Into the Mussa Puzzle: Monetary Policy Regimes and the Real Exchange Rate in a Small Open Economy*

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Abstract

Industrial countries moving from fixed to floating exchange rate regimes experience dramatic rises in the variability of the real exchange rate. This evidence, forcefully documented by Mussa (1986), is a puzzle because it is hard to reconcile with the assumption of flexible prices. This paper lays out a dynamic general equilibrium model of a small open economy that combines nominal price rigidity with a systematic behavior of monetary policy able to approximate a continuum of exchange rate regimes. A version of the model with complete exchange rate pass-through is broadly consistent with Mussa's findings. Most importantly, this holds independently of the underlying source of fluctuations in the economy, stressing the role of the nominal exchange rate regime per se in affecting the variability of the real exchange rate. However, only a model featuring incomplete exchange rate pass-through can account for a broader range of exchange rate statistics. Finally there exist ranges of values for either the degree of openness or the elasticity of substitution between domestic and foreign goods for which the baseline model is also consistent with the empirical insensitivity of output volatility to the type of exchange rate regime, as documented by Baxter and Stockman (1989).

Keywords: exchange rate regime, real exchange rate, sticky prices, endogenous monetary policy.

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1 Introduction

For a long time, economists have debated about whether fluctuations in the exchange rates reflect mere changes in relative money prices, as opposed to changes in the relative prices of goods or inputs. In a very influential paper, Mussa forcefully documents two facts:[1] i) Nominal and real exchange rates are strongly correlated; ii) Industrial countries moving from fixed to floating exchange rate regimes experience dramatic rises in the variability of the real exchange rate. In *Figure 1*, the German Mark-U.S. Dollar nominal and real exchange rates (*top panel*), the short-run variations of the real exchange rate (*medium*) and of its components (*bottom*) are plotted. The evidence is striking. Nominal and real exchange rate are almost perfectly correlated. A sharp increase in volatility stands out in the post-Bretton-Woods era for both the real and the nominal exchange rate, as opposed to a noticeably constant variability of the price level ratio. The decomposition of the real exchange rate into nominal depreciation rate and inflation differential shows a very weak correlation between these two components. *Table 1* reports exchange rates statistics for several OECD countries. The volatility of the real depreciation rate is on average more than four times higher under floating than under fixed rates. The correlation between nominal and real exchange rate under floating is close to unity. Overall, the movements of the nominal exchange rate seem to play a dominant role in shaping the short-run variations of the real exchange rate. According to Mussa, these regularities systematically apply to every postwar exchange rate regime shift undertaken by an industrial country.

At this point, it might seem that little room remains to argue that the exchange rates are a purely nominal phenomenon. Why, then, has this evidence often been treated as a puzzle? In principle the high correlation between nominal and real exchange rates may be rationalized in economies with perfectly flexible prices and a high incidence of real shocks, i.e., shocks originating in the goods market that require adjustments of the relative prices.[2] Yet this would not explain why the volatility of the real exchange rate systematically starts to increase upon switching from a regime of fixed to one of floating rates. It could also be argued that the choice of the exchange rate regime is endogenous, and that it is indeed those countries experiencing large real shocks that choose to switch to floating exchange rates.[3] The evidence on the change in volatility, however, is so overwhelming and extended over time that this does not seem a plausible explanation.[4] Nor

[1] Mussa (1986). We will refer to these as the "Mussa facts" throughout the paper.

[2] This is the theory postulated by Stockman in several papers. See Stockman (1983) and (1988). According to this view real (e.g., preference) shocks affect the marginal rate of substitution between home and foreign goods and in turn the real and the nominal exchange rate. Therefore the feedback should work from the real to the nominal exchange rate whereas the opposite would be true in sticky-price models.

[3] This would be consistent with the traditional normative view (built on the Mundell-Fleming model) prescribing fixed exchange rates when monetary shocks are prevalent, and floating exchange rates when real shocks dominate.

[4] The example of Ireland is often reported as an argument against the endogeneity view (see Krugman (1989), Obstfeld (1997)). Before Ireland joined the EMS, its real exchange rate was much more closely correlated with that

can the whole set of facts be rationalized in international real business cycle models, like the ones pioneered by the work of Backus, Kehoe and Kydland (1994), in which a switch in the exchange rate regime is simply not addressable.

The last two columns of Table 1 report two additional exchange rates facts that are worth emphasizing. For one, the variability of the real always exceeds the one of the nominal depreciation rate. Furthermore, nominal depreciation rates and inflation differentials display a negligible correlation. There is in fact a large empirical evidence documenting that the pass-through of exchange rates to prices is low, a symptom of the failure of the law of one price (LOP) at the level of individual goods. Campa and Goldberg (2001) document that such deviations from LOP are larger for consumer than for import goods. Ghosh and Wolf (1994) provide evidence that incomplete pass-through may be the result of stickiness in the adjustment of import prices expressed in units of local currency.

In Table 1 the sharp rise in volatility of the real exchange under floating stands in stark contrast with the apparent insensitivity of real output volatility to the change in the exchange rate regime. While on average output is under floating barely as volatile as under fixed rates, the real exchange rate is more than four times as variable under floating relative to fixed. This is consistent with the well-known evidence first reported in Baxter and Stockman (1989), who show that the business cycle properties of a broad range of real macroeconomic variables is independent of the underlying exchange rate regime.[5]

Along with the already described "Mussa facts", this further evidence constitutes the empirical motivation of this work. I lay out a dynamic general equilibrium model of a small open economy characterized by two main features. The first one is a certain rigidity in the adjustment of prices, in accordance with Figure 1. The second one is the commitment to (monetary) policies consistent with the maintenance of managed-fixed nominal exchange rates. This systematic component in policy stands in contrast with the supposed role of stochastic (real) shocks in explaining the change in variability of the real exchange rate after a switch in regime. The baseline version of the model assumes complete pass-through of exchange rate movements to prices.

The key insight of the paper is twofold. First, the baseline sticky-price model with complete pass-through accords well with the Mussa facts reported in Table 1. More importantly, this holds *independently* of the underlying source of fluctuations, casting doubts on the theory that stresses the prominent role of real shocks. However, it is only a model featuring incomplete exchange rate pass-through that is able to fully account for all the exchange rate facts documented above. Namely, the "Mussa facts", the observed ranking between real and nominal exchange rate variability, and the weak correlation between nominal depreciation and inflation differentials. Furthermore, the

of the UK than with that of Germany, but after joining the EMS the rank in the correlation reversed. This is a clear example of an exogenous change in the *nominal* regime affecting the dynamic properties of the real exchange rate.

[5]See Duarte (2001), Dedola and Leduc (2001) and Devereux and Engel (2002) for recent papers on this issue.

baseline model performs well in reproducing the Baxter and Stockman evidence on the insensitivity of output volatility to the shift in exchange rate regime. However this result is obtained only for specific parameterizations of the degree of openness and of the elasticity of substitution between domestic and foreign goods.

A key goal of this work is to link the recent literature on sticky-price models of the open economy with the one on interest rate rules. The latter has seen contributions almost entirely confined to the closed economy.[6] In an open economy context, however, where exchange rate regimes matter, it seems even more appropriate to think of monetary policy in terms of endogenous rules. A novelty of the present model lies, in fact, in the representation of a managed-fixed exchange rate regime by means of an interest rate rule assigning an increasing weight to the deviations of the nominal exchange rate from some theoretical parity. A central result is that a monotonic inverse relationship exists between the "degree of proximity" to a fixed exchange rate regime (measured by the weight assigned to the nominal exchange rate in the interest rate rule) and the volatility of the real exchange rate.

Recently several papers, rooted in an optimizing framework with nominal rigidities that has become the hallmark of the New Open Macroeconomics literature, have tried to address the related but distinct issue of the large and persistent deviations of the real exchange rate from the purchasing power parity (the "PPP puzzle").[7] Examples include Beaudry and Devereux (1995), Chari, Kehoe and McGrattan (2000), Betts and Devereux (2000) and Kollmann (2001) among others. This literature, however, deals solely with the problem of explaining the *absolute* level of the real exchange rate volatility. Finn (1999) constructs a flexible price dynamic general equilibrium model in which the interaction of technology shocks with an accommodative role of money is able to generate the high empirical correlation between nominal and real exchange rate. My work focuses instead on the systematically different behavior of the real exchange rate *across regimes*. Furthermore all papers above do not analyze the role of interest rate rules. Hence monetary policy affects the business cycle only via its exogenous stochastic component.

The remainder of the paper is as follows. Section 2 presents the basic model. Section 3 discusses the main findings on the relationship between real exchange rate and monetary policy regime, and the role of nominal rigidities. Section 4 presents an extension of the baseline model to include incomplete exchange rate pass-through. Section 5 concludes.

[6] See, among many others, Taylor (1993), Rotemberg and Woodford (1998), Clarida, Galí and Gertler (1999). Very recently a line of research on endogenous monetary policy in open economy has started to emerge. See Lane (2001) and references therein.

[7] For a survey on this other puzzle, see Rogoff (1996).

2 A Small Open Economy with Sticky-Prices and Complete Exchange Rate Pass-Through.

Consider a small open economy populated by identical, infinitely lived households. They consume baskets of differentiated domestic and foreign goods (which are both tradable), hold a portfolio of state contingent assets denominated in domestic currency, and own the shares of home-based monopolistic competitive firms. These households derive income from working, collecting the profits of the domestic firms and renting physical capital to the domestic producers. Like consumption, investment is a composite index of domestic and foreign goods. Define $P_{H,t} \equiv \left(\int_0^1 P_{H,t}(j)^{1-\vartheta} dj\right)^{\frac{1}{1-\vartheta}}$ and $P_{F,t} \equiv \left(\int_0^1 P_{F,t}(j)^{1-\vartheta} dj\right)^{\frac{1}{1-\vartheta}}$ as the utility-based price indexes associated to the baskets of domestic and foreign varieties of goods, both expressed in units of the domestic currency, and let $P_{\kappa,t}(j)$, for $\kappa = H, F$, be the price of the individual good j, where $\vartheta > 1$ is the elasticity of substitution between varieties within each category κ. The optimal allocation of any given expenditure within each category of goods yields the demand functions for any variety j:

$$C_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\vartheta} C_{H,t} \qquad ; \qquad C_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}}\right)^{-\vartheta} C_{F,t} \tag{1}$$

for all $j \in [0,1]$, where $C_{H,t} \equiv \left(\int_0^1 C_{H,t}(j)^{\frac{\vartheta-1}{\vartheta}} dj\right)^{\frac{\vartheta}{\vartheta-1}}$ and $C_{F,t} \equiv \left(\int_0^1 C_{F,t}(j)^{\frac{\vartheta-1}{\vartheta}} dj\right)^{\frac{\vartheta}{\vartheta-1}}$ represent composite indexes of domestic and foreign (imported) goods respectively. The aggregate consumption index C is a CES aggregate of C_H and C_F:

$$C_t = \left(\gamma^{\frac{1}{\rho}} C_{H,t}{}^{\frac{\rho-1}{\rho}} + (1-\gamma)^{\frac{1}{\rho}} C_{F,t}{}^{\frac{\rho-1}{\rho}}\right)^{\frac{\varrho}{\varrho-1}} \tag{2}$$

where $\gamma \in [0,1]$ is the share of home-produced goods in total consumption and $\varrho > 1$ is the elasticity of substitution between domestic and foreign goods. For simplicity I assume that the investment composite index $X(X_H, X_F)$ has as an identical expression. A utility-based consumer price index can then be written as:

$$P_t = \left(\gamma P_{H,t}{}^{1-\varrho} + (1-\gamma) P_{F,t}{}^{1-\varrho}\right)^{\frac{1}{1-\varrho}} \tag{3}$$

The nominal exchange rate $\mathcal{E}_t$ is the price of one unit of foreign currency expressed in units of domestic currency. In the baseline version with complete exchange rate pass-through (CPT henceforth) the *law of one price* holds for both import and export goods, implying

$$\begin{aligned} P_{F,t}(j) &= \mathcal{E}_t P^*_{F,t}(j) \quad \text{all } j \text{ and } t \\ P_{H,t}(j) &= \mathcal{E}_t P^*_{H,t}(j) \quad \text{all } j \text{ and } t \end{aligned} \tag{4}$$

As usual the household's optimization problem can be divided into a static and a dynamic stage. In the first stage the optimal allocation of any given expenditure between domestic and foreign goods yields the typical isoelastic consumption demands:

$$C_{H,t} = \gamma \left(\frac{P_{H,t}}{P_t}\right)^{-\rho} C_t \ ; \quad C_{F,t} = (1-\gamma)\left(\frac{P_{F,t}}{P_t}\right)^{-\rho} C_t \tag{5}$$

The optimal composition of investment between domestically produced goods and imported goods is exactly symmetric.

Let $s^t = \{s_0, ...s_t\}$ denote the history of events up to date t, where s_t is the event realization at date t. The date 0 probability of observing history s^t is given by d_t. The initial state s^0 is given so that $d(s^0) = 1$. Henceforth, and for the sake of simplifying the notation, let's define the operator $E_t\{.\} \equiv \sum_{s_{t+1}} d(s^{t+1}|s^t)$ as the mathematical expectation over all possible states of nature conditional on history s^t. In the second stage the domestic household maximizes

$$E_t \sum_{t=0}^{\infty} \beta^t \zeta_t \left\{U(C_t,\, N_t)\right\}$$

subject to a capital accumulation equation:

$$K_{t+1} = K_t(1-\delta) + \Phi\left(\frac{X_t}{K_t}\right) K_t \tag{6}$$

and to a sequence of budget constraints which, after considering the optimality conditions (1) and (5), can be written in units of domestic currency as

$$P_t(C_t + X_t) + \sum_{s_{t+1}} \nu_{t,t+1} B_{t+1} = W_t N_t + Z_t K_t + B_t + \tau_t \tag{7}$$

Notice that ζ_t is a demand/preference shock which affects the marginal utility of consumption and δ is the physical depreciation rate of capital. In equation (6) the presence of the function $\Phi(.)$, increasing and convex, reflects the fact that, due to adjustment costs, X_t units of investment translate only into $\Phi\left(\frac{X}{K}\right)$ units of additional capital. In equation (7) B_{t+1} is the market value (in units domestic currency) of a portfolio of state contingent securities held at the end of period t, $\nu_{t,t+1} \equiv \nu(s^{t+1}|s^t)$ is the pricing kernel of the state contingent portfolio, W is the nominal wage, Z is the nominal rental cost of capital and τ are net lump-sum transfers/taxes.

After ruling out Ponzi schemes the first order conditions of the above problem can be described as follows. The efficiency condition for the consumption-leisure choice is given by

$$U_{c,t}\frac{W_t}{P_t} = -U_{n,t} \tag{8}$$

where $U_{c,t}$ and $U_{n,t}$ denote the marginal utility of consumption and disutility of work respectively. The price of the state contingent asset (for any state of the world) must satisfy

$$\nu_{t,t+1} = d_{t,t+1} \frac{\zeta_{t+1} U_{c,t+1} P_t}{\zeta_t U_{c,t} P_{t+1}} \tag{9}$$

where $d_{t,t+1} \equiv d(s^{t+1}|s^t)$. The intertemporal conditions for efficiency in physical capital investment imply

$$Q_t = \zeta_t U_{c,t} \left[\Phi_x \left(\frac{X_t}{K_t} \right) \right]^{-1} \tag{10}$$

$$Q_t = \beta E_t \left\{ \zeta_t U_{c,t} \frac{Z_{t+1}}{P_{t+1}} + Q_{t+1}(1 - \delta + \widetilde{\Phi}_{t+1}) \right\} \tag{11}$$

where Q_t is the (indirect) value of holding capital stock K_t, and $\widetilde{\Phi}_{t+1} \equiv \Phi\left(\frac{X_{t+1}}{K_{t+1}}\right) - \frac{X_{t+1}}{K_{t+1}} \Phi_x \left(\frac{X_{t+1}}{K_{t+1}}\right)$. Equation (10) determines the investment rate as a function of Q_t (the equivalent of the Tobin's q), while equation (11) determines the evolution of Q_t over time. It is assumed that in steady state there are no average nor marginal costs of adjustment. Therefore $\Phi(.)$ is such that $Q = \left[\Phi_x\left(\frac{X}{K}\right)\right]^{-1} = 1$, and $\Phi\left(\frac{X}{K}\right) = \delta = \frac{X}{K}$.

Arbitrage conditions then imply:

$$\frac{1}{R_t} = \sum_{s_{t+1}} \nu_{t,t+1}; \qquad \frac{1}{R_t^*} = \sum_{s_{t+1}} \nu_{t,t+1} \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \tag{12}$$

where R_t and R_t^* denote the expected returns, denominated in units of domestic and foreign currency respectively, on the bond portfolio. By equalizing one obtains:

$$\sum_{s_{t+1}} \nu_{t,t+1} \left[R_t - R_t^* \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right] = 0 \tag{13}$$

The foreign demand for good j is given by:

$$\begin{aligned} C_{H,t}^*(j) &= \left(\frac{P_{H,t}^*(j)}{P_{H,t}^*} \right)^{-\vartheta} C_{H,t}^* \\ &= \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\vartheta} C_{H,t}^* \end{aligned} \tag{14}$$

where $C_{H,t}^* = (1-\gamma^*) \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\rho} C_t^*$ in analogy to equation (5). Notice that (14) implies that a domestic producer faces a downward sloping demand for its own product on the international markets. Hence in the aggregate the small economy maintains the ability to affect its own terms of trade.

2.0.1 Domestic Firms

Domestic firm j operates a constant return to scale technology $F(A, K(j), N(j))$, where A is a total factor productivity shifter. The nature of the production technology implies that unit and nominal marginal cost coincide. It useful to think of domestic firms as divided into two units, a production and a pricing unit. The *production unit* chooses factor demands in a perfectly competitive fashion, taking the level of output as given. Static efficiency conditions for the choice of capital and labor demands are respectively:

$$mc_t\ F_K(A_t, K_t, N_t) = \frac{Z_t}{P_{H,t}}; \quad mc_t\ F_N(A_t, K_t, N_t) = \frac{W_t}{P_{H,t}} \tag{15}$$

where F_K and F_N denote the marginal product of capital and labor, and mc is the real marginal cost. Notice that, since the production function is homogeneous of degree one, the above cost minimization conditions hold also for aggregate quantities. In particular in this setting each firm faces a scale invariant real marginal cost.

The *pricing unit* is allowed to reset the output price according to a stochastic time-dependent rule, which implies receiving a price signal at a constant random rate ϕ_H, as in Calvo (1983) and Yun (1996). Let then ϕ_H^k be the probability that the price set at time t will still be holding at time $t+k$. This implies that, when allowed to reset its price, domestic firm j will choose $P_{H,t}^{new}(j) = \mathcal{E}_t P_{H,t}^*(j)$ to maximize:

$$E_t \left\{ \sum_{k=0}^{\infty} (\phi_H)^k \nu_{t,t+k} \left[P_{H,t}^{new}(j) - MC_{t+k} \right] Y_{t+k}(j) \right\}$$

subject to the demand schedule

$$Y_{t+k}(j) \leq \left(\frac{P_{H,t}^{new}(j)}{P_{H,t+k}} \right)^{-\vartheta} [C_{H,t+k} + C_{H,t+k}^*]$$

The first order necessary condition of this problem is given by:

$$E_t \sum_{k=0}^{\infty} (\phi_H)^k \nu_{t,t+k} \left\{ Y_{t+k}(j) + (P_{H,t}^{new}(j) - MC_{t+k}) \frac{\partial Y_{t+k}(j)}{\partial P_{H,t}^{new}(j)} \right\} = 0 \tag{16}$$

Rearranging, the optimal pricing condition reads:

$$P_{H,t}^{new}(j) = \left(\frac{\vartheta}{\vartheta - 1} \right) \frac{E_t \{ \sum_{k=0}^{\infty} (\phi_H)^k\ \nu_{t,t+k} MC_{t+k} Y_{t+k}(j) \}}{E_t \{ \sum_{k=0}^{\infty} (\phi_H)^k\ \nu_{t,t+k} Y_{t+k}(j) \}} \tag{17}$$

Notice that (17) can be interpreted as a dynamic markup equation. In setting the current price firms forecast (in a discounted manner) future demand and marginal cost. In the case $\phi_H = 0$ equation (17) reduces to $P_{H,t}^{new} = \frac{\vartheta}{\vartheta - 1} MC_t$, which simply states that the firm sets the price as a constant markup over the nominal marginal cost or, put differently, that the real marginal cost is constant. Given the pricing rule above, in a symmetric equilibrium where the law of large numbers holds, the domestic aggregate price index evolves according to:

$$P_{H,t} = [\phi_H \; P_{H,t-1}^{1-\vartheta} + (1-\phi_H)(P_{H,t}^{new})^{1-\vartheta}]^{\frac{1}{1-\vartheta}} \tag{18}$$

2.1 Terms of Trade and Real Exchange Rate

The terms of trade are defined as the price of the imported good relative to the price of the domestic good. Under CPT this reads

$$S_t \equiv \frac{P_{F,t}}{P_{H,t}} = \frac{\mathcal{E}_t P_{F,t}^*}{P_{H,t}} \tag{19}$$

The real exchange rate is then defined as

$$\mathcal{E}_t^r \equiv \frac{\mathcal{E}_t P_t^*}{P_t} \tag{20}$$

Henceforth lower case letters denote log-deviations from respective steady state values. Domestic *consumer price* and *producer price inflation* are defined respectively as $\pi_t \equiv \log\left(\frac{P_t}{P_{t-1}}\right)$ and $\pi_{H,t} \equiv \log\left(\frac{P_{H,t}}{P_{H,t-1}}\right)$. I then assume that the share of the small economy's goods consumed in (an hypothetical consumption basket of) the rest of the world is negligible and that foreign inflation is zero.[8] This implies that $\pi_{F,t}^* = \pi_t^* = 0$. Without loss of generality it can also be assumed that $p_{F,t}^* = p_t^* = 0$. A log-linear approximation of (19), (20) and (3) leads to $s_t = e_t - p_{H,t}$ and in turn to $e_t^r = e_t - p_t = \gamma s_t$, which establishes a relationship between the real exchange rate and the terms of trade with a coefficient of proportionality γ. Hence it follows that

$$\Delta e_t^r = \gamma[\Delta e_t - \pi_{H,t}] = \gamma \Delta s_t \tag{21}$$

which relates the real depreciation rate directly to the nominal depreciation rate and inversely to producer inflation. The assumption of CPT also implies that consumer price inflation can be written (in log-linear form) as

$$\pi_t = \gamma \pi_{H,t} + (1-\gamma)\Delta e_t \tag{22}$$

which shows that the nominal depreciation rate and consumer price inflation, for a given producer inflation, are likely to be highly correlated. It will become clear later how a version of the model with incomplete pass-through (IPT henceforth) is able to affect the model's theoretical predictions with this respect.

[8]See Gali and Monacelli (2002) for a detailed description of this structure of the world general equilibrium.

2.2 Equilibrium

In a symmetric equilibrium where all firms take identical decisions it holds that $P_{H,t}(j) = P_{H,t}$, $Y_t(j) = Y_t$, $N_t(j) = N_t$ all j and t. Furthermore financial assets are in zero net supply. The aggregate supply of output of the domestic good is $Y_t \equiv \left(\int_0^1 Y_t(j)^{\frac{\vartheta-1}{\vartheta}} dj\right)^{\frac{\vartheta}{\vartheta-1}}$. As in Yun (1996) one can define the alternative price index $P'_{H,t} = \left(\int_0^1 P_{H,t}(j)^{-\vartheta} dj\right)^{-\frac{1}{\vartheta}}$ and the aggregate $Y'_t \equiv \int_0^1 Y_t(j)dj$, such that $Y'_t = F(A_t, K_t, N_t)$, with $N_t \equiv \int_0^1 N_t(j)dj$ and $K_t \equiv \int_0^1 K_t(j)dj$. Notice, in particular, that $Y'_t = \left(\frac{P_{H,t}}{P'_{H,t}}\right)^{\vartheta} Y_t$. Hence, after imposing symmetry, equilibrium in the domestic goods market requires:

$$C_{H,t} + C^*_{H,t} + X_{H,t} = \left(\frac{P_{H,t}}{P'_{H,t}}\right)^{\vartheta} Y_t = F(A_t, K_t, N_t) \tag{23}$$

2.3 Exogenous Stochastic Processes

The dynamic in the rest of the world is summarized by the following stochastic processes for the (world) interest rate and output:

$$(1 + i^*_t) = (1 + i^*_{t-1})^{\rho^{i^*}} \exp(\varepsilon^{i^*}_t); \qquad Y^*_t = Y^{\rho^{y^*}}_{t-1} \exp(\varepsilon^{y^*}_t) \tag{24}$$

Domestic exogenous variables evolve according to

$$A_t = A^{\rho^a}_{t-1} \exp(\varepsilon^a_t); \qquad \zeta_t = \zeta^{\rho^\zeta}_{t-1} \exp(\varepsilon^\zeta_t) \tag{25}$$

with $E_t\varepsilon^h_{t+1} = 0$, $E_t\varepsilon^h_{t+1}\varepsilon^{h'}_{t+1} = \Sigma$, $h = y^*, i^*, a, \zeta$.

2.4 Monetary Policy and the Exchange Rate Regime

The formulation of monetary policy by the domestic authority follows a generalized rule, in which deviations of (producer) inflation, output and nominal exchange rate from their long-run target have a feed-back on short-run movements of the nominal interest rate.[9] This can be seen as an extension to the open economy of a tool that has proved to be quite useful in the description of monetary policy in the recent closed economy literature.[10] The following equation describes the *target* for the nominal interest rate:

$$(1 + \bar{i}_t) = \left(\frac{P_{H,t}}{P_{H,t-1}}\right)^{\omega_\pi} Y_t^{\omega_y} \, \mathcal{E}_t^{\frac{\omega_e}{1-\omega_e}} \tag{26}$$

[9] An issue emerges here as to whether the monetary authority should be targeting consumer as opposed to producer price inflation. This point is extensively discussed in Svensson (2000). I abstract from these issues here.

[10] See, among many others, Taylor (1996), Rotemberg and Woodford (1998) and Clarida, Galí and Gertler (2000).

Hence the monetary authority reacts to the contemporaneous level of the nominal exchange rate (which is a jumpy forward-looking variable), and to contemporaneous inflation and output. Next I follow Rotemberg and Woodford (1998) and Clarida, Galí and Gertler (2000), and specify a model for the determination of the actual short-run interest rate that accounts for the desire of the monetary authority to smooth changes in the interest rate:

$$(1+i_t) = (1+\bar{i}_t)^{1-\chi} \; (1+i_{t-1})^{\chi} \tag{27}$$

By taking a log-linear approximation of (26) and (27) one obtains:

$$i_t = \widetilde{\omega}_\pi \pi_{H,t} \; + \; \widetilde{\omega}_y y_t \; + \; \widetilde{\omega}_e e_t \; + \; \chi i_{t-1} \tag{28}$$

where $\widetilde{\omega}_\pi \equiv (1-\chi)\omega_\pi$, $\widetilde{\omega}_y \equiv (1-\chi)\omega_y$, $\widetilde{\omega}_e \equiv (1-\chi)\frac{\omega_e}{1-\omega_e}$ and $i_t \approx \log \frac{1+i_t}{1+i}$. The specification in (26) allows to approximate the systematic behavior of monetary policy under two polar regimes (floating and fixed exchange rates) as a function of the weight ω_e assigned to the movements of the nominal exchange rate around the parity. In particular:

$$\omega_e = 0 \Longrightarrow \textit{floating} \text{ exchange rate regime}$$

$$\omega_e \in (0,1] \Longrightarrow \textit{managed-fixed} \text{ exchange rate regime}$$

A rule of this kind can describe how monetary policy is formulated in small open economies, and/or economies whose monetary policy setting is constrained by the participation to a managed/fixed exchange rate regime. Clarida, Galí and Gertler (1998) estimate an interest rate rule for the so-called E3 countries (UK, France, Italy) and show that the inclusion of the German day-to-day rate is highly significant. The result confirms that the participation to the EMS has strongly affected the conduct of monetary policy in these countries. This also suggests that the setting of ω_e and ω_π may not be independent. The more stringent the constraint of the exchange rate regime (i.e., the closer ω_e to 1), the lower should be the leverage in conducting an independent inflation-targeting strategy (i.e., the lower ω_π).[11]

The model in this paper tries to rationalize empirical facts to a large extent related to industrialized countries. However, and as discussed in Calvo and Reinhart (2002), it is interesting to notice that the specification of a range of alternative exchange rate regimes by means of an interest rate rule seems to accord well also with an increasing evidence in emerging market economies that

[11] Clarida, Galí and Gertler (1998), in fact, show that the coefficient on (expected) inflation reduces significantly when the German interest rate is added as a regressor. Hence in the analysis below I systematically test the sensitivity of the results to the simultaneous choice of ω_e and ω_π.

interest rate policies are replacing interventions in the foreign exchange market as a device for smoothing exchange rates.

3 Model Parameterization.

To solve the model I take a log-linear approximation of the equilibrium conditions around a balanced-trade zero-inflation steady state. The model is parameterized as follows. Contemporaneous utility is specified as $U(C_t, N_t) = \frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{1}{1+\varphi} N_t^{1+\varphi}$. The prudction function is $F(A, K, N) = A_t K_t^{1-\alpha} N_t^{\alpha}$. I follow the business cycle literature and set the discount rate β equal to 0.99, the quarterly capital depreciation rate δ to 0.025, the labor share α to 1/3, and the inverse elasticity of labor supply φ to 3. The steady-state markup μ is 1.2, and the elasticity of the investment rate to the shadow price of capital $\eta \equiv -\left(\frac{\Phi_x}{\frac{X}{K}\Phi_{xx}}\right) = 2$. The share of home-good consumption γ is chosen such that the steady-state sum of exports and imports is roughly 40% of output. The elasticity of substitution between home and foreign consumption ρ is set to 1.5. As it is now common in the literature with Calvo pricing, the probability of price non-adjustment ϕ_H is equal to 0.75, which implies that the average frequency of price adjustment is four quarters. As to the monetary policy rule parameters, I set, as benchmark values, ω_π to 1.5 and ω_y to 0. The reason for setting $\omega_y = 0$ is twofold. First, the monetary authority responding to detrended output as opposed to the output gap, as in the original Taylor-rule (Taylor 1993), would imply an inefficient behavior of policy. Moreover, the output gap is an unobservable variable and the central bank does not feature any trade off between inflation and output gap stabilization in the present model.[12]

To calibrate the sources of stochastic volatility I set, following McCallum and Nelson (1999), the standard deviation of the productivity shock σ_{ε^a} equal to 0.007, and the standard deviation of the preference shock $\sigma_{\varepsilon^\zeta}$ equal to 0.011, as estimated in Fuhrer (1999). Serial correlation parameters for these processes are $\rho^a = \rho^\zeta = 0.9$. I then turn to the data to estimate the statistical properties of the driving forces describing the dynamic in the rest of the world. I use quarterly OECD data and measure world output as U.S. real GDP. To seek for innovations in this variable I fit the following univariate trend-stationary stochastic process:

$$\log Y_t^* = 0.31 + 0.0003\ t\ + 0.96 \log Y_{t-1}^* + \varepsilon_t^{Y^*}$$

and obtain $\sigma_{\varepsilon^{Y^*}} = 0.00887$. The underlying assumption is therefore that world output contains a deterministic trend and that output innovations, although persistent, have only temporary effects. Finally, I need to construct a measure for the world real interest rate. I first fit an AR(1) process for U.S. inflation and obtain $log\left(\frac{P_t^*}{P_{t-1}^*}\right) = 0.0066 + 0.85\ log\left(\frac{P_{t-1}^*}{P_{t-2}^*}\right) + \varepsilon_t^{\pi^*}$, where P_t^* measures the foreign CPI. Then I rewrite the (log)world real interest rate as : $\log(1 + r_t^*) = \log(1 + i_t^*) - \log\left(\frac{P_{t+1}^*}{P_t^*}\right) =$

[12]However the main results are not particularly sensitive to the inclusion of output in the interest rate rule.

$\log(1+i_t^*) - 0.85 \log\left(\frac{P_t^*}{P_{t-1}^*}\right)$, where i_t^* is the Federal Funds Rate, and estimate the following stochastic process for the constructed series:

$$\log(1 + r_t^*) = 0.006 \ + 0.8 \log(1 + r_{t-1}^*) + \varepsilon_t^{r^*}$$

obtaining $\sigma_{\varepsilon^{r^*}} = 0.01379$. Hence the estimates point out some significant heterogeneity in the variability of the stochastic innovations. In particular shocks to the world real interest rate display a sizeable standard deviation relative to the other exogenous processes.

4 The Volatility of the Real Exchange Rate: Nominal Rigidities and the Exchange Rate Regime.

In this section I conduct a central experiment to investigate whether the baseline model illustrated above is able to replicate the quantitative evidence reported in Table 1. A key working assumption concerns the parameterization of the floating and managed-fixed exchange rate regimes. To begin with I define a regime of floating by setting $\omega_e = 0$. To characterize a managed-fixed exchange rate regime I compute the value of ω_e necessary to produce a proportional change in volatility of the *nominal* depreciation rate in line with the first column of Table 1. Conditional on the benchmark calibration described above this requires choosing $\omega_e = 0.76$. Notice that this value of ω_e is well below 1, which is the one that would precisely define a regime of fixed exchange rates. The exercise, then, consists in checking whether the model is able to generate a similar rise in volatility for the *real* exchange rate.

Table 2 summarizes the results of this experiment. Two panels are reported for alternative values of the interest rate smoothing parameter χ in the monetary policy rule (0 and 0.5 respectively). Each panel displays the volatility of the nominal and of the real depreciation rate under the two regimes (floating and managed-fixed, as defined by the calibration above). Several interesting results emerge. First, and conditional on the stochastic driving forces specified above, the model produces an *absolute* volatility of the *nominal* exchange rate which even exceeds the one in the data. The same does not hold for the real exchange rate though. Second, in moving from fixed to floating, the *proportional rise* in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate which is roughly in line with the data. Third, the introduction of interest rate smoothing, by increasing the serial correlation of the real exchange rate and possibly also its volatility, makes such volatility closer to the one in the data. This holds for both the absolute volatility and for the volatility ratio.

Table 2 reports also the correlation between nominal and real depreciation rate implied by the calibrated economy. Once again two other key stylized facts of Table 1 are matched here. First, the almost perfect correlation between nominal and real depreciation rate under floating exchange rates. This evidence was particularly striking when looking at Figure 1. Second, the decrease in that correlation under a managed-fixed exchange rate regime, which naturally tends to dampen the movements of the nominal exchange rate.

Finally notice that the baseline version of the model does not seem able to reproduce the empirical value of the output volatility ratio. The implied volatility of output under floating is *smaller* relative to the one under fixed. This is likely to be due to the excess instability in output generated by restraining the equilibrium adjustment of real relative prices under managed/fixed exchange rates. However it seems already encouraging that the output volatility ratio remains in a neighborhood of one, suggesting that such value may be sensitive to the calibration of alternative parameters in the model. Below I will show that indeed the Baxter and Stockman output volatility puzzle (discussed in the introduction) can be made consistent with the model for appropriate choices of either the degree of openness or the elasticity of substitution between domestic and foreign goods.

There are two implications of the baseline specification that stand in right contrast with the empirical evidence of Table 1. First, and independently of whether the policy rule exhibits interest rate smoothing, the implied volatility of the nominal depreciation rate is always somewhat larger than the volatility of the real depreciation rate. In the data, the opposite is true. Second, the correlation between nominal depreciation and (CPI) inflation implied by the model is much larger than the one in the data. One potential explanation for both these discrepancies lies in the benchmark model featuring complete pass-through of nominal exchange rate movements to prices. I will argue below that a modification of the baseline setting to allow for incomplete pass-through is able to reconcile the theoretical predictions of the model with those additional exchange rate facts.

It is again important to remember that the choice of ω_e so far is not necessarily the one characterizing any managed-fixed exchange rate regime. Strictly speaking, in the model, a regime of fixed exchange rates is identified by a value of ω_e approaching 1. *Figure 2* explores whether some monotonic relationship actually exists between the "proximity" (measured by ω_e) to a managed-fixed exchange rate regime and the variability of the real depreciation rate. The results for the simulation with *all the shocks* are reported. In moving from a purely floating to an increasingly fixed exchange rate regime the effect on the volatility of the real exchange rate is quite dramatic. In fact, the volatility of the real exchange rate decreases by a factor of five. The volatility of the nominal exchange rate converges monotonically to zero as ω_e approaches 1. What this figure suggests is a reduced-form relationship between the monetary policy feed-back rule postulated in the model and the equilibrium volatility of the real exchange.

The contribution of each stochastic component.

It is natural to ask to what extent the result illustrated in Figure 2 depends upon the choice of the underlying stochastic force in the system. Therefore in *Figure 3* I allow the dynamic to be driven only by one selected disturbance in each panel: productivity, domestic preferences, world interest rate and world demand. In all cases, the bulk of the result is unchanged. The relationship between exchange rate regime and real exchange rate volatility emerges *independently of the source of the shock*. The quantitative impact of the change in regime on the variability of the real exchange rate is remarkably regular across independent sources of fluctuations. In all cases the effect is a drop in the volatility of the real exchange rate by roughly five times. Overall this result seems to favor an interpretation of the movements of the real exchange across regimes based on a systematic policy component, as opposed to one based on the prominent role of real stochastic disturbances. In principle, though, the role of monetary/exchange rate policy does not suggest per se a specification of the model with sticky prices. What I investigate next is the role that in fact sticky prices play in generating such result.

The role of nominal rigidities

To address this issue I consider two extreme cases: floating ($\omega_e = 0$) *vs.* purely fixed exchange rates ($\omega_e \approx 1$). Then I construct a volatility ratio for the real depreciation rate defined as the ratio of the standard deviations of the real exchange rate under the two regimes. This ratio is plotted in *Figure 4* as a function of the degree of price rigidity in the model, measured by ϕ_H (the probability of price non-adjustment). It is clear that, as ϕ_H moves from 0 (*fully flexible prices*) to 1 (*fully rigid prices*), the volatility ratio of the real exchange rate increases substantially. Under fully flexible prices, the value of this ratio is always close to 1, suggesting that the exchange rate regime is almost irrelevant for the business cycle behavior of the real exchange rate. Quantitatively, for higher degrees of nominal rigidity and approaching full rigidity of prices, the relative volatility of the real exchange rate increases up to a factor of nine. Notice also that for values of ϕ_H still close to the baseline value of 0.75 the volatility ratio rapidly increases.

4.1 Sensitivity Analysis: the Effect of Varying Openness and the Elasticity of Substitution

In this section I test the sensitivity of the predictions of the model to alternative values of two crucial parameters: the degree of openness (measured by the import share $1-\gamma$) and the elasticity of substitution between domestic and foreign goods, measured by ρ. *Figure 5* displays the simulated volatility ratio as a function of the degree of openness for three variables: nominal exchange rate, real exchange rate and output. A few interesting results stand out. First, and independently of the degree of openness, the volatility ratio of the nominal exchange rate exceeds the one of the real exchange rate (and in turn the one of output). Second, increasing the degree of openness beyond the baseline value of 0.4 allows an even better performance of the model in terms of matching the basic Mussa real exchange rate facts. When the degree of openness reaches its highest possible value (i.e., for $\gamma \to 0$) the real exchange rate is more than five times more variable under floating than it is under fixed. While for simplicity I report here only the implied volatility *ratio* it is important to be aware that while such ratio is increasing in the degree of openness, the reverse holds for the *absolute* volatility of the real exchange rate. For the fall in the absolute volatility is proportionally larger under fixed relative to floating, this generates an upward sloping ratio.

Third, while both exchange rates are always more volatile under floating (as the data suggest), the same is not true for output. In this model the switch to a regime of floating exchange rates tends to boost the relative volatility of output if the economy is sufficiently open, while the reverse holds if the economy is sufficiently closed. This implies that the model can easily comply with the Baxter and Stockman output puzzle for a suitable parameterization of the degree of openness of the economy. Most importantly such output volatility ratio remains always well below the real exchange rate volatility ratio for any calibrated degree of openness.

A similar logic applies when I explore the sensitivity of the same alternative volatility ratios to the choice of the elasticity of substitution between domestic and foreign goods. *Figure 6* reports the results of such exercise, with the parameter ρ varying between 1 (the Cobb-Douglas case) and 5. Like in the exercise above the ranking across the three variables is independent of the underlying value of ρ , and all the volatility ratios increase for larger values of the elasticity of substitution. Notice that the real exchange rate volatility ratio is particularly sensitive to the underlying value of ρ. For values of ρ greater than 1.5, which is our baseline parameterization, the proportional rise in volatility of the real exchange rate can be substantial. For an appropriate parameterization of ρ the implied output volatility ratio is again consistent with the Baxter and Stockman evidence. In particular for a value of ρ close to 2.6 the exchange rate regime is perfectly neutral on the volatility of output. However this value is a bit larger than the one commonly used in the literature, which varies (although with a lot of uncertainty) between 1.5 and 2 (see Backus, Kehoe and Kydland, 1994).

4.2 Incomplete Exchange Rate Pass-Through.

The above section has documented a central result. The benchmark model with endogenous monetary policy, sticky domestic producer prices and complete pass-through is quite successful in replicating some of the "Mussa facts" illustrated in the introduction of this work. One problem of that specification, though, is that the implied correlation between nominal depreciation rates and inflation is too high. This may rationalize why the volatility of the *nominal* depreciation rate is always larger than the volatility of the *real* rate. The opposite, in fact, holds in the data.[13] One can easily understand this point by looking at the decomposition of the variance of the real depreciation rate:

[13] I thank an anonymous referee for stimulating this discussion.

$$Var(\Delta e_t^r) = Var(\Delta e_t) + Var(\pi_t) - 2Cov(\Delta e_t, \pi_t)$$

where again, for simplicity, I have used the assumption $\pi^*_{F,t} = \pi^*_t = 0$ all t. One obvious way to increase the volatility of the real depreciation rate above the one of the nominal rate (and therefore be more in line with the data reported in Table 1) is to reduce the covariance between nominal depreciation and CPI inflation. A candidate modelling strategy is to relax the assumption that complete exchange rate pass-through characterizes the dynamic of import prices.

I assume that, along with domestic producers, the domestic market is populated also by local importers, who use no resources. Their task is to purchase a foreign good j at an international price $\mathcal{E}_t P^*_t(j)$ and distribute it to the domestic consumers by charging a price $P_{F,t}(j)$. To determine such price the importers solve a dynamic markup problem similar to the one of the domestic producers, subject to a downward sloping demand for the imported good. Therefore their problem consists in choosing a price $P^{new}_{F,t}(j)$, expressed in units of domestic currency, to maximize:

$$E_t \left\{ \sum_{k=0}^{\infty} \beta^k \left(\phi_F\right)^k \Lambda_{t,t+k} \; \left[P^{new}_{F,t}(j) - \mathcal{E}_{t+k}(j) P^*_{F,t+k}(j)\right] C_{F,t+k}(j) \right\}$$

$$s.t. \; C_{F,t+k}(j) = \left(\frac{P^{new}_{F,t}(j)}{P_{F,t+k}} \right)^{-\vartheta} C_{F,t+k}$$

where $P^*_{F,t}(j)$ is the foreign-currency price of the imported good, ϕ^k_F is the probability that the price $P_{F,t}(j)$ set for good j at time t is still holding after k periods, and $\beta^k \Lambda_{t,t+k}$ is an appropriate stochastic discount factor. Notice that in this context ϕ_F is also a measure of the *degree of exchange rate pass-through*. In general, I allow ϕ_F to differ from ϕ_H. The first order condition of the above problem yields:

$$P^{new}_{F,t}(j) = \left(\frac{\vartheta}{\vartheta - 1} \right) \frac{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \left(\phi_F\right)^k \Lambda_{t,t+k} \mathcal{E}_{t+k} P^*_{F,t+k} C_{F,t+k}(j) \right\}}{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \left(\phi_F\right)^k \Lambda_{t,t+k} C_{F,t+k}(j) \right\}} \tag{29}$$

The log-linear aggregate import price evolves according to:

$$p_{F,t} = \phi_F \; p_{F,t-1} \; + \; (1 - \phi_F) p^{new}_{F,t} \tag{30}$$

The log-linear version of (29) in turn yields:

$$p^{new}_{F,t} = (1 - \beta\phi_F) E_t \left\{ \sum_{k=0}^{\infty} (\beta\phi_F)^k (\psi_{F,t+k} + p_{F,t+k}) \right\} \tag{31}$$

where $\psi_{F,t+k} \equiv (e_{t+k} + p^*_{F,t+k} - p_{F,t+k})$. Notice that a depreciation of the nominal exchange, causes a wedge $\psi_{F,t}$ between the price paid by the importer in the foreign market and the price applied in the local market. This wedge, which measures the deviation from the law of one price, acts as a fall in the importer's markup.

Under the IPT specification equation (21) is modified to yield

$$\begin{aligned} \Delta e_t^r &= \Delta e_t - \pi_t \\ &= (\Delta e_t - \pi_{F,t}) + \gamma \Delta s_t \end{aligned} \quad (32)$$

where the first term in the last expression is a wedge that is equal to zero under the CPT specification.

Table 3 reports results for the calibrated model with IPT. Once again I set, under floating exchange rates, $\omega_e = 0$ and then choose, under managed-fixed rates, the value of ω_e necessary to reproduce the same proportional rise in volatility of the nominal exchange rate observed in the data. Hence we see that the IPT model seems to outperform the CPT version in one key implication. As expected, the volatility of the real depreciation rate is now larger than the volatility of the nominal rate. This is crucial in generating a correlation between nominal depreciation and consumer price inflation which is in line with the data. Along with this the IPT model is also able to reproduce the already discussed Mussa facts. However the volatility ratio of the real exchange rate across regimes remains much larger than the empirical one. This motivates the exercise in the following section.

4.2.1 Matching the Absolute Volatility of the Nominal Exchange Rate

Until now the calibration of the exchange rate regime has been performed on the basis of two constraints: i) Invariably setting $\omega_e = 0$ to define a regime of floating rates; ii) Choosing ω_e under managed-fixed rates in order to reproduce the volatility ratio of the nominal exchange rate observed in the data. It can be easily seen from both Table 2 and 3 that some divergence between the model and the data stands out in the absolute volatility of the exchange rate (both nominal and real). In this last section I therefore consider an alternative approach. I maintain the IPT version of the model (which seems to be able to rationalize in a unified manner both groups of exchange rate facts discussed in the paper), and calibrate the value of ω_e under floating and fixed in order to generate, in the model, the same *absolute* volatility of the *nominal* depreciation rate observed in the data. The calibration of the driving forces is left unchanged. The results of this experiment are shown in *Table 4*. By calibrating ω_e in such a manner the IPT model is able to approximate the exchange rate data quite well. In particular the absolute volatility of the real exchange rate under floating is very close to the empirical one and larger than the volatility of the nominal depreciation rate. The correlation between nominal and real exchange rate matches the one in the data under *both* regimes. The volatility ratio of the real exchange rate is closer to the observed one, although still a bit high. Overall the outcome of this exercise conveys two main ideas. First, a representation of major regularities concerning the behavior of exchange rates as well as prices requires a model in which incomplete exchange rate pass-through plays a central role. Second, the way the monetary policy rule is able to approximate the underlying exchange rate regime is also crucial to better bring the predictions of the theoretical economy in line with the data.

5 Conclusions

The formulation of monetary policy in terms of interest rate rules has attracted considerable attention in the recent macroeconomic literature. This tool has proved to be particularly useful in capturing the systematic role played by monetary policy over the business cycle. In this paper I have shown that a generalization of this setting to the open economy allows an evaluation of a central topic in international macroeconomics: the short-run dynamic effects of a change in the nominal exchange rate regime. Armed with this tool the paper rationalizes a series of facts characterizing the joint behavior of nominal exchange rates, real exchange rates and prices: the observed striking increase in volatility of the real exchange rate, the high correlation between nominal and real exchange rates under floating, and the very weak comovement between the components of the real depreciation rate, namely the nominal depreciation rate and the inflation differential. The central result of the paper is that a model with sticky prices, endogenous monetary policy and incomplete exchange rate pass-through is best suited to match the exchange rates regularities described above. The key idea conveyed is that the choice of the monetary policy regime and therefore of the exchange rate arrangement is not neutral for the short-run adjustments of international relative prices.

The present framework lends itself to several extensions. For example, a recent series of papers, in the light of work by Flood and Rose (1995), has reinterpreted the Baxter and Stockman results in a broader sense and argued about a more general exchange rate ”disconnect puzzle”. According to this view it seems difficult, in optimizing rational expectation models, to relate the equilibrium movements of the exchange rate to the ones of the macroeconomic fundamentals. This holds in particular for the relationship between relative consumption and real exchange rate. I have abstracted from this issue here and concentrated on output only. Recent contributions by Devereux and Engle (2002), Corsetti, Dedola and Leduc (2002) have made important steps in this direction.

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Table 1

Exchange Rates and Output Statistics

	Standard Deviation (%)						Correlation with nominal depreciation	
	Nominal Exchange Rate		Real Exchange Rate			Output	Real Depr.	Inflation differential
Country	60:1-71:1	71:2-00:1	60:1-71:1	71:2-00:1	Ratio float/fixed	Ratio float/fixed		
Austria	0.00	5.00	1.23	5.15	4.20	1.22	0.99	0.09
Belgium	0.00	5.03	0.62	5.17	8.31	1.26	0.99	0.10
Canada	1.06	1.62	1.17	1.73	1.47	1.35	0.94	0.02
France	1.32	4.86	1.36	5.04	3.71	0.62	0.99	0.20
Italy	0.10	4.84	0.89	5.24	5.89	1.15	0.98	0.25
Japan	0.00	5.31	1.10	5.38	4.89	0.91	0.98	-0.05
Netherlands	0.54	4.94	1.45	5.01	3.45	0.64	0.99	0.01
Norway	0.00	4.22	1.07	4.35	4.07	2.29	0.98	0.04
Spain	1.73	4.87	2.44	5.28	2.16	0.91	0.97	0.20
Switzerland	0.00	5.60	0.65	5.77	8.84	1.10	0.99	0.11
United Kingdom	1.71	4.86	1.88	5.02	2.68	1.44	0.97	0.00
West Germany	1.10	5.06	1.37	5.18	3.79	0.80	0.99	0.07
Average	0.63	4.69	1.27	4.86	**4.46**	**1.14**	**0.98**	**0.09**

Note: Data are quarterly HP filtered from OECD and IFS. Ratio refers to the volatility of a variable under floating relative to fixed
The real exchange rate is each country's CPI converted in dollars relative to the U.S. CPI. Output statistics refer to real GDP for all countries except for Austria, Belgium,and Norway for which is measured as the industrial production.

Table 2

Exchange Rates Statistics for the Calibrated Economy

Complete Pass-Through **Model**

	Float			*Managed / Fixed*			*Ratio float / fixed*		
	model		**data**	**model**		**data**	**model**		**data**
	no smoothing	with smoothing		no smoothing	with smoothing		no smoothing	with smoothing	
***sd(Δe)* in %**	5.73	6.14	4.69	0.77	0.83	0.63	7.44	7.44	7.44
***sd(Δrer)* in %**	3.59	3.83	4.86	1.06	0.95	1.27	3.39	4.03	3.83
***sd(output)* in %**	2.85	3.26		4.67	4.56		0.61	0.72	1.14
Corr(Δe, Δrer)	0.99	0.99	0.98	0.62	0.38	0.66			
Corr(Δe, CPI infl.)	0.97	0.98	0.09	0.14	0.47	-0.03			

Table 3

Exchange Rates Statistics for the Calibrated Economy

Incomplete Pass-Through **Model**

	Float			*Managed / Fixed*			*Ratio float / fixed*		
	model		**data**	**model**		**data**	**model**		**data**
	no smoothing	with smoothing		no smoothing	with smoothing		no smoothing	with smoothing	
***sd(Δe)* in %**	7.40	7.32	4.69	0.99	0.98	0.63	7.44	7.44	7.44
***sd(Δrer)* in %**	7.58	7.56	4.86	1.36	1.17	1.27	5.57	6.44	3.83
***sd(output)* in %**	2.37	2.48		5.43	5.56		0.44	0.45	1.14
Corr(Δe, Δrer)	0.95	0.98	0.98	0.79	0.67	0.66			
Corr(Δe, CPI infl.)	0.08	-0.07	0.08	-0.10	0.22	-0.03			

Note: In both panels the exchange rate smoothing parameter in the interest rate rule is calibrated to match the proportional increase in the volatility ratio of the nominal . exchange rate.

Table 4

Exchange Rates Statistics for the Calibrated Economy

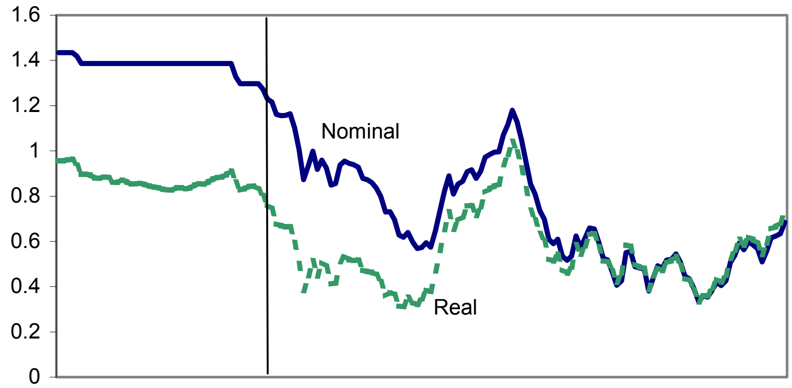
Matching the Absolute Volatilities (IPT model)

	Float		*Managed/Fixed*		*Ratio float / fixed*	
	model	**data**	**model**	**data**	**model**	**data**
sd(Δe) in %	4.69	4.69	0.63	0.63	7.44	7.44
sd(Δrer) in %	4.70	4.87	0.91	1.28	5.15	3.80
Corr(Δe, Δrer)	0.99	0.98	0.72	0.66		
Corr(Δe, CPI infl.)	-0.01	0.08	-0.05	-0.03		

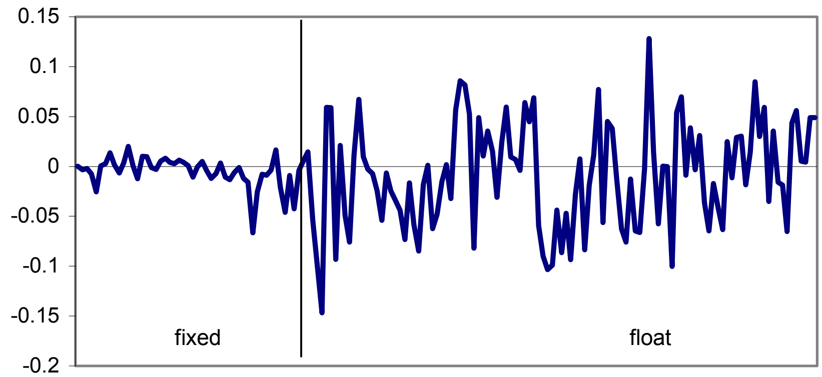
Note: In this panel the exchange rate smoothing parameter in the interest rate rule is calibrated to match the absolute volaitility of the nominal exchange rate under both floating and fixed rates. The interest rate smoothing parameter is set equal to zero.

Figure 1 Germany/U.S Exchange Rates

Nominal and Real Exchange Rate



Real Depreciation Rate



Nominal Depreciation and Inflation Differential

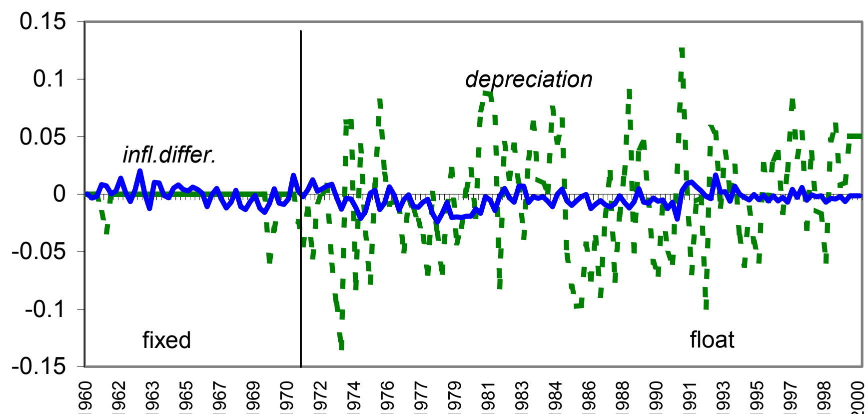


Figure 2. Ex. Rates Volatility in Moving from Float to Fixed
(all shocks)

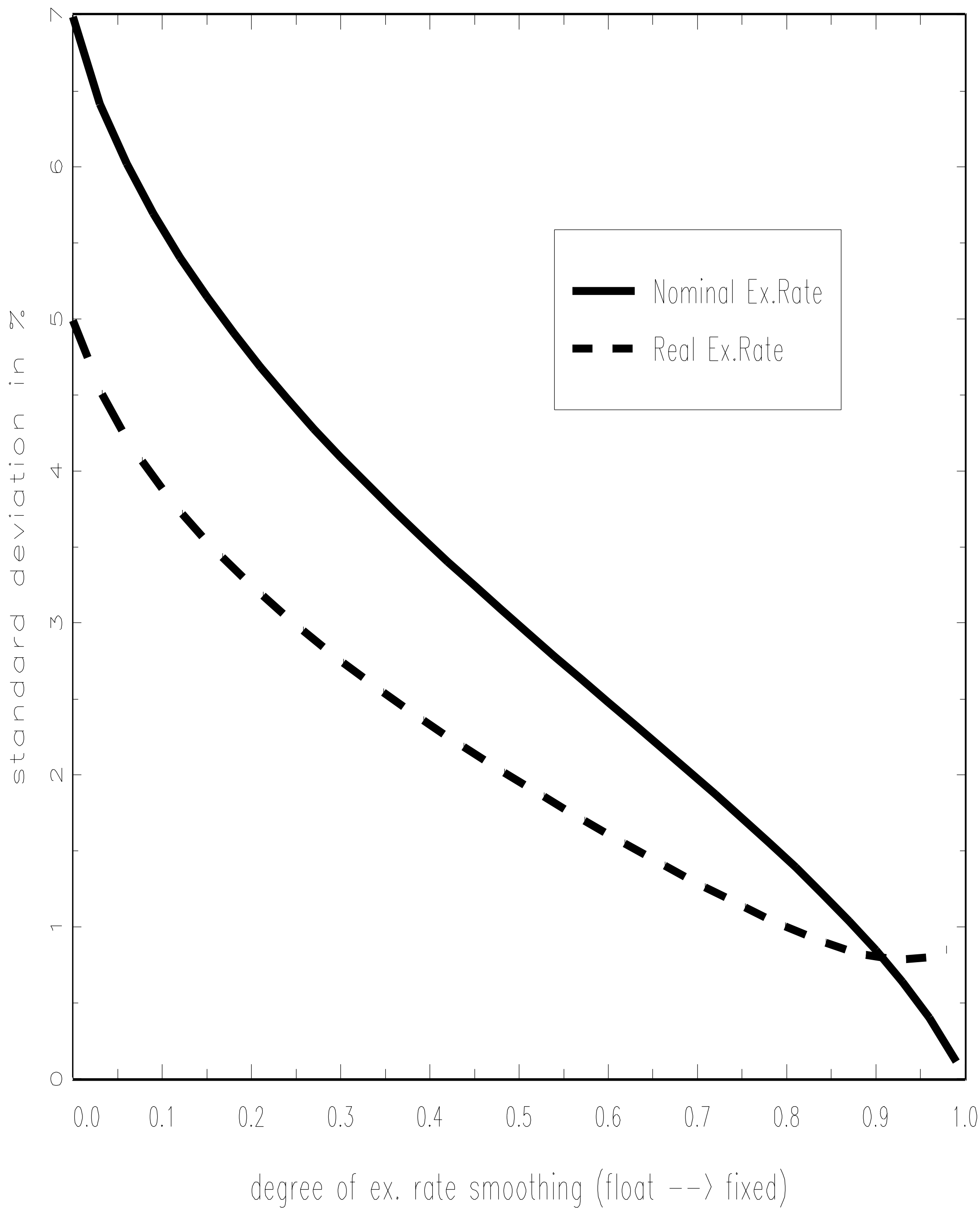


Figure 3. Exchange Rates Volatility in Moving from Float to Fixed

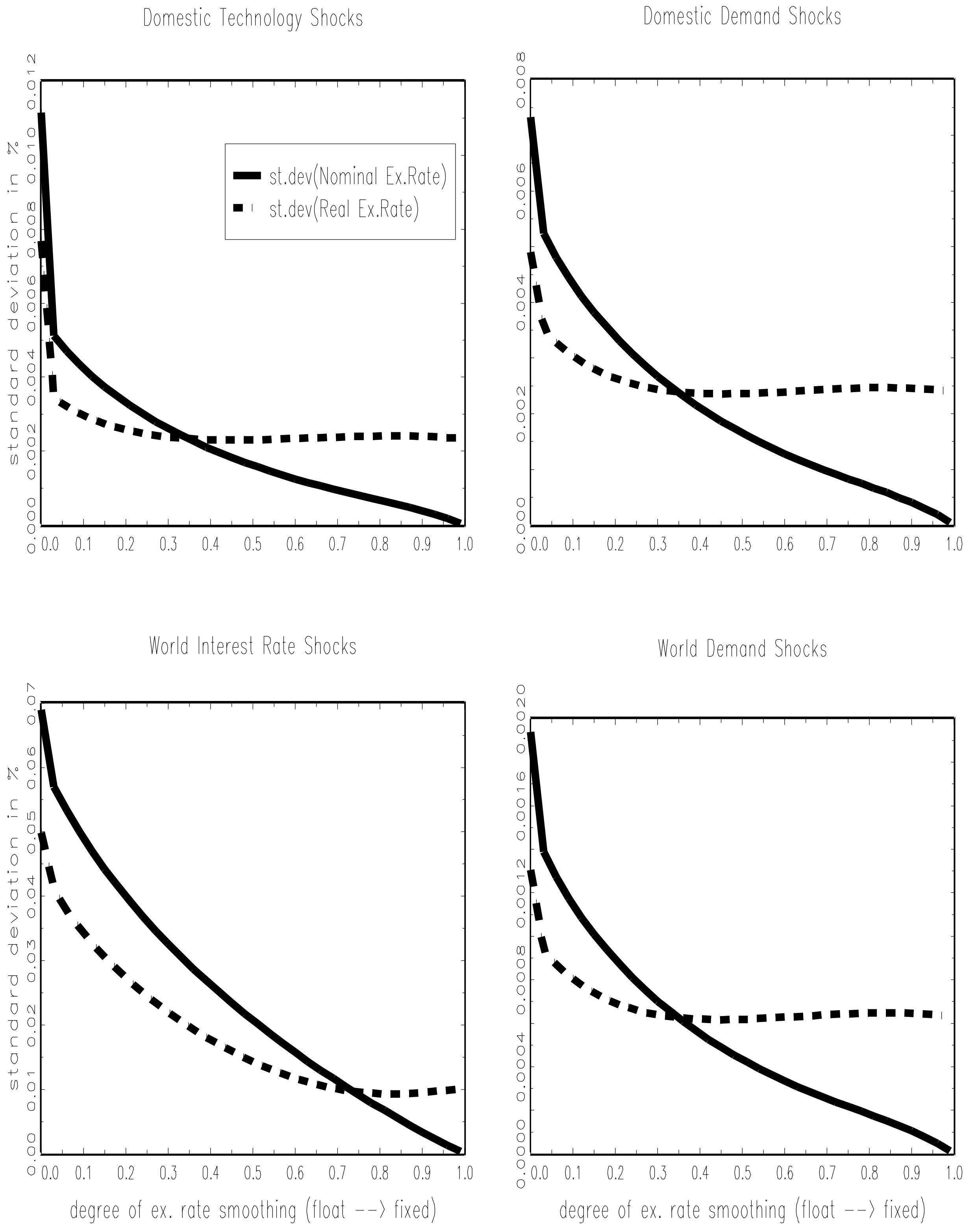


Figure 4. Real Ex.Rate Volatility Ratio and Price Stickiness

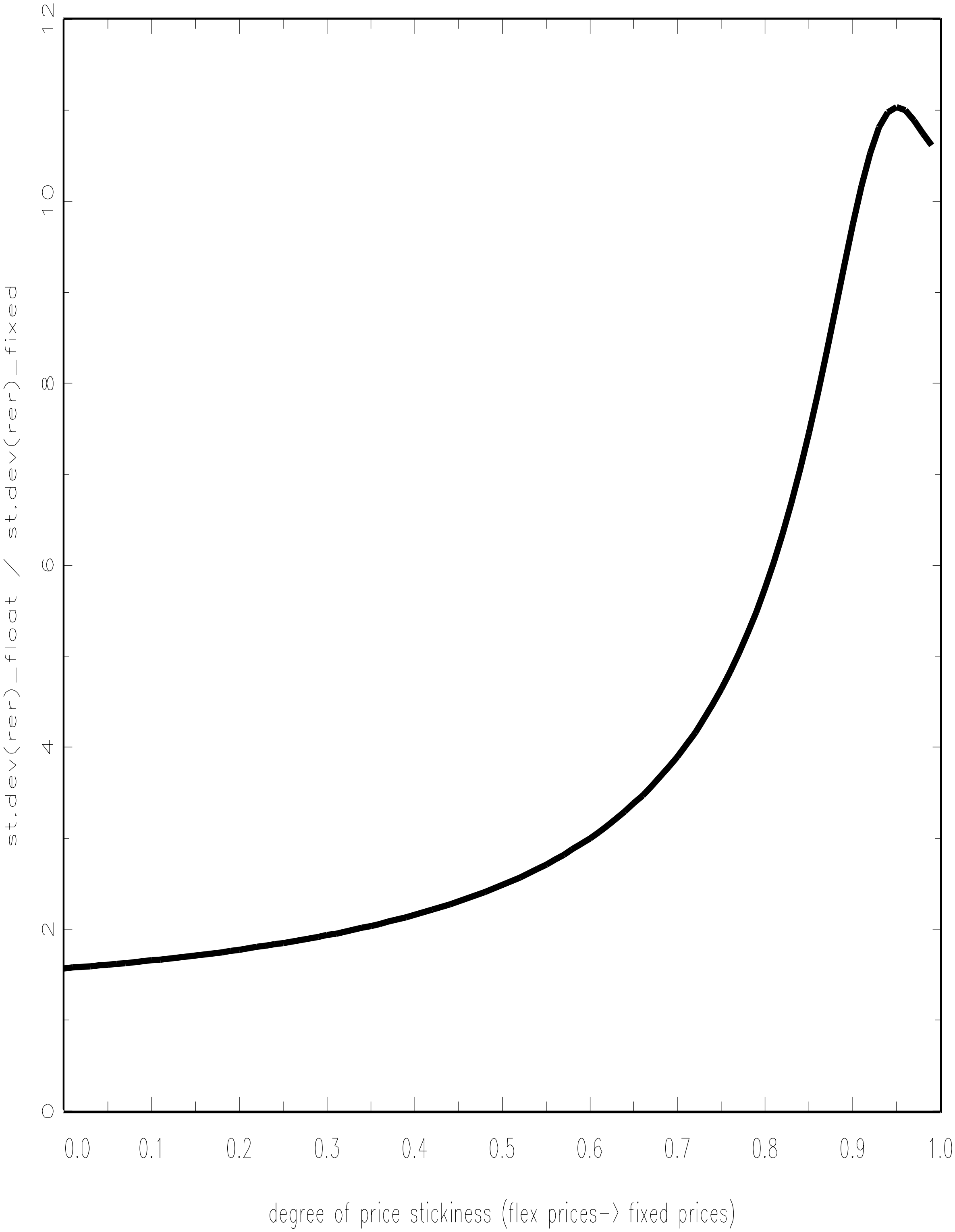


Figure 5. Volatility Ratio and Degree of Openness

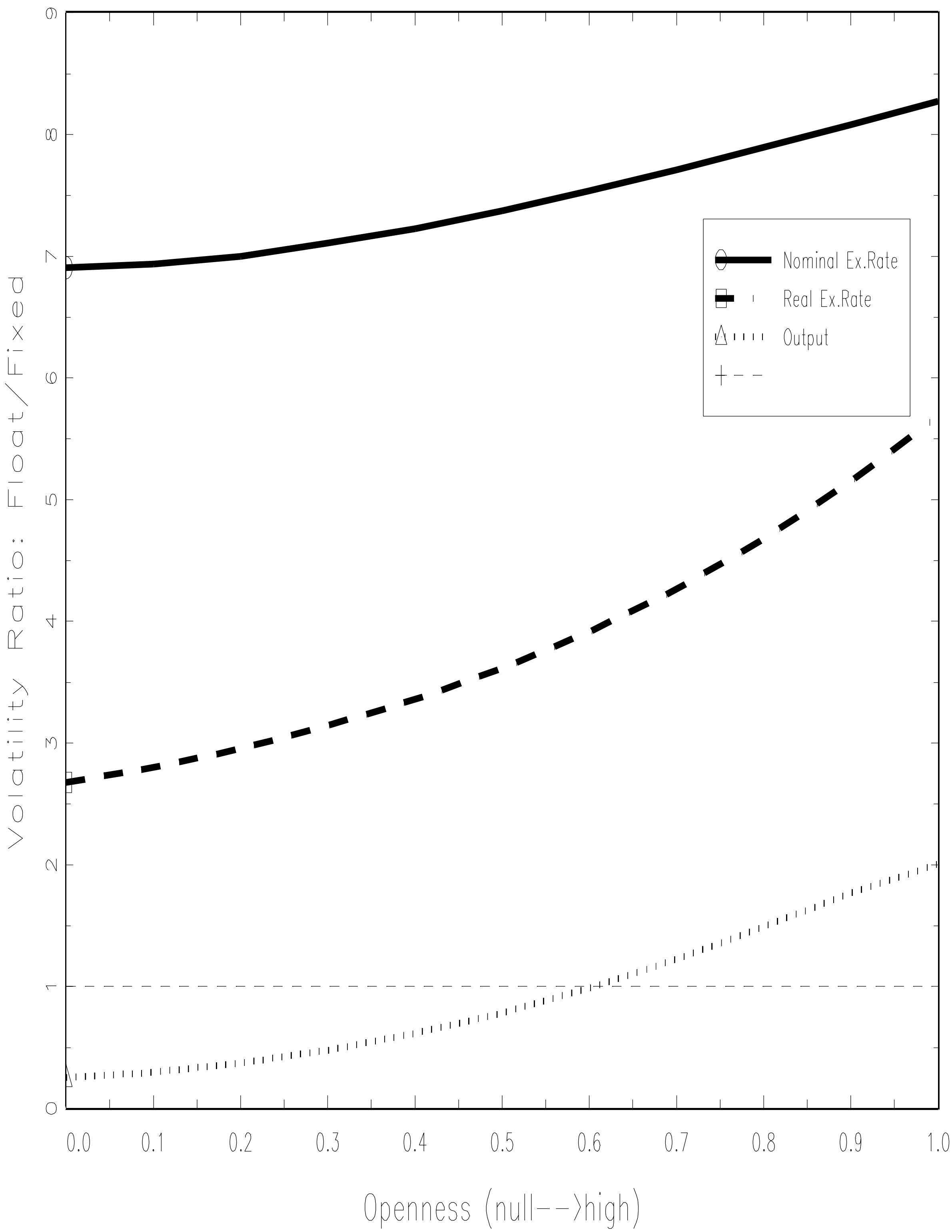


Figure 6. Volatility Ratio and the Elasticity of Substitution