}\right) \tag{B.2}$$

where Z is the Lagrange multiplier on the constraint. Consequently, the first order condition can be solved to yield demand curves of the form:

$$\left(\frac{d(z)}{d}\right) = \Gamma'^{-1}\left(\frac{P(z)}{Z}\right) \tag{B.3}$$

Given the demand curves and the multipliers, the aggregate producer price indices are determined by

$$\int_0^1 \left(\frac{P(z)}{P^P}\right)\left(\frac{d(z)}{d}\right) dz = 1 \tag{B.4}$$

In the case of our specific aggregator Γ, the relative demand curves are given by

$$\frac{d(z)}{d} = \frac{1}{1-\varphi}\left[\left(\left(\frac{P(z)}{P^P}\right)\left(\frac{P^P}{Z}\right)\right)^{\frac{1}{\gamma-1}} + \varphi\right] \tag{B.5}$$

which is the sum of a constant elasticity of demand augmented by a constant.

7.3 Appendix C: Adjustment Costs Structure

We adopt the costs structure used in Dotsey and King (2005). The adjustment costs are stochastic and idiosyncratic across firms, and are governed by country-specific cumulative distribution functions (CDF) $G(x)$ on the interval $0 \leq x \leq \overline{B}$ and corresponding density functions $g(x)$. Under the adjustment rules, a country-specific firm's probability of adjustment is:

$$\alpha(\xi) = G(\xi) = \int_0^\xi g(x) dx \tag{C.1}$$

or more intuitively

$$\alpha = G(\xi) = G\left(\frac{v_0 - v}{w}\right) \tag{C.2}$$

Hence, the fraction of price-adjusting firms in each vintage is determined by a marginal firm being indifferent to price adjustment.

The functional form used to derived the adjustment costs functions is the arctangent. This functional form is a monotonically increasing function that maps the real line into the interval $(-\pi, \pi)$ in different shapes. In this paper, we use the an interval of the arctangent $[\underline{x}, \overline{x}]$ and assume that

$$x(\alpha) = \alpha \cdot (\overline{x} - \underline{x}) + \underline{x} \tag{C.3}$$

where α is restricted to the range $0 \leq \alpha \leq 1$. Finally, we assume that the inverse of the

CDF takes the form

$$\xi(\alpha) = K_1 s(\underline{x}) + K_2 \tag{C.4}$$

The inverse CDF takes on a zero value at $\alpha = 0$ and a value of $\overline{B}$ at $\alpha = 1$:

$$0 = K_1 s(\underline{x}) + K_2 \tag{C.5}$$

$$\overline{B} = K_1 s(\underline{x}) + K_2$$

so that the values of the parameters are given by

$$K_1 = \frac{\overline{B}}{s(\overline{x}) - s(\underline{x})}$$

$$K_2 = \frac{\overline{B} s(\underline{x})}{s(\overline{x}) - s(\underline{x})}$$

The results reported in the paper use value of $B = 0.015$ and $x \in [0, 4]$. Since the steady-state fractions of househlods' times devoted to production are $n = 0.2$, setting $B = 0.015$ involves that the maximum adjustment costs are 7.5 percent of production times in the hypothetical economy. Consistent with empirical studies, this also implies that the ressources devoted to price adjustments correspond roughly to 0.8 percent of firm's revenues with a maximum adjustment cost of 8.2 percent of revenues (see Levy et al. (1997)).

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Parameter values governing:		Country 1	Country 2
Preferences			
β	Discount rate	0.99	0.99
σ	Intertemporal elasticity of substitution	0.25	0.25
η	Elasticity of labor supply	0.05	0.05
n	Fraction of time working	0.20	0.20
Demands			
γ	Demand curvature	1.02	1.02
ϵ	Elasticity of demand at 1	10	10
Countries			
s	Country's relative size	0.50	0.50
θ	Degree of openness	0.20	0.20
ς	Elasticity of substitution - Country	1	1
Productivity			
a	Total factor productivity	1	1
Monetary policies			
μ	Steady-state money growth rate	0.015	0.015
ρ	Money growth autocorrelation	0.50	0.50

Table 1: Benchmark Parametrization

		Quarter(s) since last adjustment						
		0	**1**	**2**	**3**	**4**	**5**	**6**
α_j	Probability of adjustment	—	0.04	0.11	0.22	0.39	0.67	1
ω_j	Population density	0.25	0.24	0.21	0.17	0.10	0.03	—

Table 2: Stationary distributions of firms across countries

Parameter values governing:	US Economy	G4 Economy
Preferences		
β Discount rate	0.99	0.99
n Fraction of time working	0.20	0.20
Countries		
s Country's relative size	0.5	0.5
θ Degree of openness	0.025	0.025
Productivity		
a Total factor productivity	1	1
Monetary policies		
μ Steady-state money growth rate	0.04	0.038

Table 3: Calibrated Parameters

Parameter values governing:	US Economy	G4 Economy
Preferences		
σ Intertemporal elasticity of substitution	$0.2319_{(0.0019)}$	$0.2668_{(0.0167)}$
η Elasticity of labor supply	$0.0517_{(0.0016)}$	$0.0480_{(0.0216)}$
ς Elasticity of substitution - Country	$1.3009_{(0.2688)}$	$1.4310_{(0.2689)}$
Demands		
γ Demand curvature	$1.0200_{(0.0012)}$	$1.0200_{(0.0098)}$
ϵ Elasticity of demand at 1	$8.7441_{(0.0177)}$	$9.4789_{(0.4751)}$
US Monetary policies		
ρ Money growth autocorrelation	$0.5125_{(0.0153)}$	0

Table 4: Estimated Parameters

		Quarter(s) since last adjustment						
		0	**1**	**2**	**3**	**4**	**5**	**6**
	US Economy							
α_j	Probability of adjustment	—	0.040	0.120	0.234	0.413	0.500	1
ω_j	Population density	0.249	0.239	0.210	0.161	0.094	0.047	—
	G4 Economy							
α_j	Probability of adjustment	—	0.033	0.106	0.209	0.357	0.594	1
ω_j	Population density	0.242	0.234	0.209	0.166	0.106	0.043	—

Table 5: Estimated stationary distributions of firms across countries

	Data		Models	
Correlation	Unconditional	Conditional	SDP	TDP
with domestic output:				
CPI inflation	-0.18	0.13	0.38	0.97
Trade balance	-0.24	-0.18	-0.99	-0.99
Nominal exchange rate	0.17	0.14	-0.42	0.48
between US and G4:				
Output	0.49	0.67	0.79	0.97
Consumption	0.35	0.55	0.53	0.88
CPI	0.85	0.79	0.02	-0.36

Table 6: Contemporaneous moments[21]

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[21]Unconditional and conditional moments were calculated using approximate Band-Pass filtered series.
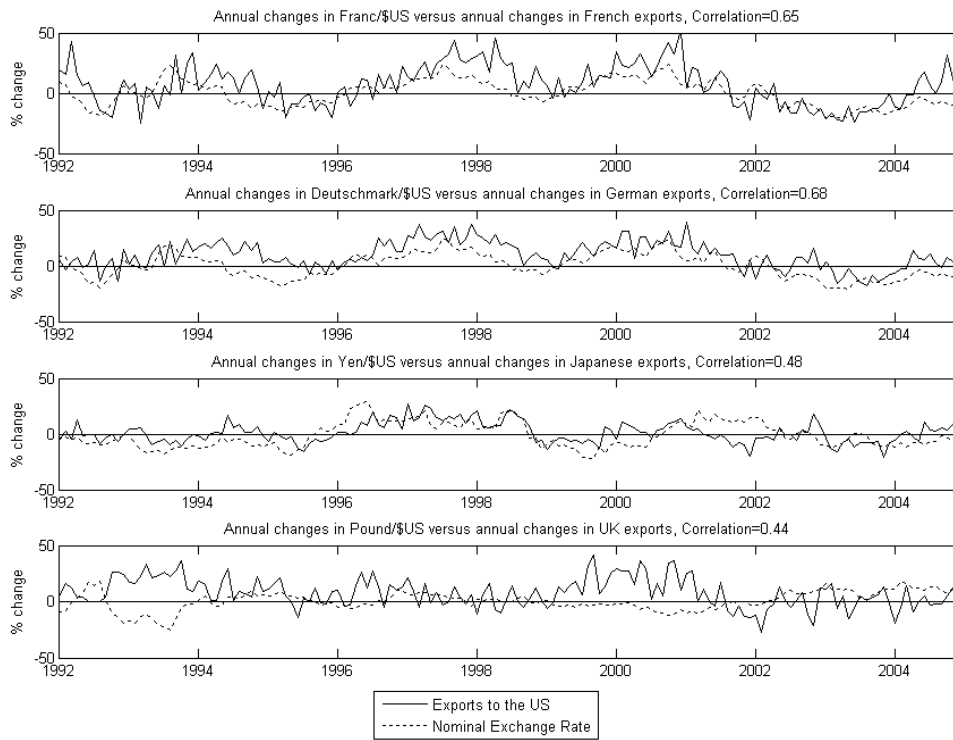
Figure 1: Annual changes in exports* to the United States versus annual changes in nominal exchange rate

*Exports are seasonnally adjusted in domestic currency
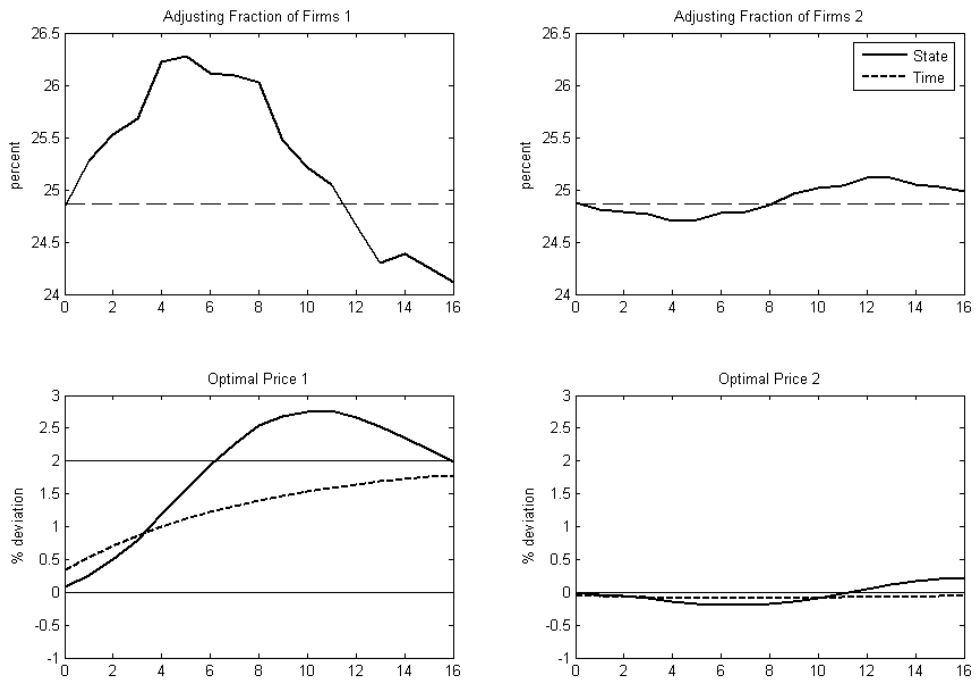
Figure 2: Firms' reactions

44
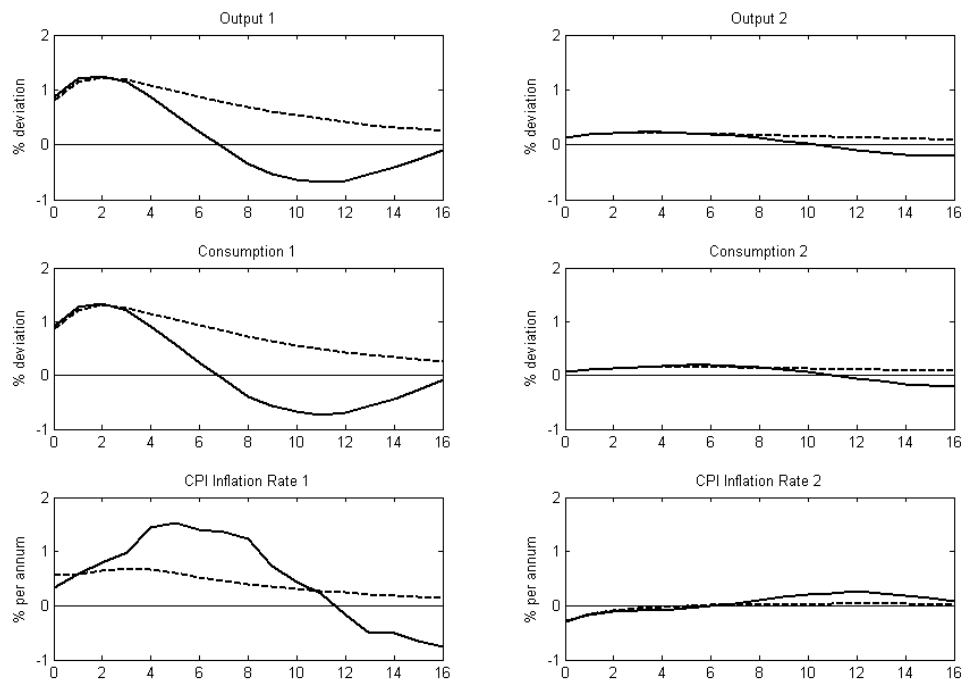
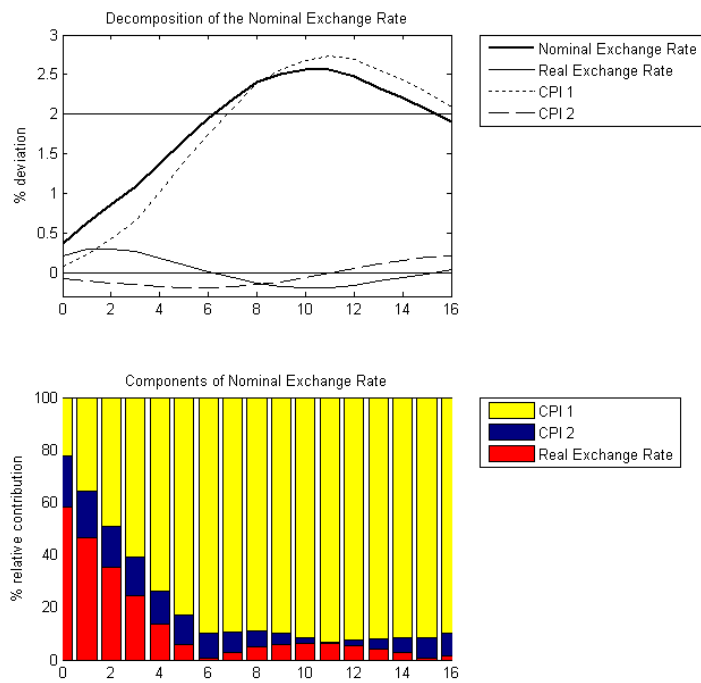Figure 3: Output, consumption, and CPI inflation
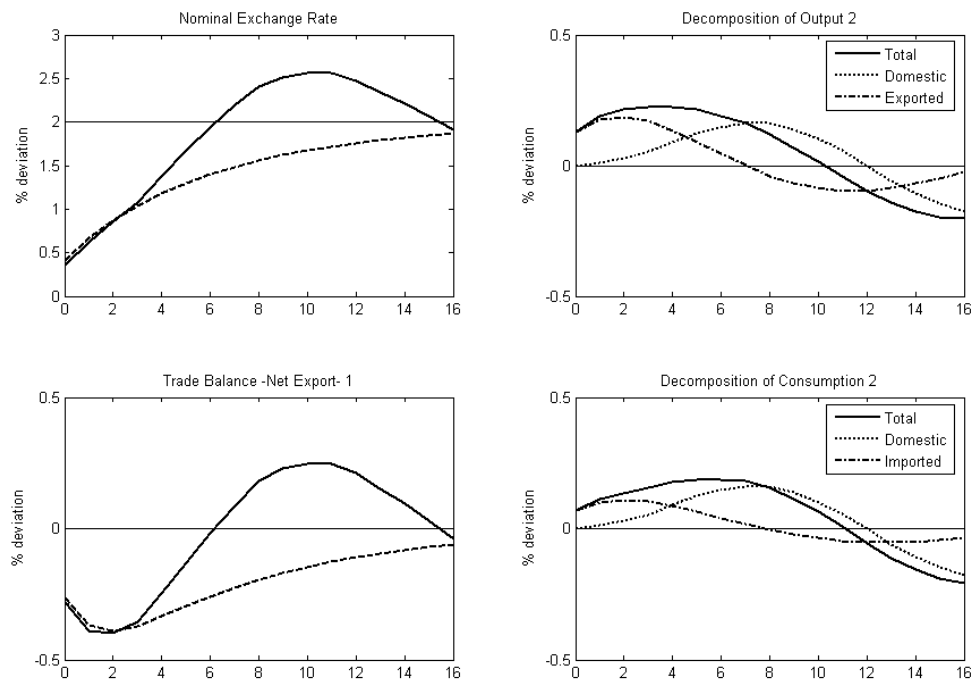
Figure 4: Nominal exchange rate
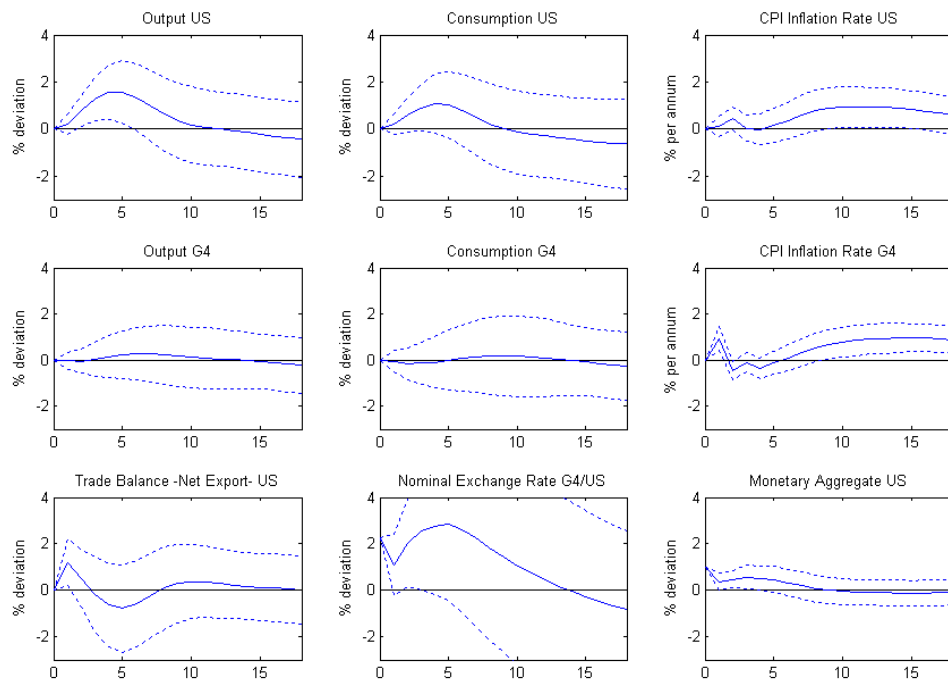
Figure 5: Nominal exchange rate and trade

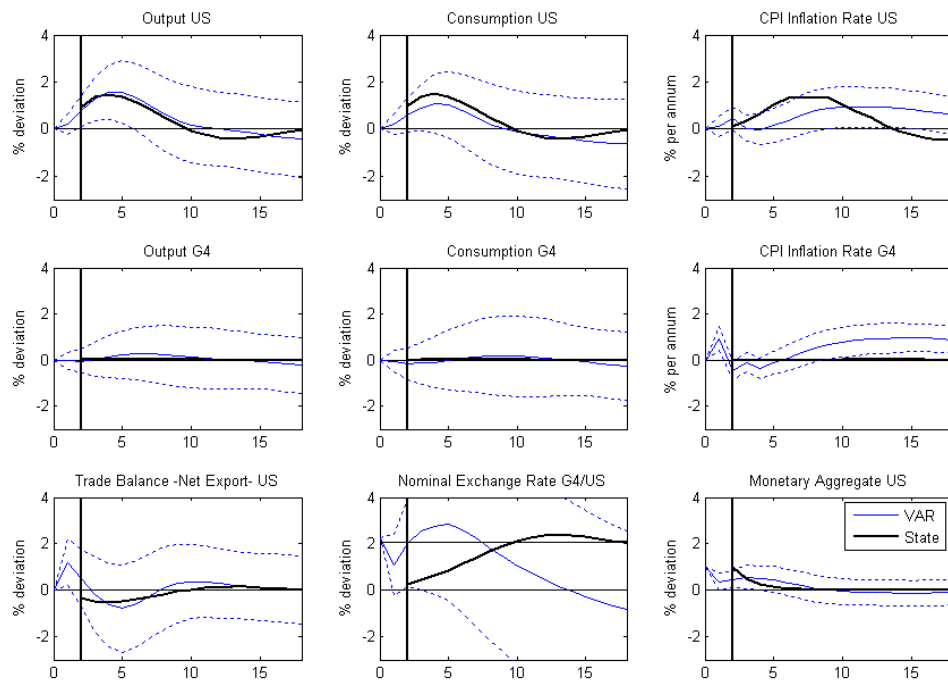Figure 6: US and G4 responses to a US monetary policy shock

Figure 7: International VAR versus state-dependent pricing model