The Mundell-Fleming-Dornbusch Model in a New Bottle*

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Abstract

We introduce elements of state-dependent pricing and strategic complementarity within an otherwise standard "New Open Economy Macroeconomics" model, and develop its implications for the dynamics of real and nominal economic activity. Under a traditional Producer-Currency-Pricing environment, our framework replicates key international features following a domestic monetary shock. In contrast with its time-dependent counterpart, our approach delivers (i) a high international output correlation relative to consumption correlation, (ii) a delayed surge in inflation across countries, (iii) a delayed overshooting of exchange rates, and (iv) a J-curve dynamic in the domestic trade balance. Moreover, our model emphasizes the expenditure-switching effect as an important channel of monetary policy transmission, and consequently keeps the spirit of the Mundell-Fleming-Dornbusch model within the confines of the microfounded dynamic general equilibrium approach.

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1 Introduction

The Mundell-Fleming-Dornbusch (MFD) model remains the dominant paradigm for the analysis of international monetary policy issues. At its core is the intuitive notion that exchange rate changes redirect global expenditure through the price of imports. 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 really produced "an old wine in a new bottle"[1]: the canonical NOEM model has only a marginal expenditure-switching effect and has many other empirical predictions that differ sharply from both MFD model and the observed empirical evidence. Further, both 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, while optimizing price setters can only change the magnitude, but not the timing of adjustments in the NOEM literature.

We introduce elements of state-dependent pricing and strategic complementarity within an otherwise standard NOEM model, and develop its implications for the dynamics of real and nominal economic activity. In contrast with previous NOEM work, complementarity in the timing of price adjustment dramatically alters an open economy's response to monetary disturbances. Under a traditional Producer-Currency-Pricing (PCP) environment, our model delivers key international features following a domestic monetary shock: (i) a high international output correlation relative to consumption correlation, (ii) a delayed surge in inflation across countries, (iii) a delayed overshooting of exchange rates, and (iv) a J-curve dynamic in the domestic trade balance. Overall, our open economy macroeconomic model is therefore consistent with many aspects of international economic fluctuations, while at the same time sharing the central pricing elements of international trade that motivated the MFD approach. In parallel, our model emphasizes the expenditure-switching effect as an important channel of international monetary policy transmission and consequently keep the spirit of Mundell (1963), Fleming (1962), and Dornbusch (1976) within the confines of the microfounded dynamic general equilibrium approach[2].

The remainder of the paper is organized as follows. Section 2 describes the model. Section 3 discusses the model's solution and parametrization. Section 4 analyzes the endogenous evolution in the distribution of prices in response to a monetary shock, and describes the way this distribution influences international economic activity. It also contrasts 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. Section 5 concludes.

[1] As for the title, this expression was inspired from Phelps and Taylor (1977)'s reformulation of a Keynesian doctrine within a rational expectations framework.

[2] A longer version of this paper including the correlation moments, and model's extensions that allow for Pricing-to-Market/Local-Currency-Pricing environment, interest rate rules, and international financial market incompleteness is available upon request.

2 Structure of the Model

The NOEM builts small scale dynamic general equilibrium models for open economy macroeconomics and is the departure point of our work[3]. 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's 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 ones denotes the country of production and the country of consumption respectively, while the last subscript defines time.

2.1 The Households

Households are identical across countries except for a 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 ($1 - n$):

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

where β is the subjective discount factor and $u\left(c_t, n_t\right)$ is the momentary utility function with characteristics $u_c > 0$, $u_{cc} < 0$, $u_n > 0$, and $u_{nn} > 0$. 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 labour supply. More specifically, our momentary utility function, separable in consumption and leisure, has the following form, where σ represents the intertemporal elasticity of substitution and ϕ represents the elasticity of labour supply:

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

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's specific output movements affects 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 $(1 - o)$ of domestic goods, and the remaining o of foreign goods. This specification is consistent with the data since the ratios of import to GDP are relatively stable in the long-run. We let the parameter

[3] Famous examples include Betts and Devereux (2000), Chari, Kehoe, and McGrattan (2002), Kollmann (2001), Bergin and Feenstra (2001), and Obsfeld and Rogoff (1995, 2000).

o determines the degree of openness in the steady-state, and ι the elasticity of substitution between domestic and imported goods. The consumption indices for both countries are defined as:

$$
\begin{aligned}
c_{1,t} &= \left((1-o_1)^{\frac{1}{\iota}} c_{1,1,t}^{\frac{1-\iota}{\iota}} + o_1^{\frac{1}{\iota}} c_{2,1,t}^{\frac{1-\iota}{\iota}}\right)^{\frac{\iota}{1-\iota}} \\
c_{2,t} &= \left((1-o_2)^{\frac{1}{\iota}} c_{2,2,t}^{\frac{1-\iota}{\iota}} + o_2^{\frac{1}{\iota}} c_{1,2,t}^{\frac{1-\iota}{\iota}}\right)^{\frac{\iota}{1-\iota}}
\end{aligned}
\tag{3}
$$

In this context, the optimal allocations between domestic and imported consumption are represented by the following equations

$$
\begin{aligned}
c_{1,1,t} &= (1-o_1)\left(\frac{P_{1,t}}{I_{1,t}}\right)^{-\iota} c_{1,t} \qquad & c_{2,1,t} &= o_1\left(\frac{S_t P_{2,t}}{I_{1,t}}\right)^{-\iota} c_{1,t} \\
c_{2,2,t} &= (1-o_2)\left(\frac{P_{2,t}}{I_{2,t}}\right)^{-\iota} c_{2,t} \qquad & c_{1,2,t} &= o_2\left(\frac{P_{1,t}}{S_t I_{2,t}}\right)^{-\iota} c_{2,t}
\end{aligned}
\tag{4}
$$

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

Furthermore, 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 bond b and corresponding stochastic discount factor D, such that $E_t[D_{t+1}b_{t+1}] = \sum_{s_{t+1}} \rho(s_{t+1}) \cdot D(s_{t+1}|s_t)b(s_{t+1})$ where $\rho(s_t)$ denotes the probability of the state of nature s_t. The households also receive nominal wages W from labour services, and a series of dividend payments Z from firms. The sequence of intertemporal budget constraints can be represented in terms of aggregates as:

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

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 amount of consumption, labour, 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 $q_t = S_t \cdot (I_{2,t}/I_{1,t})$ 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 so that levels of consumption defined in (3) differ only to the extent that the real exchange rate deviates from its steady-state value[4]. Finally, the level of nominal aggregate demand is governed by a money demand relationship of the form $M_t/I_t = c_t$ along with country specific monetary policies.

2.2 Strategic Complementarity and Demand Functions

We introduce strategic complementarity among individual firms by allowing for variable demand elasticity through the curvature of demand curves. This approach is consistent with microeconomic evidence suggesting that competitors' actions play a central role in the behaviour of price adjustments[5]: when setting their prices, firms are influenced by other firms with which they must compete[6]. On theoretical grounds, this concept has been introduced by Stiglitz (1979), Ball and Romer (1990), and Kimball (1995), 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.

2.2.1 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:

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

where d represents country specific aggregate demand for goods which is implicitly defined by a demand aggregator Γ such that an aggregate producer price index 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 η and γ which govern the curvature of the demand

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

[5] 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.

[6] The literature typically assume that firms faced 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).

function[7] (derivation of the following equations are provided in Appendix A):

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

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 fuction of individual and aggregate prices:

$$\frac{d_t\left(z\right)}{d_t}=\frac{d_t\left(z\right)}{d_t}\left(\frac{P_t(z)}{P_t},\eta,\gamma\right) \tag{9}$$

2.2.2 Price Indices

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

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

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

$$\begin{aligned} I_{1,t} &= \left(\left(1-o_1\right)P_{1,t}^{1-\iota}+o_1\left(S_tP_{2,t}\right)^{1-\iota}\right)^{\frac{1}{1-\iota}} \\ I_{2,t} &= \left(\left(1-o_2\right)P_{2,t}^{1-\iota}+o_2\left(P_{1,t}/S_t\right)^{1-\iota}\right)^{\frac{1}{1-\iota}} \end{aligned} \tag{11}$$

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.

2.3 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 $P_t(z)$, 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 $G(\xi)$ 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 P_t^*. 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 a finite fractions of firms sharing a common price in each country denoted by J_1 and J_2 and defined as vintages.

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

2.3.1 Production and Demand

In this environment, labor used for price adjustment is denoted $n^a(z)$ and labor used for production is denoted $n^y(z)$ such that $n^a(z) + n^y(z) = n(z)$. Technology is linear in labour, and firms are subject to a common country specific stochastic total productivity factor 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

$$\begin{aligned} d_{1,t} &= (1-o_1)\left(\frac{P_{1,t}}{I_{1,t}}\right)^{-\iota} c_{1,t} + o_2\left(\frac{P_{1,t}}{S_t I_{2,t}}\right)^{-\iota} c_{2,t} \\ d_{2,t} &= (1-o_2)\left(\frac{P_{2,t}}{I_{2,t}}\right)^{-\iota} c_{2,t} + o_1\left(\frac{S_t P_{2,t}}{I_{1,t}}\right)^{-\iota} c_{1,t} \end{aligned} \tag{12}$$

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

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

Equations (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.

2.3.2 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 relative to domestic CPI $i(z) = P(z)/I$ which is the appropriate price in the firm's decision making, 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:

$$v\left(i_{jt}, \xi_t | s_t\right) = \max \left\{ \begin{array}{c} v_{jt} = \pi\left(i_{jt}|s_t\right) + \beta E_t \Lambda_{t,t+1} v\left(i_{j+1,t+1}, \xi_{t+1}|s_{t+1}\right) \\ v_{0t} = \max_{i_t^*} \pi\left(i_t^*|s_t\right) + \beta E_t \Lambda_{t,t+1} v\left(i_{t+1}^*, \xi_{t+1}|s_{t+1}\right) - w_t \xi_t \end{array} \right\} \tag{14}$$

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

$$\pi\left(i_{jt}|s_t\right) = \left(i_{jt} - \psi_t\right) \cdot y_{jt} \tag{15}$$

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

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

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 a prices that satisfy

$$0 = \frac{\partial \pi\left(i_t^*, s_t\right)}{\partial i_t^*} + \beta E_t\left[\Lambda_{t,t+1} \cdot \frac{\partial v\left(i_t^*, \xi_{t+1}, s_{t+1}\right)}{\partial i_t^*}\right]. \tag{17}$$

Iterating the Euler equation (17) forward, the country specific firm optimal prices can be expressed as an explicit function of current and expected future variables:

$$P_{1,t}^* = \frac{\sum_{j=0}^{J1-1} \beta^j E_t\left[\Omega_{1,j,t,t+j} \cdot \Lambda_{1,t,t+j} \cdot \epsilon_{1,j,t+j} \cdot \psi_{1,t+j} \cdot P_{1,t+j} \cdot d_{1,j,t+j}\right]}{\sum_{j=0}^{J1-1} \beta^j E_t\left[\Omega_{1,j,t,t+j} \cdot \Lambda_{1,t,t+j} \cdot (\epsilon_{1,j,t+j} - 1) \cdot P_{1,t+j}/I_{1,t+j} \cdot d_{1,j,t+j}\right]}$$

$$P_{2,t}^* = \frac{\sum_{j=0}^{J2-1} \beta^j E_t\left[\Omega_{2,j,t,t+j} \cdot \Lambda_{2,t,t+j} \cdot \epsilon_{2,j,t+j} \cdot \psi_{2,t+j} \cdot P_{2,t+j} \cdot d_{2,j,t+j}\right]}{\sum_{j=0}^{J2-1} \beta^j E_t\left[\Omega_{2,j,t,t+j} \cdot \Lambda_{2,t,t+j} \cdot (\epsilon_{2,j,t+j} - 1) \cdot P_{2,t+j}/I_{2,t+j} \cdot d_{2,j,t+j}\right]} \tag{18}$$

where $\Omega_{j,t,t+j}$ represents the probability of non-adjustment from t to $t+j$[8], 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. They also represent an open economy version of the state-dependent pricing rules of Dotsey, King, and Wolman (1999), and Dotsey and King (2005), in which 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 include global consumption, domestic and foreign CPIs, domestic PPIs, and the nominal exchange rate). In this environment, firms are forward looking when choosing an

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

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 and depend on the state of the economy such that the pricesetting 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 pricesetting firms expect future adjustment probabilities to be high, they will weight more heavily their current beliefs of global economic conditions.

2.4 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 (country's specific money supply process), and Θ represent 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 $y_{1,t}(z), n_{1,t}(z), P_{1,t}(z)$ and $y_{2,t}(z), n_{2,t}(z), P_{2,t}(z)$, and a collection of prices $P_{1,t}, I_{1,t}, W_{1,t}, D_{1,t+1}$ and $P_{2,t}, I_{2,t}, W_{2,t}, D_{2,t+1}$ 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.

3 Solution and Parametrization

We use numerical methods to solve the model and quantitatively evaluate 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[9]. 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

[9] In the case of PCP, each country is isolated from its trading partner level of inflation by the nominal exchange rate in the steady-state. 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).

compute the resulting linear rational expectations equilibrium using an algorithm developed by King and Watson (1998).

3.1 Benchmark Parametrization

Parameter values governing:		**Country 1**	**Country 2**
Preferences			
β	Discount rate	0.99	0.99
σ	Intertemporal elasticity of substitution	0.25	0.25
ϕ	Elasticity of labour 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	0.91	0.09
o	Degree of openness	0.035	0.35
ι	Elasticity of substitution - Country	1	1
Monetary policies			
μ	Steady-state money growth rate	0.04	0.04
ρ	Autocorrelation of the money growth process	0.50	0.50

Table I: Benchmark Parametrization

The benchmark model is composed of two countries. Without lost of generality, we choose to replicate some key features of two economies that form an almost closed system, and share similar economic structures and levels of technology. The first feature is essential from the description of the model, while the second feature is primary chosen because of the nature of the paper which emphasizes the effects of money on international comovements. With more than 80 percents of Canada's exports entering the United States, the trade relationship between Canada and the United States forms the benchmark parametrization of our model[10].

The benchmark parametrization is presented in Table I. We use parameter values generally accepted in the macroeconomic and open economy literature. The time frequency of the model corresponds to a quarter of a year. The subjective discount factor β implies an annual real rate of return 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 parameter governing the degree of risk aversion σ to 0.25, and the parameter governing the elasticity of labour supply ϕ to 0.05. Those parameters

[10] Altering country sizes and other reasonable parameter values do not change the general results.

generates an elasticity of marginal cost of approximately 0.3[11]. Agents work 20 percent of their time endowment. Country 2 (Canada) is characterized by a degree of openness o of 35%, and represents 1/11 of the world's labour force. The former correspond roughly to the share of imports to GDP in Canada, while the latter corresponds to the ratio of Canada to U.S. GDP[12]. We set the elasticity of substitution between domestic and imported consumption goods ι to unity. Bergin (2004) offers empirical evidence from macro-level data which supports this common practice in the literature. Finally, we assume that the two countries share similar levels of productivity by setting a to 1.

3.2 Monetary Policies

The monetary policy rules are specified as exogenous money supply rules[13]. More specifically, the nominal money supply growth follows an autoregressive process in both countries

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

where ε_t are normally distributed zero-mean disturbances. Previous researchers, such as Grilli and Roubini (1995), evoke the possibility of policy endogeneity across countries. However, recent research, including Kim (2001) and Bergin and Jordā (2002), found no substantial endogenous reactions by OECD monetary authorities from U.S. monetary shocks. For our benchmark economy, we follow the latter, and assume that monetary policy shocks are not correlated across economies. Finally, we set the steady-state money growth rate to 4 percent, and the autoregressive coefficient on the money growth rate ρ to 0.5 in each country.

3.3 Demand Structure and Adjustment Costs

The variable elasticity demand curve is parametrized by choosing a value of η so that demand curves have an elasticity of 10 at $d(z)/d = 1$. Restricting γ to take a value of 1.02 implies that a 1.5 percent increase in price decreases demand by 20 percent, which is somewhere between what is assumed by Kimball (1995), and Bergin and Feenstra (2001)[14].

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[11] Given that the households efficiency condition is $w_t = c_t^{\sigma} n_t^{\phi}$, and that consumption and labor are approximately equal to output, the elasticity of marginal cost is approximately equal to $\sigma + \phi$.

[12] Identical solutions were given by the model's simulation using different aggregation approaches. In the first case, which is what is reported here, we aggregate country sizes by their labour force. That is, we kept the number of firms identical in each country and normalize individual firm's output. In the second case, we aggregate country sizes by their relative number of firms consistent with their given labour force. Identical solutions are consistent with the way we modeled the supply side.

[13] This choice is arbitrary but consistent with recent reseach in open economy macroeconomics. The model can easily accomodates other monetary policy rules, such as interest rate rules.

[14] Dotsey and King (2005) contrast the marginal revenue, elasticity and profit implications of the variable elasticity of demand curve used in this paper to a constant "Dixit and Stiglitz" elasticity of demand curve.

		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 II: Stationary distribution of firms across countries

The remaining parameters involve the distributions of adjustment cost which, alongside the demand functions, determine the timing and distribution of prices. Table II displays the steady-state fractions of price adjusting firms as well as the population density associated with the parametrized model for both countries[15]. The chosen adjustment cost 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)[16]. It implies an average age of prices of 1.72 quarters, and an expected price duration of 4 quarters under the steady-state inflation rate of 4 percent. Together, the demand and adjustment cost specifications provide a good approximation of the main features governing the pattern of price adjustments and pricing policies observed in OECD economies.

4 International Dynamics

In this section, we analyze the model 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 on impact by 1 percent and then gradually increases to 2 percent above its initial value. The following figures display the impulse response of microeconomic and macroeconomic aggregates over an horizon of 20 quarters. The solid lines represent our state-dependent version of the model, while the dashed lines represent the corresponding time-dependent model. The time-dependent model is calibrated so that the fractions of price adjusting firms is 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.

4.1 Firms' Reactions to a Monetary Shock

4.1.1 Firms'Adjusting Fractions

Figure 1 displays firms' reactions following the monetary shock. A novel feature of the state-dependent pricing open economy model is the evolving distribution of price

[15] Choice of the adjustment cost parameters are detailed in Appendix B.

[16] In the steady state $\log P_t^* - \log P_{t-j}^* = j \cdot \log \pi$.

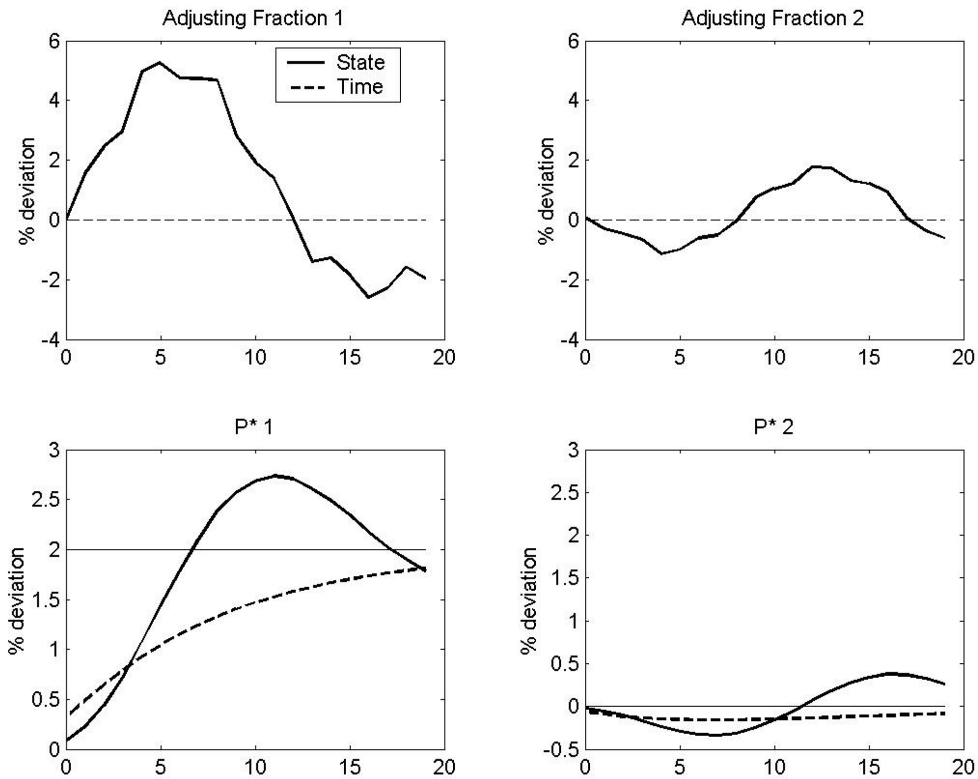

Figure 1: Firms' Reactions

adjusting firms across countries. Looking at the top row of the figure, we observe that Country 1 experiences an increasing number of price adjusting firms: raising product demand increases the value of price adjusting firms, and consequently induces a larger fraction of firms to reset their prices. In contrast, Country 2 experiences a decreasing number of price adjusting firms: 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 are relatively smooth: the introduction of variable elasticity demand curves within a state-dependent pricing framework does not allow for immediate deviations in the fractions of price adjusting firms[17]. Initially, the monetary shock translates very little to prices because firms are not willing to price differently from one another. However, over time, rising movements

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

in price levels enforce the extent of adjustment of individual firms and consequently result into increasing movements 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, movements in aggregate prices are relatively slow and therefore much closer to the MFD pricing framework.

4.1.2 Firms' Optimal Prices

Associated with movements in adjusting fractions are the optimal prices depicted in the bottom row of Figure 1. In contrast to its time-dependent counterpart, optimal prices in a state-dependent environment react very weakly to the monetary shock: the initial price responses are almost absent. On the one hand, the forward looking pricesetting 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 losing 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 the inability to reset prices in their pricing policy.

Although the initial response of optimal prices charged by individual firms are relatively small, the strategic interaction among firms that follows the monetary shock generates greater delayed movements in them. In particular, we observe an overshooting of optimal prices in Country 1 peaking almost 11 quarters after the shock: the larger fraction of price adjusting firms increases aggregate prices and consequently generates upward movements in optimal prices. This overshooting result is also absent in the time-dependent model counterpart. In Country 2, the optimal price oscillates around its long-run value: at first, the optimal price decreases as the country faces a lower demand for its products. However, as domestic demand increases, the optimal price surges to positive territory.

4.2 Aggregate Implications of a Monetary Shock

4.2.1 Output, Consumption, and Inflation Dynamics

We now turn to the aggregate implications of our model. Figure 2 displays the responses of output and consumption, and shows CPI inflation rates. First, the domestic monetary shock generates a positive hump-shaped responses in output and consumption across countries. In Country 1, the maximum output and consumption responses arise contemporaneously after 3 quarters. In Country 2, output responds first and peaks after 4 quarters, while the peak response of consumption is delayed to the 7th quarter. The dynamics of output and consumption in Country 2 arises as follows: output responds to an increase in exports demand followed by an increase

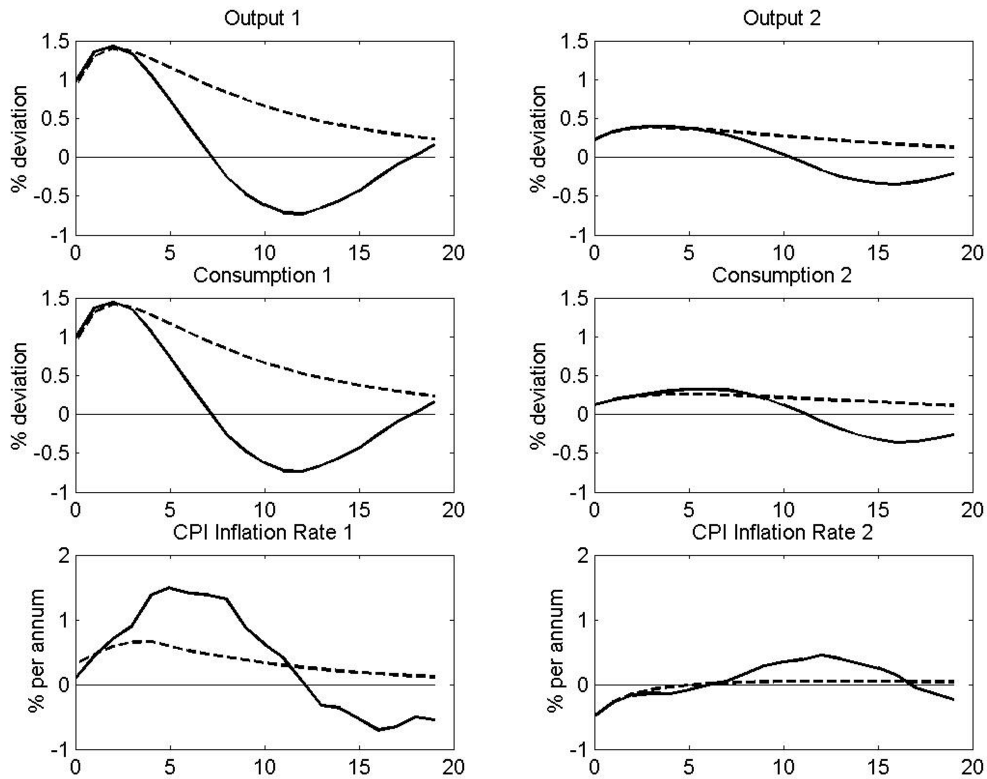

Figure 2: Output, Consumption, and CPI Inflation

in domestic demand, while consumption rises later as CPI attains a through. We explore in further detail the components of foreign output and consumption below.

In relation to Figure 2, we reproduce the observed high international output correlation relative to consumption correlation documented by Backus, Kehoe, and Kydland (1995), and Baxter (1995). Using a Hodrick-Prescott filter, the model generates a cross-correlation of output of 0.62 in contrast to a cross-correlation of consumption of 0.38 which is perfectly in line with the data (vs 0.97 and 0.91 for the time-dependent counterpart). This result is impressive given that the model does not rely on international market segmentation: the simple introduction of strategic complementarity into an otherwise state-dependent pricing framework generates the desired outcome[18].

[18] 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

Output and consumption aggregates in both economies also display oscillating cycles associated with movements in aggregate prices. The stimulation of economic activity lasts roughly 8 and 12 quarters in the domestic and foreign economies respectively, followed by a period of real contractions. Altogether, the output and consumption aggregates return to their pre-shock level in both countries after roughly four years. Although this real contraction in economic activity lasts for a substantial amount of time, it does not undo the initial stimulation generated by the monetary expansion in either countries. Interestingly, similar oscillating dynamics have been observed by Christiano, Eichembaum, and Evans (2005) in VAR-based impulse responses following a monetary shock in a closed economy setting.

Those fluctuations in real economic activity are induced by corresponding movements in price indices. An important strength of our model is its ability to generates the relationship between CPI inflation and lagged output observed in the data. In the bottom row of Figure 2, CPI inflation peaks 6 quarters after the monetary shock in Country 1, and surges slowly to peaks after 13 quarters in Country 2. This delayed response of CPI inflation rates observed in our model is 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 higher rate during high inflation periods.

4.2.2 Delayed Overshooting of the Nominal Exchange Rate and Trade

Figure 3 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. First, the monetary shock induces a significant and persistent depreciation in the nominal exchange rate, and displays the delayed overshooting effect stresses by Eichembaum and Evans (1995) empirical study on the effects of U.S. monetary policy shocks on exchange rates. The variations in the nominal exchange rate quickly become primarily driven by the CPI price ratio of both countries and more specifically the corresponding movements in optimal prices set by firms in Country 1.

Second, our model emphasizes the expenditure-switching effect as an important channel of international adjustment, and is at the heart of the transmission of monetary policy shocks across economies. From the perspective of Country 1, movements related to trade can be explained by looking at the trade balance. Following a monetary shock, the trade balance displays a J-curve dynamics: it worsens within a year, then starts to improve and becomes positive after 6 quarters. The trade improvement is quite persistent, peaking 3 years after the shock before returning to its long-run

correlation moments. Instead, Chari, Kehoe, and McGrattan (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.

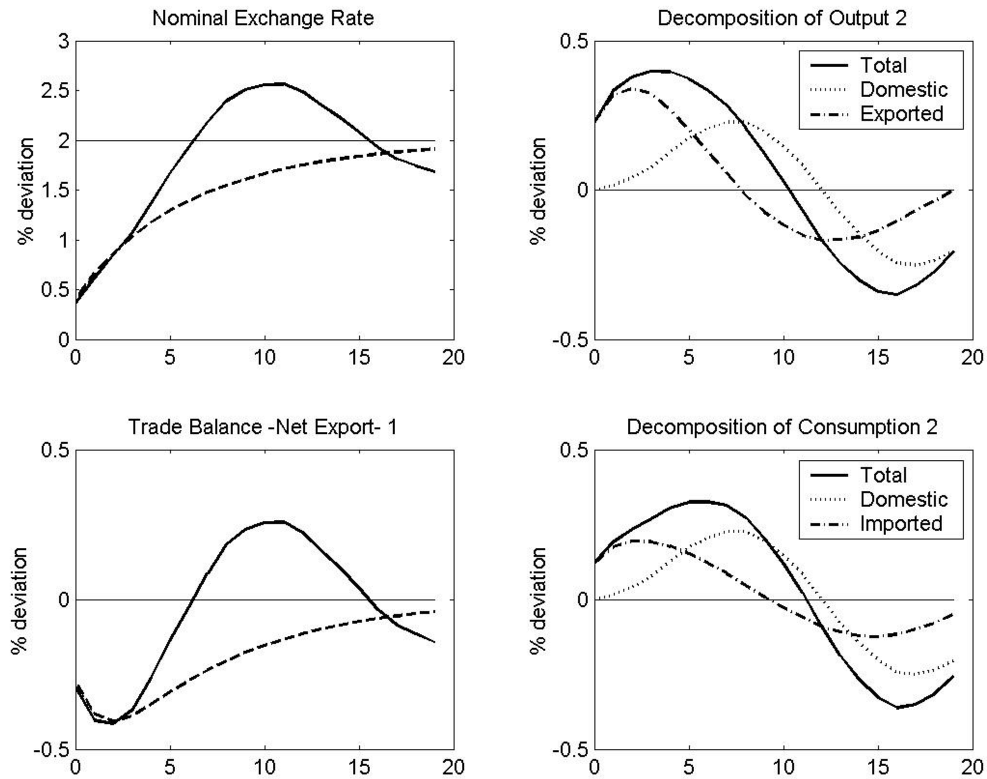

Figure 3: Nominal Exchange Rate and Trade

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-absortion effect. However, the smooth depreciation of the nominal exchange rate feeds into 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[19]. In particular, the expenditure-switching effect corresponds to the overshooting response of the nominal exchange rate: goods produce in Country 1 becomes relatively competitive on the global market.

From the perspective of Country 2, real economic activity and trade dynamics are better understood by undertaking a decomposition of output and consumption into their domestic and foreign components. The expansion of output falls in two phases: initially, rising exports demand (which is associated with the income-absortion effect

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

present in Country 1) launches output, then the accumulation of wealth in Country 2 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[20], and leads to declining producer prices which further propel the consumption boom.

5 Conclusion

Overall, we demonstrated that incorporating elements of state-dependent pricing and strategic complementarity within a standard NOEM model generates key international comovements following a monetary shock. Moreover, by building on a traditional PCP environment, our approach highlights the expenditure-switching effect as an important channel of international monetary policy transmission. Consequently, by including those elements to a NOEM framework, we put and keep the spirit of the Mundell-Fleming-Dornbusch model in a new microfounded bottle.

By generating plausible movements in real and nominal economic activity, our model offers a framework in which policy makers can analyze the economic implications of monetary shocks in an open economy setting. Further theoretical and empirical investigations will guide us toward a better understanding of the sources and dynamics of international economic activity.

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6 Appendices

6.1 Appendix A: Demand Aggregators

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

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

The country specific aggregate demand for goods d are implicitly defined by a demand aggregator Γ such that an aggregate producer price index P holds for each country. For an individual country, the producer prices index is defined as

$$\int_0^1 \left(\frac{P\left(z\right)}{P}\right)\left(\frac{d\left(z\right)}{d}\right)dz = 1 \tag{AA.2}$$

The first order condition of the expenditure minimization problem yields:

$$P\left(z\right) = Z \cdot \Gamma'\left(\frac{d\left(z\right)}{d}\right) \tag{AA.3}$$

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

$$\left(\frac{d\left(z\right)}{d}\right) = \Gamma'^{-1}\left(\frac{P\left(z\right)}{Z}\right) \tag{AA.4}$$

Given the demand curve and the multiplier, the aggregate producer price indices are determined by

$$\int_0^1 \left(\frac{P\left(z\right)}{P}\right)\left(\frac{d\left(z\right)}{d}\right)dz = 1 \tag{AA.5}$$

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

$$\frac{d\left(z\right)}{d} = \frac{1}{1-\eta}\left[\left(\left(\frac{P\left(z\right)}{P}\right)\left(\frac{P}{Z}\right)\right)^{\frac{1}{\gamma-1}} + \eta\right] \tag{AA.6}$$

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