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 works, there are new implications for the dynamics of real and nominal economic activity: complementarity in the timing of price adjustment 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 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, the model is consistent with many empirical aspects of international economic fluctuations, while stressing pricing behavior and exchange rate effects highlighted in traditional Keynesian works.

JEL Classification: F41, F42.

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1 Introduction

The international economic literature has long believed that exchange rate changes redirect global expenditure in the presence of price rigidity. Dornbusch (1987), Krugman (1991), Obstfeld and Rogoff (2000), and Obstfeld (2002) provide empirical evidence that the expenditure-switching effect of exchange rate changes is alive and well among industrial countries. To represent this relationship, Figure 1.1 displays annual changes in US nominal exchange rates versus annual changes in US bilateral real exports to Japan, Germany, France and the United Kingdom over the past 30 years. The positive correlations between changes in currency values and changes in export demand suggest that exchange rate movements remains an important determinant of trade flows.

Like the traditional international economic 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 intuition, features, and predictions found in the traditional Keynesian approach: the canonical NOEM model has at best a small expenditure-switching effect and has many other predictions that differ sharply from the observed empirical evidence. Furthermore, both the traditional Keynesian approach and the NOEM literature have been criticized because of ad hoc pricing elements. The traditional Keynesian approach keeps prices fixed for the duration of the analysis or adopts mechanical price adjustment rules while in the NOEM literature, optimizing price-setters can only change the magnitude but not the timing of adjustments.

This paper introduces elements of state-dependent pricing and strategic complementarity into an otherwise standard NOEM model. Relative to previous NOEM works, there are new implications for the dynamics of real and nominal economic activity: complementarity in the timing of price adjustment alters an open economy's response to monetary disturbances. Under a 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 traditional Keynesian approach. 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 framework.

The key to the model's results is the combination of state-dependent 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 offers an environment in which firms can choose the timing of price adjustment and consequently coordinate their actions. 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 the aggregate price level. This behavior leads to price responses that are extremely slow and therefore closed to those engineered in the traditional Keynesian approach. On aggregate, this implies a gradual transmission of monetary policy shocks to prices, inflation, and the nominal exchange rate, and ultimately to aggregate economic activities: relative price movements lead to fluctuations in output, consumption, and trade balances that are similar to those observed in the data, and which were the focus of standard Keynesian models.

The remainder of the paper is organized as follows. Section 2 offers a background 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 a corresponding time-dependent variant 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 Background: The Received Wisdom

The following standard views form our background 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.** Dornbusch (1987), Krugman (1991), Obstfeld and Rogoff (2000), and Obstfeld (2002) document the expenditure-switching role of nominal exchange rate: 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 view that US monetary expansions have 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) finds that US monetary policy expansions generate a dynamic pattern in the domestic trade balance similar to the famous J-curve effect: domestic monetary expansions lead 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 same qualitative conclusion about delayed overshooting of exchange rates, Kim and Roubini (2000), Faust and Rogers (2003), and Scholl and Uhlig (2005) note quicker responses.

5. **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 conclude 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

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

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.

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 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 $(1-\theta)$ determines the degree of home bias in the steady-state, and γ the elasticity of substitution between domestic and imported goods. The consumption indices for both countries are defined as

$$\begin{aligned} c_{1,t} &= \left((1-\theta_1)^{\frac{1}{\gamma}} c_{1,1,t}^{\frac{1-\gamma}{\gamma}} + \theta_1^{\frac{1}{\gamma}} c_{2,1,t}^{\frac{1-\gamma}{\gamma}} \right)^{\frac{\gamma}{1-\gamma}} \\ c_{2,t} &= \left((1-\theta_2)^{\frac{1}{\gamma}} c_{2,2,t}^{\frac{1-\gamma}{\gamma}} + \theta_2^{\frac{1}{\gamma}} c_{1,2,t}^{\frac{1-\gamma}{\gamma}} \right)^{\frac{\gamma}{1-\gamma}}. \end{aligned} \tag{3}$$

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

$$c_{1,1,t} = (1-\theta_1)\left(\frac{P^P_{1,t}}{P^C_{1,t}}\right)^{-\gamma} c_{1,t} \qquad c_{2,1,t} = \theta_1\left(\frac{S_t P^P_{2,t}}{P^C_{1,t}}\right)^{-\gamma} c_{1,t} \tag{4}$$
$$c_{2,2,t} = (1-\theta_2)\left(\frac{P^P_{2,t}}{P^C_{2,t}}\right)^{-\gamma} c_{2,t} \qquad c_{1,2,t} = \theta_2\left(\frac{P^P_{1,t}}{S_t P^C_{2,t}}\right)^{-\gamma} c_{2,t}$$

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

$$\begin{aligned} P^C_{1,t}c_{1,t} + E_t[D_{t+1}b_{1,t+1}] &\leq b_{1,t} + W_{1,t}n_{1,t} + Z_{1,t} \\ P^C_{2,t}c_{2,t} + E_t[D_{t+1}b_{2,t+1}] &\leq b_{2,t} + W_{2,t}n_{2,t} + Z_{2,t}. \end{aligned} \tag{5}$$

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 $q_t = S_t \cdot \left(P^C_{2,t}/P^C_{1,t}\right)$ 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 $M_t/P^C_t = c_t$ along with country-specific monetary policies.

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

3.2 Strategic Complementarity and Demand Functions

Strategic complementarity among individual firms is introduced by allowing for variable demand elasticity as suggested by Kimball (1995). This approach is consistent with microeconomic evidence suggesting that competitors' actions play a central role in the behavior of price adjustments.[3] The Kimball demand function makes it more costly for firms to get their prices out of line with the average price set by other firms than the standard Dixit-Stiglitz demand as illustrated by the relative demand and corresponding profit functions plotted in Figure 1.2.[4] This concept has 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, strategic complementarity and state-dependent pricing increases the interaction between firms as they opt to keep their price in line with the general level of product prices: strategic complementarity makes it desirable for firms to keep their prices similar to those of others while state-dependent pricing makes it feasible for them to do so.

3.2.1 Firm's Relative Demand

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

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

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 $P\left(z\right)$ identifies the price of the good charged by an individual firm z with corresponding relative demand $d\left(z\right)/d$. Moreover, our specific aggregator Γ is an increasing and concave function reflecting diminishing demand elasticity, and is defined over the parameters φ and ϱ which govern the curvature of the demand function[5]

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

[3] Examples include Bills and Klenow (2004), and Blinder (1991, 1994) for the United States.

[4] The NOEM 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 (2004).

[5] The parameter ϱ determines the elasticity of demand at the average level of product prices while φ determines the curvature of the demand function. A nice property of this specification is that the Dixit and Stiglitz aggregator is a special case represented by $\varphi = 0$. Derivation of the above equations are provided in Appendix B.

This demand aggregator implicitly defines firm's relative demand as a function of individual and aggregate prices, and the curvature parameters of the demand function

$$\frac{d_t(z)}{d_t} = f\left(\frac{P(z)}{P^P}, \varphi, \varrho\right).$$

3.2.2 Price Indices

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

$$\begin{aligned} P_t^P &= \int_0^1 P_t(z)\left(d_{1,t}(z)/d_{1,t}\right)dz \\ P_t^P &= \int_0^1 P_t(z)\left(d_{2,t}(z)/d_{2,t}\right)dz \end{aligned} \tag{9}$$

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

$$\begin{aligned} P_{1,t}^C &= \left((1-\theta_1)\left(P_{1,t}^P\right)^{1-\gamma} + \theta_1\left(S_t P_{2,t}^P\right)^{1-\gamma}\right)^{\frac{1}{1-\gamma}} \\ P_{2,t}^C &= \left((1-\theta_2)\left(P_{2,t}^P\right)^{1-\gamma} + \theta_2\left(P_{1,t}^P/S_t\right)^{1-\gamma}\right)^{\frac{1}{1-\gamma}}. \end{aligned} \tag{10}$$

As in standard Keynesian models, 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

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. 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

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

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

$$\begin{aligned} y_{1,t}(z) &= f\left(\frac{P_{1,t}(z)}{P_{1,t}^P}, \varphi, \varrho\right) \cdot d_{1,t} \\ y_{2,t}(z) &= f\left(\frac{P_{2,t}(z)}{P_{2,t}^P}, \varphi, \varrho\right) \cdot d_{2,t}. \end{aligned} \tag{12}$$

Equation (12) illustrates that production by an individual firm depends on its price relative to other domestic firms (PPI), and on its country-specific aggregate demand (11) which is determined by the degree of home bias, 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 (12), 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:

$$v\left(p_{jt}^C, \xi_t | s_t\right) = \max \left\{ \begin{array}{c} v_{jt} = \pi\left(p_{jt}^C | s_t\right) + \beta E_t \Lambda_{t,t+1} v\left(p_{j+1,t+1}^C, \xi_{t+1} | s_{t+1}\right), \\ v_{0t} = \max_{\widehat{p}_t^C} \pi\left(\widehat{p}_t^C | s_t\right) + \beta E_t \Lambda_{t,t+1} v\left(\widehat{p}_{t+1}^C, \xi_{t+1} | s_{t+1}\right) - w_t \xi_t \end{array} \right\} \tag{13}$$

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

$$\pi\left(p^C_{jt}|s_t\right) = \left(p^C_{jt} - \psi_t\right) \cdot y_{jt} \tag{14}$$

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, $\Lambda_{t,t+1} = \lambda_{t+1}/\lambda_t$ 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 (13) 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

$$\xi\left(\alpha_{j,t}\right) \cdot w\left(s_t\right) = v_{0,t}(s_t) - v_{j,t}(s_t). \tag{15}$$

Finally, the dynamic program (13) 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

$$0 = \frac{\partial \pi\left(\widehat{p}^C_t|s_t\right)}{\partial \widehat{p}^C_t} + \beta E_t\left[\Lambda_{t,t+1} \cdot \frac{\partial v\left(\widehat{p}^C_t, \xi_{t+1}|s_{t+1}\right)}{\partial \widehat{p}^C_t}\right]. \tag{16}$$

Iterating the Euler equation (16) forward, the country-specific firm nominal optimal prices $\widehat{P}$ can be expressed as an explicit function of current and expected future variables

$$\begin{aligned}
\widehat{P}_{1,t} &= \frac{\sum_{j=0}^{J_1-1} \beta^j E_t\left[\Omega_{1,j,t,t+j} \cdot \Lambda_{1,t,t+j} \cdot \epsilon_{1,j,t+j} \cdot \psi_{1,t+j} \cdot P^P_{1,t+j} \cdot d_{1,j,t+j}\right]}{\sum_{j=0}^{J_1-1} \beta^j E_t\left[\Omega_{1,j,t,t+j} \cdot \Lambda_{1,t,t+j} \cdot \left(\epsilon_{1,j,t+j} - 1\right) \cdot \left(P^P_{1,t+j}/P^C_{1,t+j}\right) \cdot d_{1,j,t+j}\right]} \\
\widehat{P}_{2,t} &= \frac{\sum_{j=0}^{J_2-1} \beta^j E_t\left[\Omega_{2,j,t,t+j} \cdot \Lambda_{2,t,t+j} \cdot \epsilon_{2,j,t+j} \cdot \psi_{2,t+j} \cdot P^P_{2,t+j} \cdot d_{2,j,t+j}\right]}{\sum_{j=0}^{J_2-1} \beta^j E_t\left[\Omega_{2,j,t,t+j} \cdot \Lambda_{2,t,t+j} \cdot \left(\epsilon_{2,j,t+j} - 1\right) \cdot \left(P^P_{2,t+j}/P^C_{2,t+j}\right) \cdot d_{2,j,t+j}\right]}
\end{aligned} \tag{17}$$

where $\Omega_{j,t,t+j}$ represents the probability of non-adjustment from t to $t+j$ 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 (17) are generalizations of the types derived in NOEM models with exogenous probabilities (Obstfeld and Rogoff (1995)). 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).

3.4 Monetary Policies

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

$$\begin{aligned} \Delta M_{1,t} &= \rho_1 \Delta M_{1,t-1} + \vartheta_1 \Delta M_{2,t} + \nu_{1,t} \\ \Delta M_{2,t} &= \rho_2 \Delta M_{2,t-1} + \vartheta_2 \Delta M_{1,t} + \nu_{2,t} \end{aligned} \tag{18}$$

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 $P^P_{1,t}, P^C_{1,t}, W_{1,t}$, $D_{1,t+1}$ and $P^P_{2,t}, P^C_{2,t}, W_{2,t}, D_{2,t+1}$ such that (i) consumers maximize their 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 the steady state equilibrium by imposing trade account balance to the long-run behavior of the model. The steady-state equilibrium for this economy involves the lowest value 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 1.1. 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. Those parameters generate elasticities of marginal cost of approximately 0.3.[6] Agents work 20 percent of their time endowment. Country 1 and 2 are of equal sizes and have degrees of home bias of 20 percent. We set the elasticities of substitution between domestic and imported consumption goods γ 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 ϱ so that demand curves have elasticities of 10 at $d(z)/d = 1$. Restricting φ to take values of 1.02 implies that a 1 percent increase in price decreases demand by 13 percent,

[6] 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 $\sigma + \eta$.

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 1.2 displays the steady-state fractions of price-adjusting firms as well as the population densities associated with the parametrized model for both countries.[7] 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 reasonable approximation of the main features governing the pattern of price adjustments and pricing policies observed in empirical studies on pricing behavior in developed economies.

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 1 percent on impact with a long-run response approaching 2 percent above its initial level. Figures 1.3-1.6 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

Figure 1.3 displays the firms' reactions to Country 1's monetary expansion. The top row displays the fractions of price-adjusting firms while the bottom row displays the associated optimal prices chosen by the price-adjusting firms. Relative to similar experiments in the NOEM literature, a novel feature of the state-dependent pricing open economy model is the evolving distributions of price-adjusting firms across countries and their corresponding influences on firm's optimal prices.

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

In Country 1, raising product demand generated by the monetary expansion increases the value of price-adjusting firms and consequently induces a larger fraction of firms to reset their prices. The introduction of variable elasticity demand curves generates smooth movements in adjusting fractions as firms bunch their actions.[8] Initially, the monetary expansion translates very little to firm's adjusting fraction and corresponding optimal price as firms are not willing to act differently from one another. 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. After a few quarters, the monetary expansion snowballs into the adjusting fraction and corresponding optimal price as changes in individual prices feed into the aggregate price level and increase the benefit of price adjustments. Finally, the optimal price overshoots its long-run value as firms try to keep up with the inflation dynamics: the larger fraction of price-adjusting firms has increased the level of aggregate prices above their long-run values and consequently induces price-adjusting firms to price high. This overshooting dynamics is absent in the time-dependent counterpart but will revealed to be important in explaining international economic fluctuations. Altogether, the 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 Country 2, the fraction of price-adjusting firms and corresponding optimal prices initially decreases. Country 1's monetary expansion generates an appreciation of the foreign currency and consequently decreases domestic and export demands for Country's 2 products. Domestic demand decreases because of the inflow of cheaper goods coming from Country 1 while higher export prices decreases export demand. In turn, lower product demand decrease the value of price-adjusting firms and consequently induces a smaller fraction of firms to adjust prices: to compete against foreign goods, some firms delay their price adjustment while others decrease their prices. A few quarters later, adjusting fraction and corresponding optimal prices surge in positive territories as demand increases.

The firms' reactions under the state-dependent model is in sharp contrast with its time-dependent counterpart. In time-dependent models, 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. This results into a jump in optimal prices followed by a monotonic adjustment to long-run values. This pricing behavior is responsible for the front-loading aspect of aggregate prices common to time-dependent pricing models.

[8] This is in contrast with a Dixit and Stiglitz demand specification exploited in Landry (2004).

4.2.2 Aggregate Implications of a Monetary Shock

Domestic Aggregates

Output, Consumption, and Inflation Dynamics We now turn to the aggregate implications of our model. Figure 1.4 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 driven by price movements in the CPI.

The timing of output and consumption movements generates a high cross-country output correlation relative to consumption correlation: the cross-correlation of output is 0.55 and the cross-correlation of consumption is 0.32. This is in sharp contrast with correlation numbers obtained in the time-dependent counterpart where the cross-correlation of output is 0.96 and the cross-correlation of consumption is 0.92. This result arises even if (i) the model embodies international risk-sharing, and (ii) the model does not rely on international market segmentation to induce discrepancies in consumption aggregates.[9] We explore in further detail the components of foreign output and consumption below.

Output and consumption aggregates in both economies also display oscillating cycles 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 16 quarters.

Those fluctuations in output and consumption are induced by corresponding movements in price indices. An important strength of the model is its ability to generate

[9] 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.

initial price inertia and consequently delayed responses in CPI inflations. The bottom row of Figure 1.4 displays the 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 alters the CPI. However, as Country 2's demand increases, CPI inflation surges into positive territory and 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 movements in country-specific firm's adjustment fractions and optimal prices during high inflation periods.

International Aggregates

In our model, movements in relative prices dictate the behavior of real aggregates, both within and across countries. Therefore, before turning to the real side of trade, we study the model's implications for the nominal exchange rate and the terms of trade. Then, we turn to the model's implications for trade flows and other real macroeconomic aggregates.

Nominal Side of 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 1.5. 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 1.5 displays the relative contribution of nominal exchange components. Short-term responses of the nominal exchange rate are mostly in the real exchange rate: these are relative price changes that affect demand composition. At longer horizons, the nominal exchange rate is mainly affected by the domestic price level in a close to neutral manner.[10]

The left column of Figure 1.6 displays the nominal exchange rate, the price of exports and imports, and the terms of trade described as the ratio of imports to exports prices. The terms of trade turns positive following the domestic monetary expansion: while domestic prices remain relatively stable, nominal exchange rate movements feeds into import prices. However, after a few quarters, the terms of

[10]Figure 1.5 aknowledges the model's failure to generate real and nominal exchange rate movements that are highly correlated as in the data. However, most of the correlation between real and nominal exchange rates often found in the NOEM literature results from simultaneous front-loading aspects of prices and consumption common to time-dependent models.

trade becomes negative as the domestic monetary expansion snowballs into domestic prices and neutralizes movements in nominal exchange rate.

Real Side of Trade The right column of Figure 1.6 displays the trade balance for Country 1, and decomposes Country 2's output and consumption aggregates into their domestic and foreign components. From the perspective of Country 1, movements related to trade can be explained by looking at the trade balance. Following the domestic 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. Improvement in the trade-balance arises as domestic prices overshoot their long-run values and turn the economy into a recession. The relatively better foreign economic conditions keep the trade-balance in surplus.

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, later relatively low domestic producer prices translate 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.

In short, the domestic monetary expansion generates trade flows and induces movements in relative prices and real aggregates. On impact, both countries experience rising export and import demands. On the one side, Country 1's export demand increases because foreign agents substitute cheaper imported goods in their consumption basket while imports demand rises to fulfill domestic demand. On the other side, Country 2's export demand increases to fulfill foreign demand while import demand rises because domestic agents substitute cheaper imports in their consumption basket. Subsequently, both countries experience falling export and import demand as relative prices overshoot their long-run values. However, while Country 2 lags the business cycle, it also keeps Country 1 afloat.

5 Open Economy Economic Fluctuations

This section first describes the dynamic behavior of international business cycles by focusing on correlations in real and nominal macroeconomic variables between economies of the G5. Then, 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 received wisdom. This agnostic exercise permits us to illustrate the model's plausibility and to capture its crucial elements.

5.1 Open Economy Business Cycle Statistics

Table 1.3 displays the correlations that occur at business-cycle frequencies for the US and a aggregate of Japan, Germany, France, and the UK called G4 Economy. The US data are from the BEA, and the Japanese, German, French, and British data are from OECD Economic Outlook. The quarterly data cover the period 1974Q1 to 2005Q4 and when necessary are expressed in per capita 2000 US dollars at purchasing-power-parity.[11] For comparison with our business cycle model, we also compute the moments conditional on a monetary shock using bootstraps methods on the VAR estimated below.

Output, consumption, exports, and imports tend to be strongly procyclical. The trade balance is countercyclical with respect to output and consumption. CPI inflation and the expenditure components are procyclical using the unconditional data but countercyclical using the data conditional on a monetary shock. As for international prices, the nominal exchange rate is acyclical relative to output and consumption. Relative to the trade balance, the nominal exchange rate is procyclical with respect to the unconditional data but countercyclical with respect to the data conditional on a monetary shock. The terms of trade are countercyclical relative to output and consumption with respect to the unconditional data but procyclical with respect to the data conditional on a monetary shock. In terms of cross-country correlation, we observed a higher cross-country output correlation relative to consumption correlation. Finally, CPI inflation across countries are highly correlated.

5.2 Econometric Methodology

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 and G4 economies to a US monetary policy shock.

$$FFR_t = f\left(\Upsilon_t\right) + \varepsilon_t \tag{19}$$

Characterization of US monetary policy is given by equation (19) where FFR_t represents the monetary instrument, f is a linear function of the information included

[11] The data sources and aggregation are described in Appendix A.

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.

$$Y_t = [Y_{1t}, FFR_t, Y_{2t}]' \tag{20}$$

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, G4 personal expenditure deflator, and per capita US real trade balance with the G4 economy. The variables in Y_{2t} are the growth rate of per capita US real M1, the nominal exchange rate, and the terms of trade. 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 monetary 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.

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 except for the deflators and the monetary instrument. When the constant term is ignored, the VAR takes the following representation:

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + Ce_t \tag{21}$$

where C is a 11×11 lower triangular matrix, and e_t is an eleventh-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. Chari, Kehoe, and McGrattan (2002), and Christiano, Eichembaum, and Evans (2005) support this type of money growth process as a good approximation to an interest rate rule.

The impulse response functions are displayed in Figures 1.7 and 1.8. The straight lines correspond to the estimated average while the dotted lines represent their 95 percent confidence intervals about the point estimates evaluated using Bootstraps method. The VAR results generally agree with the received wisdom and consequently pave the way to the estimation of the model.

5.3 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 1.4. As in the previous exercise, the discount factors β are 0.99 and households work 20 percent of their time endowment. The US Economy is characterized by a degree of home bias of 3.74 percent and represents 1/2 of the world's GDP. The former corresponds to the average share of US exports to GDP traded with the G4 Economy over the sample period, 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, 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 $\psi = (\sigma_1, \sigma_2, \eta_1, \eta_2, \gamma_1, \gamma_2, \varphi_1, \varphi_2, \epsilon_1, \epsilon_2, \rho_1)$, 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

$$J = \min_{\psi} \left[\widehat{\Psi} - \Psi(\psi)\right]' W \left[\widehat{\Psi} - \Psi(\psi)\right] \tag{22}$$

where W is a diagonal matrix with the inverse of each impulse response's variances along the diagonal. Such weighting matrix accounts for the fact that some points of the impulse response functions are less precisely estimated than others and hence guarantees that $\Psi(\psi)$ lies as much as possible inside the confidence intervals.[12] We consider the first 16 elements of the impulse response functions and discard the first empirical point estimates from the estimation procedure to minimize the impact of the VAR identification strategy in the estimation of the model.

The estimated parameters and related standard errors are shown in Table 1.5. Following Ireland (2004), we express the standard errors of our estimates as the square root of the diagonal elements of the matrix $V \equiv \left([\partial g(\psi)/\partial\psi]' W [\partial g(\psi)/\partial\psi]\right)^{-1}/T$, where $g(\psi) = \left(\widehat{\Psi} - \Psi(\psi)\right)$ and T is the number of impulse responses used in the esti-

[12] See Boivin and Gianoni (2006) and Christiano et al. (2005).

mation.[13] The parameters governing preferences produce a low elasticity of marginal cost with respect to real output of approximately 0.25. The elasticity of substitution between domestic and imported consumption goods are close to the unitary elasticity of substitution 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 φ, this implies that a 1 percent increase in prices decreases demand by roughly 9 percent in the US and 12 percent in the G4 Economy. In line with Chari et al. (2002) and Christiano et al. (2005), we estimated the coefficient governing the US autocorrelation of money growth to be 0.61.

Table 1.6 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 4.06 quarters for the US, and an average age of prices of less then 2.78 quarters and an expected price duration of 4.06 quarters for the G4 Economy.

5.4 Hits and Misses

Figures 1.9 and 1.10 display the estimated state-dependent model impulse response functions alongside the VAR impulse response functions. In line with both the received wisdom and with the empirical estimates, our estimated model replicates some key macroeconomic comovements. Following a US monetary expansion: (i) domestic and foreign output and consumption expand and display hump-shaped responses, (ii) foreign output expands first followed by foreign consumption, (ii) monetary policy has a delayed and gradual effect on domestic and foreign inflations, (iv) on impact, domestic monetary policy has a deflationary effect on foreign inflation, (v) the domestic trade balance displays a J-curve dynamic, (vi) the nominal exchange rate overshoots its long-run value, and (vii) the domestic terms of trade improve.

On the domestic front, the model does fairly well in replicating the shapes and amplitudes of output, consumption, and the trade balance responses to a US monetary policy shock. Although the model based impulse response functions are qualitatively consistent with the data, the inflation process implied by the model is not as persistent as the one implied by the data. Moreover, the model is able to replicate the

[13] 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 is appropriate, 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 problematic associated with our estimation strategy.

shapes and timing of foreign output, consumption and inflation, but has some difficulties matching their amplitudes. As for international trade flows and prices, the model is successful at explaining the procyclicality of exports and imports, and the countercyclicality of the trade balance. The model also replicates reasonably well the behavior of the nominal exchange rate and the terms of trade up to a 8-12 quarters after the shock. Finally, the estimated model does fairly well in replicating within and cross-country correlations between prices and real quantities.[14] Altogether, the relatively basic model studied here does far better than current NOEM models in accounting for open economy business cycle responses to monetary policy shocks.

6 Conclusion

This paper builds a modern NOEM model consistent with many empirical aspects of international economic fluctuations while stressing pricing behavior and exchange rate effects highlighted in the traditional Keynesian approach. In contrast with previous NOEM works, the introduction of state-dependent pricing and strategic complementarity implies a gradual transmission of monetary policy actions to aggregate economic activity and emphasizes the expenditure-switching role of exchange rate adjustments. The resulting movements in relative prices and real macroeconomic aggregates mimic the comovements observed in the data that were the focus of standard Keynesian models. By replicating key fluctuations in real and nominal economic activity, our model therefore offers a new framework in which to address different issues related to international economic activity.

[14] In this model, real quantities correlations are high because consumption is the sole expenditure component. Baxter and Landry (2006) introduce capital accumulation to a similar model and observed moments in real quantities that are close to the empirical estimates.

7 Appendices

7.1 Appendix A: Data

Source: BEA

- Quarterly real gross domestic product
- Quarterly real personal consumption expenditure
- Quarterly personal consumption expenditure price deflator
- Quarterly exports price index
- Quarterly imports price index
- Quarterly working-age population
- Monthly effective Federal Funds rate
- Monthly M1 money stock
- Monthly Trade Weighted exchange rate index - Major Currencies
- 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

- Quarterly nominal gross domestic product for Japan, Germany, France, and the UK.
- Quarterly nominal private final consumption expenditure for Japan, Germany, France, and the UK.
- Quarterly gross domestic product deflator for Japan, Germany, France, and the UK.
- Quarterly private final consumption expenditure deflator for Japan, Germany, France, and the UK.
- Quarterly Working-age population for Japan, Germany, France, and the UK.
- Annual Purchasing Power Parity in US dollars for Japan, Germany, France, and the UK.

G4 aggregates are built using working-age population weights and translated in 2000 US dollars using the year 2000 PPP values.

7.2 Appendix B: Demand Aggregators

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

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

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

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

7.3 Appendix C: Adjustment Costs Structure

We adopt the costs structure used in Dotsey and King (2005) and described in Johnston, King, and Landry (2006). 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 $\alpha = 1$:

$$\begin{aligned} 0 &= K_1 s(\underline{x}) + K_2 \\ \overline{B} &= K_1 s(\underline{x}) + K_2 \end{aligned} \tag{C.5}$$

so that the values of the parameters are given by

$$\begin{aligned} K_1 &= \frac{\overline{B}}{s(\overline{x}) - s(\underline{x})} \\ K_2 &= \frac{\overline{B} s(\underline{x})}{s(\overline{x}) - s(\underline{x})} \end{aligned}$$

The results reported in the paper use value of $B = 0.015$ and $x \in [0, 4]$. Since the steady-state fractions of households' 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. This also implies that the resources 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.

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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			
ϱ	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 home bias	0.20	0.20
γ	Elasticity of substitution - Country	1	1
Productivity			
a	Total factor productivity	1	1
Monetary policies			
μ	Steady-state money growth rate	0.01	0.01
ρ	Money growth autocorrelation	0.50	0.50

Table 1.1: Benchmark parameters

		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 1.2: Stationary distributions of firms across countries

Table 1.3: Within and Cross-Country Contemporaneous Correlation

	Correlations						
	US y	US c	US x	US m	US tb	US CPII	US S
US Consumption (c)	0.86	1.00					
	0.98	1.00					
	1.00	**1.00**					
	1.00	*1.00*					
US Exports (x)	0.28	0.01	1.00				
			1.00				
	0.99	**0.99**	**1.00**				
	1.00	*1.00*	*1.00*				
US Imports (m)	0.72	0.57	0.18	1.00			
				1.00			
	0.99	**0.99**	**0.99**	**1.00**			
	1.00	*1.00*	*1.00*	*1.00*			
US Trade balance (tb)	-0.26	-0.36	0.64	-0.45	1.00		
	-0.55	-0.57			1.00		
	-0.99	**-0.99**	**-0.99**	**-0.99**	**1.00**		
	-1.00	*-1.00*	*-1.00*	*-1.00*	*1.00*		
US CPI inflation (CPII)	0.18	0.09	0.33	0.14	0.09	1.00	
	-0.21	-0.30			-0.25	1.00	
	0.36	**0.36**	**0.42**	**0.36**	**-0.34**	**1.00**	
	0.99	*0.99*	*0.99*	*0.99*	*-0.99*	*1.00*	
US Nom. exchange rate (S)	0.09	-0.09	0.48	0.22	0.20	0.35	1.00
	0.06	0.01			-0.40	0.01	1.00
	-0.54	**-0.55**	**-0.51**	**-0.54**	**0.55**	**0.30**	**1.00**
	0.50	*0.50*	*0.52*	*0.50*	*-0.50*	*0.55*	*1.00*
US Terms of trade (TOT)	-0.17	-0.39	0.50	0.14	0.40	0.34	0.43
	0.23	0.12			0.51	0.51	0.07
	0.99	**0.99**	**0.99**	**0.99**	**-1.00**	**0.34**	**-0.55**
	1.00	*1.00*	*1.00*	*1.00*	*-1.00*	*0.99*	*0.50*

	Cross-Correlations		
	G4 y	G4 c	G4 CPII
US Output (y)	0.43	0.36	0.02
	0.60	0.53	-0.15
	0.89	**0.57**	**-0.79**
	0.98	*0.85*	*0.99*
US Consumption (c)	0.30	0.29	-0.06
	0.64	0.42	-0.30
	0.89	**0.57**	**-0.79**
	0.98	*0.85*	*0.99*
US CPI inflation	0.32	0.32	0.88
	0.26	0.18	0.93
	0.71	**0.93**	**0.13**
	0.99	*0.88*	*-0.49*

Unconditional moments using a Band-Pass filter
Moments conditional on a monetary shock using 10000 bootstraps
State-depedent model moments conditional on a monetary shock
Time-depedent model moments conditional on a monetary shock

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 home bias	0.0375	0.0375
Productivity			
a	Total factor productivity	1	1
Monetary policies			
μ	Steady-state money growth rate	0.01	0.0095

Table 1.4: Calibrated parameters

Parameter values governing:		US Economy	G4 Economy
Preferences			
σ	Intertemporal elasticity of substitution	$0.202_{(0.002)}$	$0.220_{(0.071)}$
η	Elasticity of labor supply	$0.042_{(0.016)}$	$0.041_{(0.145)}$
γ	Elasticity of substitution - Country	$0.836_{(0.342)}$	$0.9276_{(0.343)}$
Demands			
ϱ	Demand curvature	$1.020_{(0.001)}$	$1.020_{(0.035)}$
ϵ	Elasticity of demand at 1	$7.006_{(0.004)}$	$9.171_{(0.180)}$
US Monetary policies			
ρ	Money growth autocorrelation	$0.6058_{(0.006)}$	0

Table 1.5: Estimated parameters

		Quarter(s) since last adjustment						
		0	**1**	**2**	**3**	**4**	**5**	**6**
	US Economy							
α_j	Probability of adjustment	—	0.034	0.111	0.219	0.378	0.641	1
ω_j	Population density	0.246	0.238	0.211	0.165	0.103	0.037	—
	G4 Economy							
α_j	Probability of adjustment	—	0.039	0.116	0.226	0.396	0.500	1
ω_j	Population density	0.246	0.236	0.209	0.162	0.098	0.049	—

Table 1.6: Estimated stationary distributions of firms across countries

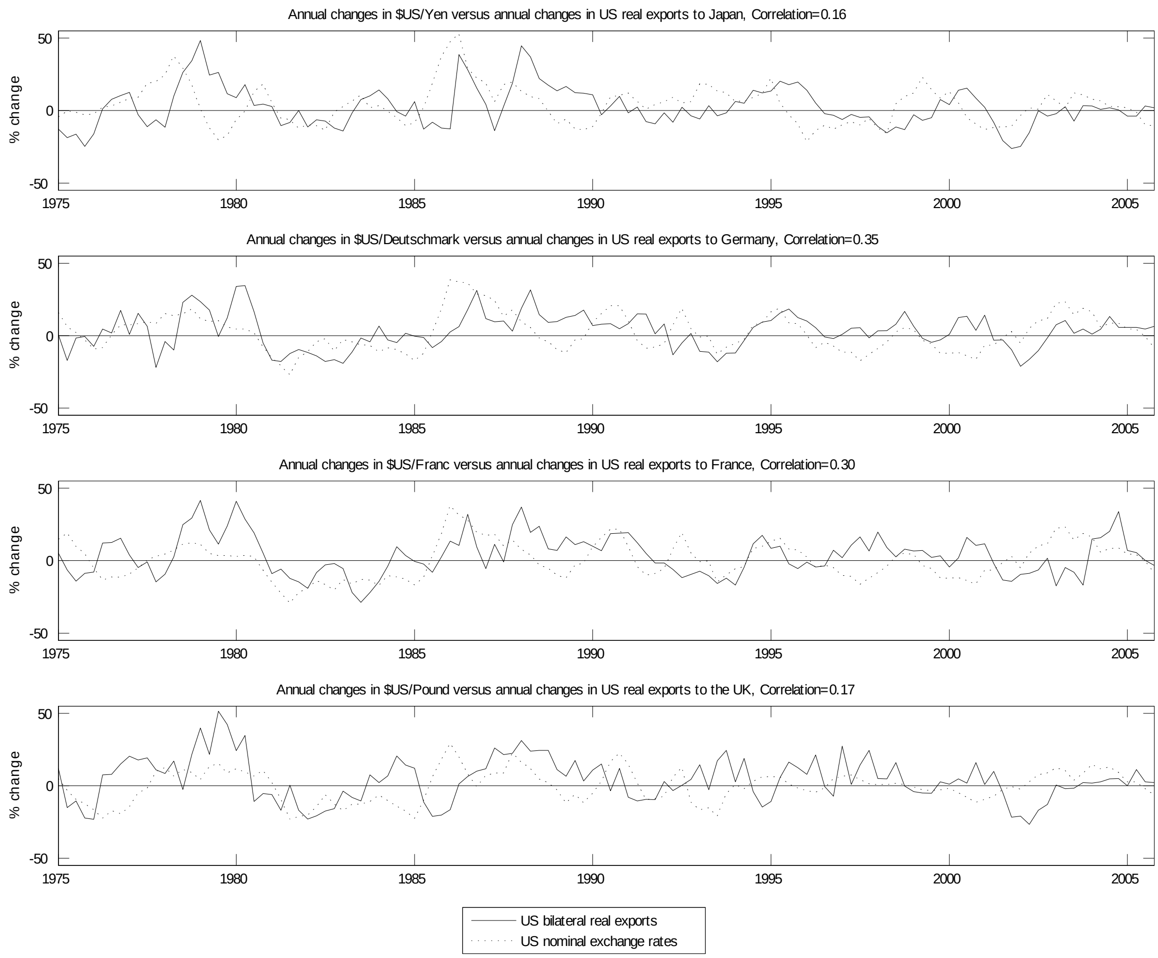

Figure 1.1: Annual changes in US nominal exchange rates versus annual changes in bilateral US real exports.

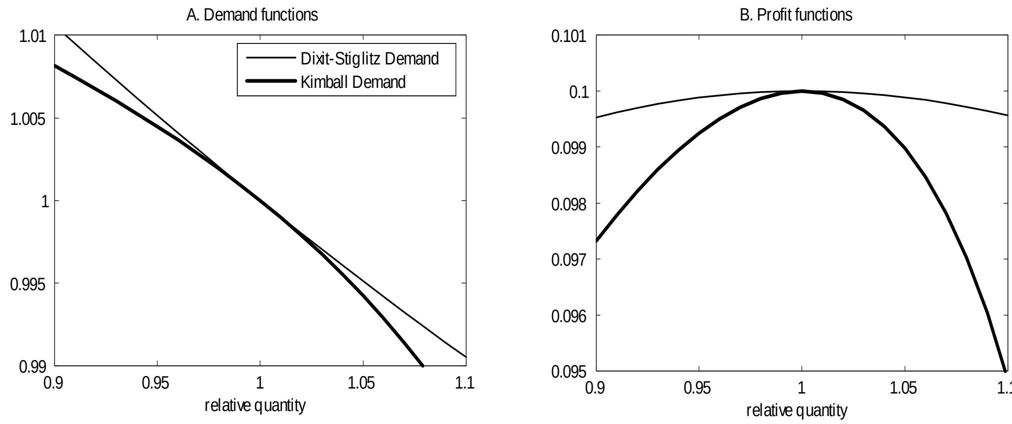

Figure 1.2: Dixit-Stiglitz and Kimball demand and profit functions

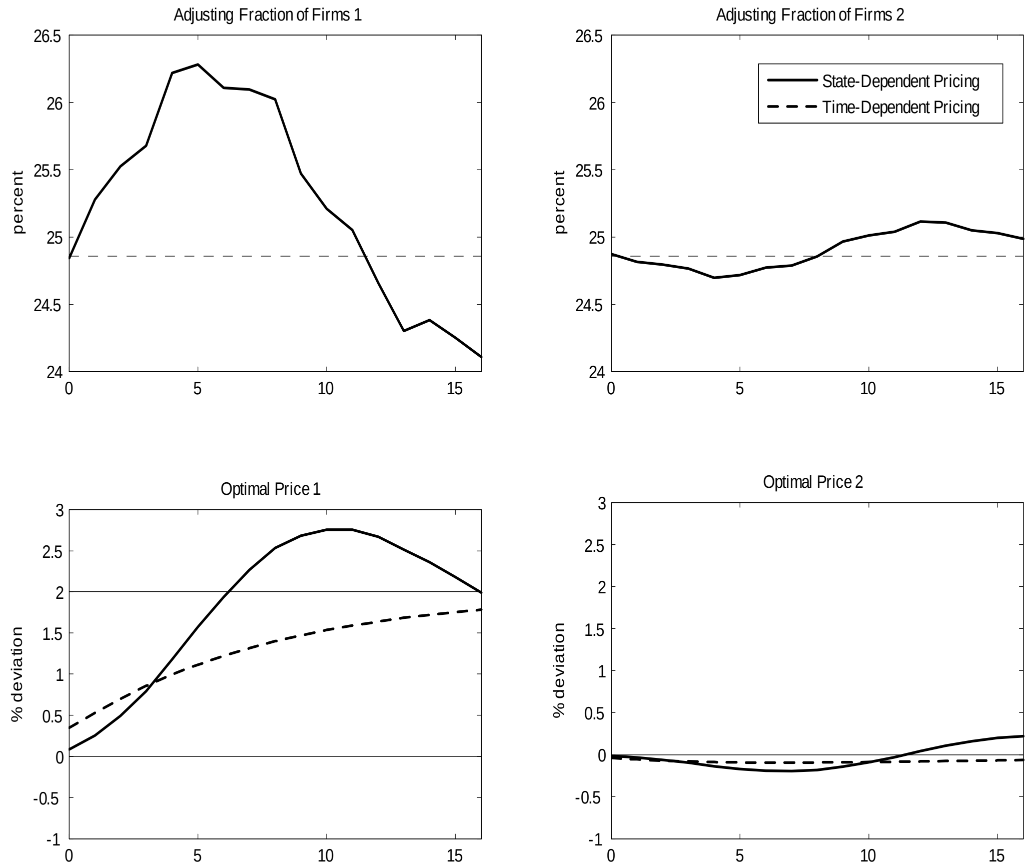

Figure 1.3: Firms' reaction

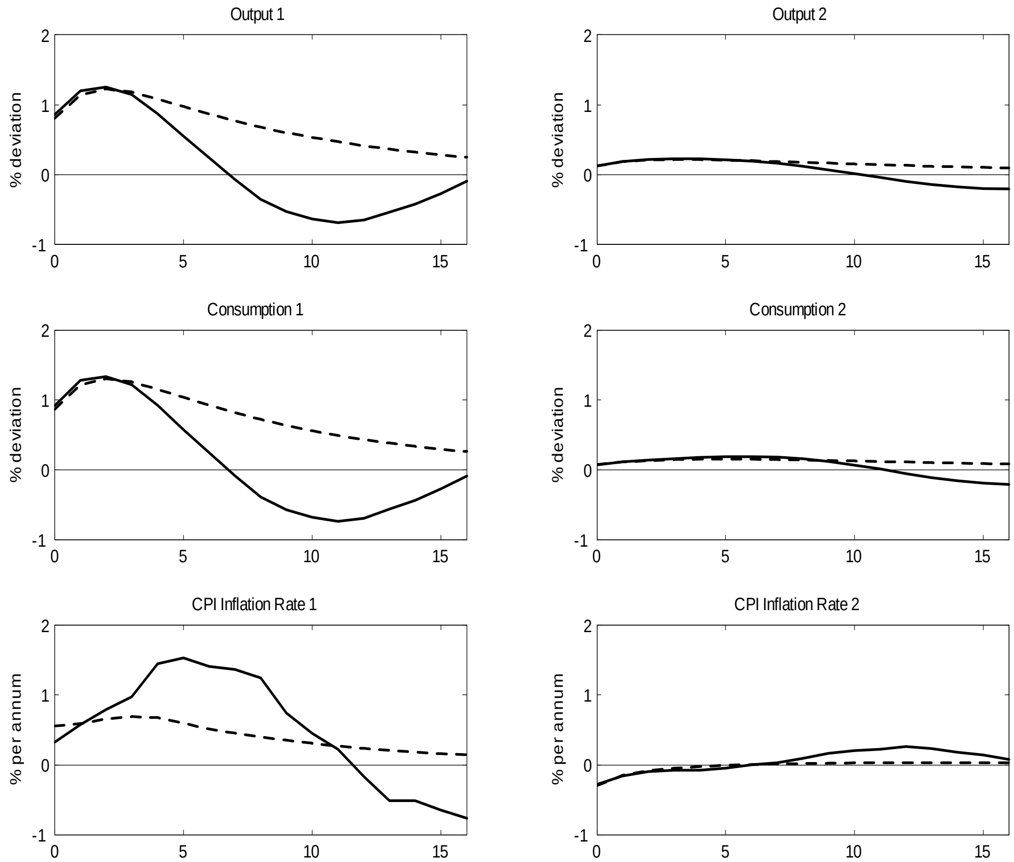

Figure 1.4: Output, consumption, and CPI inflation

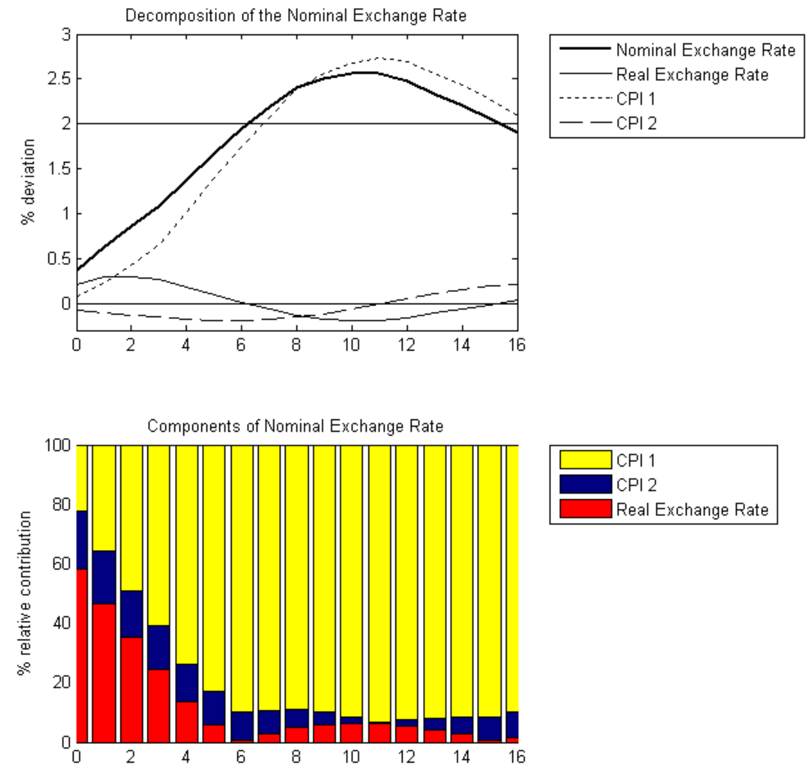

Figure 1.5: Nominal exchage rate decomposition

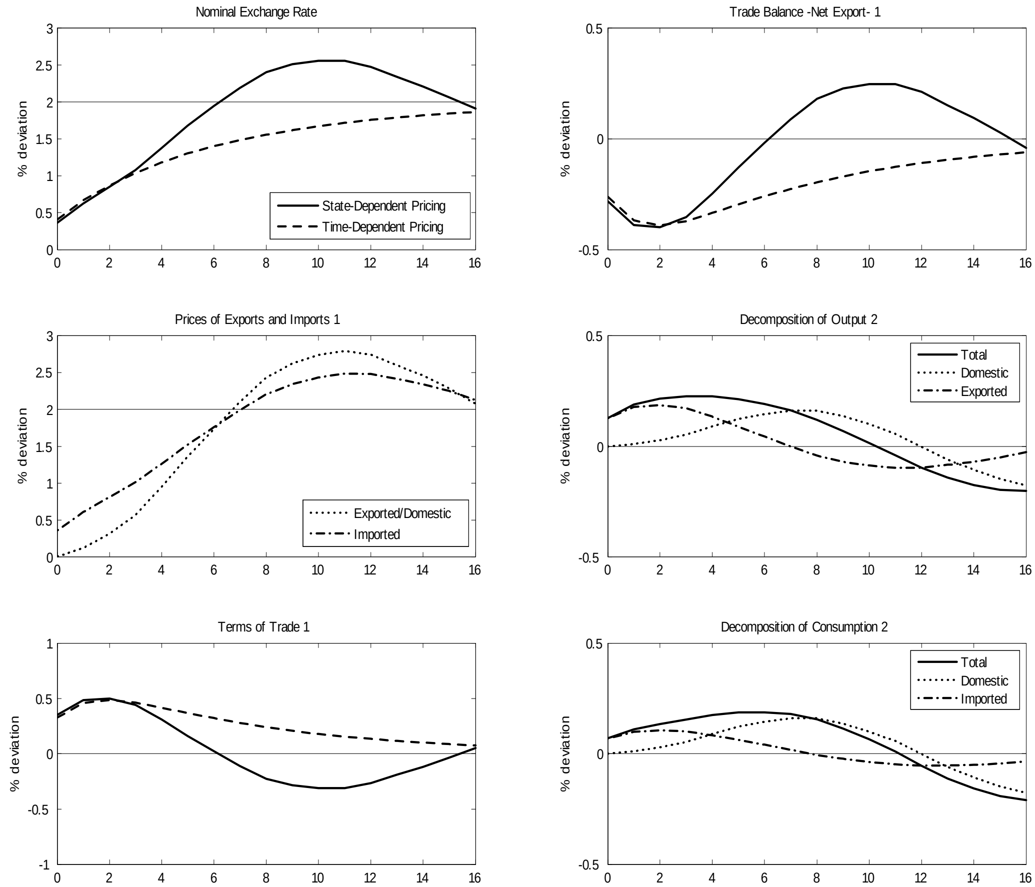

Figure 1.6: Nominal and real side of trade

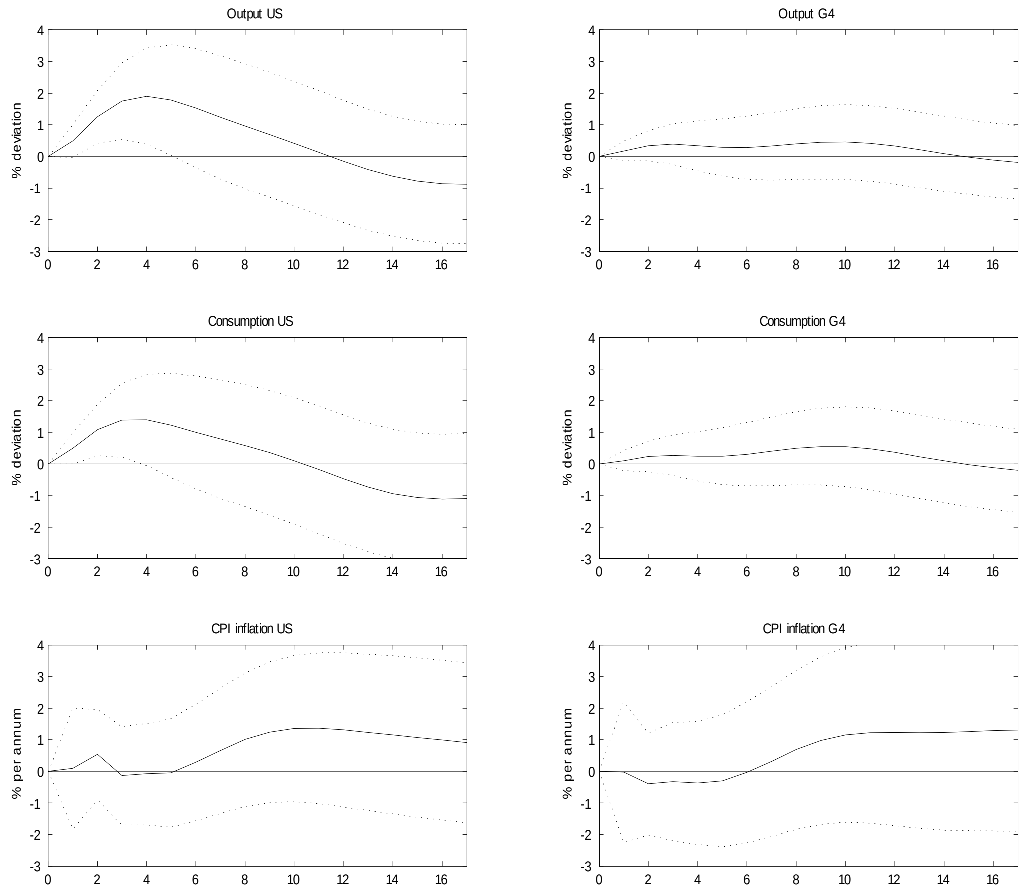

Figure 1.7: US and G4 domestic responses to a US monetary policy shock

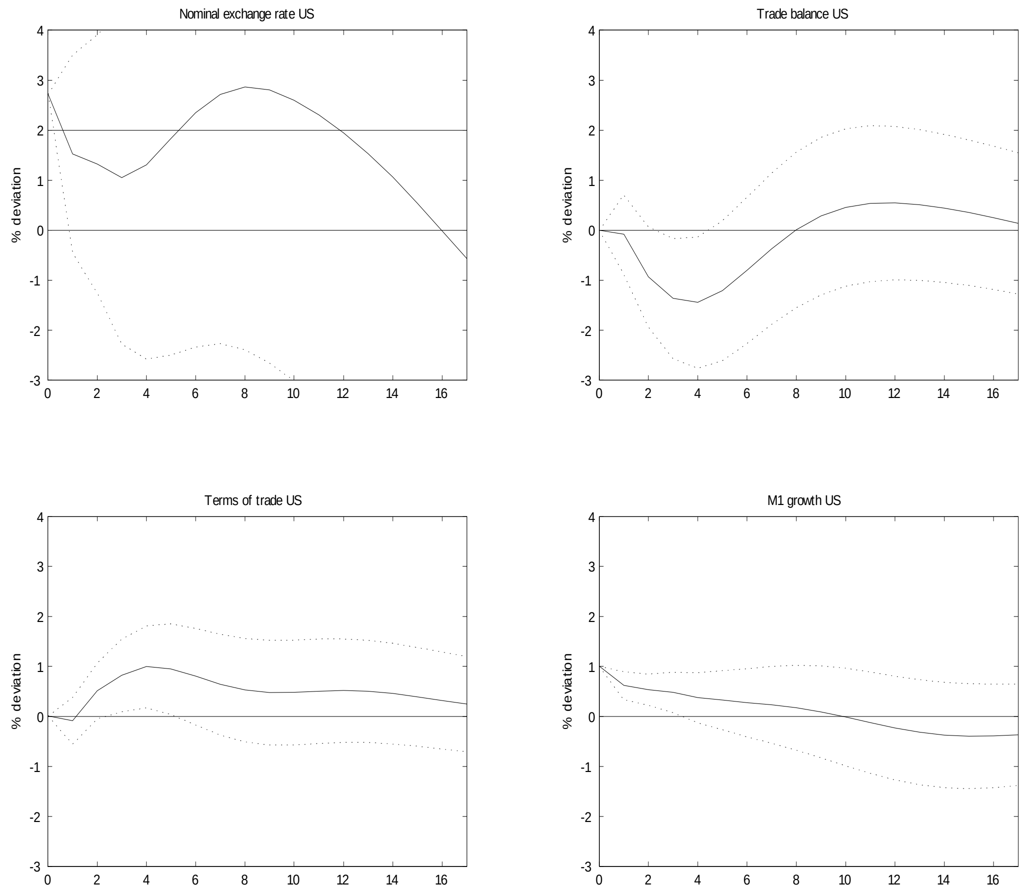

Figure 1.8: US international aggregates responses to a US monetary policy shock

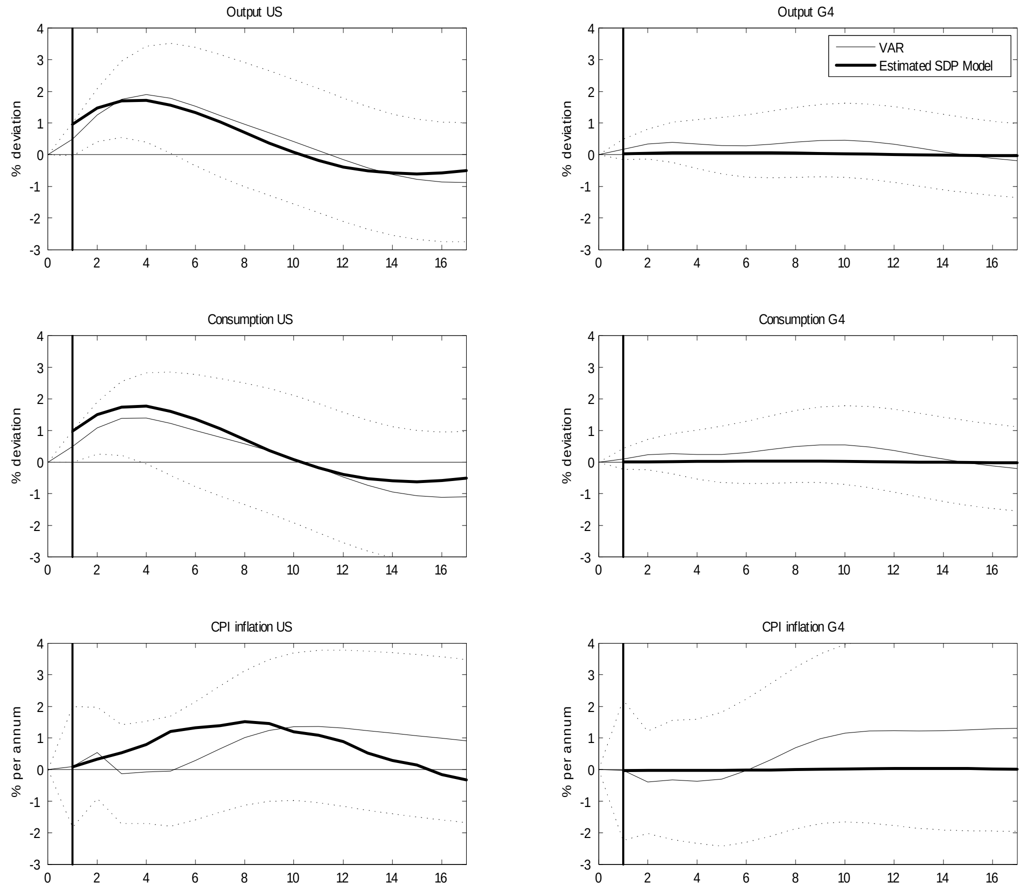

Figure 1.9: International VAR versus state-dependent pricing model

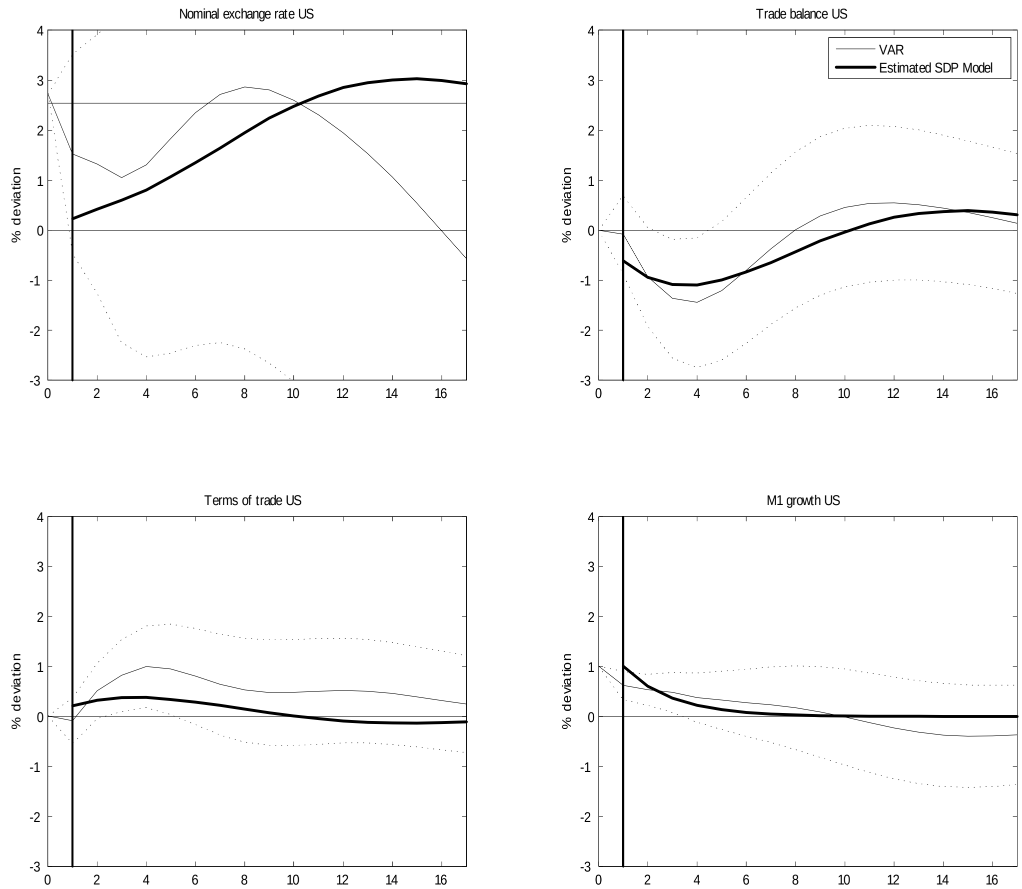

Figure 1.10: International VAR versus state-dependent pricing model