Why Is the Business Cycle Behavior of Fundamentals Alike Across Exchange Rate Regimes?*

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First Draft: December 1998
This Draft: December 1999

Abstract

This paper develops a two-country, two-sector general equilibrium business cycle model with nominal rigidities featuring deviations from the law of one price. A model with such building blocks can quantitatively account for the well-established fact that, of the statistical properties of most macroeconomic variables, only the volatility of the real and nominal exchange rates has dramatically changed after the fall of the Bretton Woods system. Moreover, we show that simulated data from our artificial economy can reproduce the findings of some explicit tests proposed in the literature, relating the volatility of fundamentals and exchange rates across regimes.

JEL classification: E32, E52, F31, F33, F41. Keywords: equilibrium business cycle, price-adjustment costs, pricing to market, exchange rate regime, exchange rate volatility, fundamentals.

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*We thank Michael Devereux, Peter Ireland, Urban Jermann, Per Krusell, Tommaso Monacelli, Kevin Moran, Alan Stockman, Jeff Wrase, and Pierre Sartre for many helpful comments, as well as seminar participants at the Banca d'Italia, Boston College, the Chicago Fed 1999 Workshop in International Finance, the 1999 EEA Meeting, the 1999 SED Meeting, and Wharton. All remaining errors are our own. The views expressed here are those of the authors and do not necessarily represent those of the Banca d'Italia, the Federal Reserve Bank of Philadelphia, or the Federal Reserve System. This paper was previously circulated under the title *On Exchange Rate Regimes, Exchange Rate Fluctuations, and Fundamentals*.

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1. Introduction

The main industrial countries have experienced a wide range of exchange rate arrangements in the last century, ranging between the two polar systems of fixed and flexible exchange rates. The same variety of exchange rate regimes we observe across time for an individual country also exists today across countries. It is a well-established fact in international finance, documented by Stockman (1983) and Mussa (1986), among others, that exchange rate regimes have non-neutral effects, as they affect the behavior of the real exchange rate. The latter is much more variable under the current managed float than it was under Bretton Woods. There is also overwhelming evidence that since 1973, wild swings in nominal and real exchange rates have been highly correlated while ratios of price indices have been rather stable. Many economists view this as evidence that price rigidities matter and that they should be one of the basic ingredients in any theory of international economic fluctuations.[1]

However, as pointed out by Baxter and Stockman (1989), the puzzle is that the statistical properties of most other macroeconomic variables have remained very similar under the current managed float to what they were under Bretton Woods.[2] This fact poses a serious challenge to any economic model, with or without nominal rigidities, in which relative prices (like the real exchange rate) play a critical role in the allocation of real quantities. One would *a priori* expect that a change in the volatility of the real exchange rate would be associated with a change in that of other macoeconomic series. In this vein, Flood and Rose (1995), having shown that the increase in the volatility of the nominal exchange rate across exchange rate systems has no counterpart in that of any "traditional" fundamental, consider that "this suggests that exchange rate models based only on macroeconomic fundamentals are unlikely to be very successful."

Recently, Betts and Devereux (1998) showed that the combination of firms pricing-to-market and price rigidity in the buyers' currency magnify the volatility of the real and the nominal exchange rates for a given pattern of fundamental shocks. Moreover, since these features also lead to an imperfect pass-through of exchange rates' movements to consumer prices, they can mitigate the effects of exchange rate changes on equilibrium allocations, making a model with such building

[1] Stockman (1988) argues that equilibrium models with no price rigidity may account for the non-neutrality of the exchange rate regime as well.

[2] More recently, Sopraseuth (1999) finds similar results for both the Bretton Woods era and the European Exchange Rate Mechanism, using bootstrap techniques to test the significance of the change in the given statistics of interest.

blocks potentially capable of accounting for the above stylized facts. Therefore, in this paper, we attempt to account for the puzzle by introducing pricing-to-market and price rigidity in a relatively standard framework. More specifically, we quantitatively analyze the effects of different exchange rate arrangements on business cycle properties in a two-country, two-sector, dynamic general equilibrium model in which some firms price-to-market and face convex price-adjustment costs. Therefore, consistent with the growing empirical evidence, deviations from purchasing power parity (PPP) arise from a failure of the law of one price (LOP), in our environment. We examine a two-sector model for two reasons. The first relates to the evidence of a whole range of pricing behavior.[3] By introducing two sectors with different speeds of price-adjustment, we capture this aspect of the data and view the findings of our model as *quantitatively* more convincing. The second reason is that with pricing-to-market and convex price-adjustment costs, the level of the nominal exchange rate becomes indeterminate. With the presence of a good for which the LOP holds we avoid this indeterminacy.[4]

In our model, we find that the real exchange rate is clearly the variable most affected by the exchange rate regime. The variability of the real exchange rate falls dramatically under a fixed exchange rate regime relative to that when the exchange rate floats. On the other hand, the volatility of most other variables is practically unchanged across the two regimes. In this sense, the model is able to account for the empirical fact that more variability in real exchange rates does not get transmitted to other macroeconomic variables. We find that pricing-to-market is an important aspect of our results. Relative to the case in which firms do not price-discriminate, local-currency pricing, under a flexible exchange rate regime, increases the volatility of the real exchange rate and decreases the volatility of net exports. Pricing-to-market weakens the expenditure switching effect monetary policy shocks bring about due to price rigidity, since movements in nominal exchange rates are not fully passed-through to international prices. As a result, large variations in exchange rates are not necessarily associated with large movements in net exports. We also find that the presence of two sectors with different pricing behavior can be crucial. For instance, when the relative share of the flexible-price sector is small, the variance of net exports approximately dou-

[3] Wynne (1994) presents a detailed discussion and analysis of the relative evidence.

[4] Betts and Devereux (1998) solve this problem by postulating that the prices of the pricing-to-market firms are fixed for only one period, after which they fully adjust and PPP then holds. Since PPP determines the (long-run) level of the nominal exchange rate in this case, they can also determine it for periods in which prices are fixed solving backwards the Euler equation for bonds.

bles when the nominal exchange rate is allowed to float. Allowing for a larger flexible-price sector dampens the effect of the exchange rate regime on net exports at the cost, however, of generating a less variable real exchange rate. In our model, we also decompose the variance of the real exchange rate, under each exchange rate arrangement, into the variance of relative prices in each country and their covariance. The higher volatility of the real exchange rate, when the nominal exchange rate is allowed to float, is mainly due to a fall in the covariance of relative prices across countries. Since the variability of relative prices is approximately unchanged across exchange rate regimes, so is the variability of output and consumption.

As a final quantitative assessment of our model, we replicated the experiment conducted by Flood and Rose (1995) with the simulated time series from our model economy. We find that, as in their empirical test, the variability of (log)linear functions of observed fundamentals (*e.g.* output, money supply, price levels and interest rates) is barely affected by the exchange rate regime while that of the exchange rate increases substantially under a float.

This paper complements recent research exploring the persistence and volatility of both nominal and real exchange rates in dynamic stochastic general equilibrium models with nominal rigidities, *e.g.* Chari et al. (1998) and Kollman (1997). While these previous papers focus on the exchange rate properties under floating exchange rates, we direct our attention to the effects of different exchange rate regimes on the business cycle properties of exchange rates and other macroeconomic variables. In a vein close to ours, Monacelli (1998) accounts for the increase in the variability of the real exchange rate under the current managed float, in a (semi)small open economy with nominal rigidities. Nevertheless, his attempt is only partially successful at shedding some light on the puzzle. Bacchetta and van Wincoop (1998) and Devereux and Engle (1998) study the impact of the exchange rate regime on macroeconomic activity looking at the impact of exchange rate risks on trade and investment in models with imperfect pass-through. Finally, Moran (1998) studies the welfare consequence of establishing a monetary union in a model similar to ours.

The rest of the paper is organized as follows. Section 2 lays down the structure of the model; we then go on to discuss the model's calibration procedure. Impulse responses and business cycle statistics are presented in Section 4, while Section 5 replicates the Flood and Rose (1995) results; Section 6 concludes.

2. The Model

Building from the work of Obstfeld and Rogoff (1995), we model a two-country world in which each economy is composed of two sectors: one sector produces a homogeneous good and the other sector produces a set of differentiated products.[5] Specifically, the differentiated goods sector comprises a continuum of monopolistic firms, each producing a distinct differentiated good using labor and capital. These firms, contrary to the firms in the competitive sector, face convex price-adjustment costs of the type analyzed in Hairault and Portier (1993). We assume that because of barriers to trade, the monopolistic firms are able to price discriminate across markets. The homogeneous good, which is perfectly traded in world markets, is also produced using capital and labor. Capital and labor are mobile across sectors. For simplicity, we assume that investment is carried out in the homogeneous good only. To generate plausible investment volatility, we postulate a cost to adjusting the amount of capital in a country, as in Baxter and Crucini (1993). We now describe the model in more detail.

2.1. Preferences

A representative agent inhabits each economy. The agent maximizes his expected lifetime utility as given by

$$E_0\left[\sum_{t=0}^{\infty}\beta^t U\left(C^T, C^m, \frac{M'}{P}, (1-H)\right)\right] \tag{2.1}$$

where[6] C^T represents the agent's consumption of the homogeneous good, H represents the agent's supply of labor, M' denotes the agent's demand for nominal money balances, P is the country's price index, and C^m is an index of consumption of differentiated goods given by

$$\left[\int_0^1 (c^m(j))^{\frac{\theta-1}{\theta}} dj\right]^{\frac{\theta}{\theta-1}} \tag{2.2}$$

[5] The presence of a perfectly competitive sector for which the law of one price holds across countries is a way to circumvent the indeterminacy in the level of the nominal exchange rate that may potentially arise in models with PTM and price-adjustment costs.

[6] In the text, a superscript prime variable will denote a time $t+1$ variable, whereas a variable with no superscript represents a time t variable. Foreign variables will be denoted by an asterisk. A superscript T represents the purely tradable good, while a superscript m denotes the imperfectly competitive sector.

where $c^m(j)$ is the agent's consumption of differentiated good j, at time t. There is a continuum of these goods, with measure one. We assume that the home country produces the goods in the interval $[0,k]$, whereas foreign firms produce goods in the interval $(k,1]$.

The demand for the differentiated good j, obtained by maximizing the differentiated good consumption index subject to expenditure, is given by:

$$c^m(j) = (\frac{p^m_{h,l}(j)}{P^m})^{-\theta} C^m, \ l = h, f \tag{2.3}$$

where $p^m_{h,h}(j)$ is the home currency price of the home-produced differentiated good (for $j \in [0,k]$), $p^m_{h,f}(j)$ is the home currency price of a foreign-produced differentiated good (for $j \in (k,1]$) sold in the home country.[7] P^m is the differentiated goods' price index:

$$P^m = \left[\int_0^k \left(p^m_{h,h}(j)\right)^{1-\theta} + \int_k^1 \left(p^m_{h,f}(j)\right)^{1-\theta} \right]^{\frac{1}{1-\theta}}. \tag{2.4}$$

2.2. Production Technologies

The production of the homogeneous and differentiated goods requires combining labor and capital using Cobb-Douglas production functions:

$$Y^T = A\left(K^T\right)^{\gamma}\left(H^T\right)^{1-\gamma} \quad 0 < \gamma < 1 \tag{2.5}$$

$$y^m(j) = A\left(K^m(j)\right)^{\alpha}\left(H^m(j)\right)^{1-\alpha} \quad 0 < \alpha < 1, \forall\ j \tag{2.6}$$

where A represents an economy-wide, country-specific random technology shock.[8]

Capital accumulation is assumed to be carried out in the homogenous good only. In any given period, K will represent the capital stock in place in the home country. To have realistic investment flows (investment volatility tends to be too high otherwise), we follow Baxter and Crucini (1993) and assume that the law of motion of capital is subject to adjustment costs. The law of motion is described by the following equation:

$$K' = \psi(I/K)K + (1-\delta)K \tag{2.7}$$

[7] The first subscript h in $p^m_{h,l}(j)$ denotes that the good is sold in the home country, while the second subscript indicates where that good was produced.

[8] We also examined a version of the model with sector specific real shocks. The main findings of the paper were not affected, however, by this different stochastic structure.

where δ is the depreciation rate and $\psi(.)$ is an increasing, concave, and twice continuously differentiable function with two properties entailing no adjustment costs in steady state: $\psi(\delta) = \delta$ and $\psi'(\delta) = 1$.

2.3. The Firm in the Purely Tradable Good Sector

The firm's problem is the usual one:

$$\max_{K^T, H^T} \Pi^T \equiv P^T A \left(K^T \right)^{\gamma} \left(H^T \right)^{1-\gamma} - R^T K^T - W^T H^T \tag{2.8}$$

where P^T, R^T, and W^T denote the nominal price of the purely tradable good, the rental rate of capital, and the nominal wage rate in the purely tradable good sector.

The problem yields the standard efficiency conditions:

$$R^T = P^T A \gamma \left(K^T \right)^{\gamma - 1} \left(H^T \right)^{1-\gamma} \tag{2.9}$$

$$W^T = P^T A (1 - \gamma) \left(K^T \right)^{\gamma} \left(H^T \right)^{-\gamma} \tag{2.10}$$

2.4. Firms in the Pricing to Market Sector

We assume that firms in the PTM sector face a price-adjustment cost: when the firm decides to change the price it sets in the home (foreign) country, it must purchase an amount $\mu_h^m(j)$ ($\mu_f^m(j)$) of the homogenous good. The adjustment costs are given by the following convex functions:

$$\mu_h^m(j) = \varphi \left(p_{h,h}^m(j), p_{-1h,h}^m(j) \right) \tag{2.11}$$

and

$$\mu_f^m(j) = \varphi \left(p_{f,h}^m(j), p_{-1f,h}^m(j) \right) \tag{2.12}$$

The convex price-adjustment cost could be thought of as being due to customer loyalty in the presence of imperfect information (Okun (1980)). For instance, suppose consumers have imperfect information about the distribution of prices and that this information is costly to acquire. In such an environment, firms may prefer to make frequent small price changes rather than sporadic large ones. On the one hand, a firm may be unwilling to raise its price by a large amount for fear of antagonizing consumers and inducing them to search for better price offers from its competitors. On the other hand, a firm may also be reluctant to reduce its price by a large amount in such an environment. The cost for consumers to look for better prices gives an incentive to the firm to reduce its price by a smaller amount than in a world of perfect information. Of course, very little consensus has been reached on the form of these costs. Carlton (1986) concludes that there are many instances of small price changes, although a whole spectrum of pricing behavior is encountered. Kashyap (1995) reaches a similar conclusion studying data from retail catalog prices. By having two sectors with different price flexibility, we can capture some aspects of these findings.[9]

The (postulated) presence of trade barriers makes it possible for firms to price-to-market, by choosing $p^m_{h,h}(j)$, the home-currency price they charge in the home market, to be different from $p^m_{f,h}(j)$, the foreign-currency price they charge foreign consumers. Specifically, due to the presence of a price-adjustment cost, firms choose prices and inputs to maximize profits solving the following dynamic programming problem (where we dropped the index j for simplicity):

$$J(p^m_{-1h,h}, p^m_{-1f,h}; s) = \max_{p^m_{h,h}, p^m_{f,h}, K^m, H^m} \left\{ \rho \Pi^m + E\left[\rho' J\left(p^m_{h,h}, p^m_{f,h}; s' \right) \right] \right\} \qquad (2.13)$$

subject to

$$\Pi^m = p^m_{h,h}\ y^{m^d}_h + e\ p^m_{f,h,}\ y^{m^d}_f - R^m K^m - W^m H^m - P^T(\mu^m_h + \mu^m_f) \qquad (2.14)$$

$$y^m = A\,(K^m)^\alpha\,(H^m)^{1-\alpha} \qquad (2.15)$$

$$\mu^m_h = \varphi\left(p^m_{h,h}, p^m_{-1h,h})\right) \qquad (2.16)$$

$$\mu^m_f = \varphi\left(p^m_{f,h}, p^m_{-1f,h}\right) \qquad (2.17)$$

$$y^m \geq y^{m^d}_h + y^{m^d}_f \qquad (2.18)$$

$$y^{m^d}_h = (\frac{p^m_{h,h}}{P^m})^{-\theta} C^m \qquad (2.19)$$

$$y^{m^d}_f = (\frac{p^m_{f,h}}{P^{*m}})^{-\theta} C^{*m} \qquad (2.20)$$

where $s \equiv (A, A^*, g, g^*, PD^m_{t-1}, PD^{*m}_{t-1})$ denotes the aggregate state of the world in period t, with g (g^*) denoting the domestic (foreign) growth rate of money and PD^m (PD^{*m}_{t-1}) representing the distributions of differentiated goods' prices in the domestic (foreign) economy. As in Rotemberg and Woodford (1992), ρ is a pricing kernel for contingent claims.

[9] Woodford (1995) shows that an adjustment-cost model of price rigidity is observationally equivalent in its implications for the aggregate price level to the Calvo (1983) setup used, for example, in Kollman (1997).

2.5. The Household

Each period the household decides how much labor to supply to the monopolistic sector, ϕH, and to the competitive sector, $(1-\phi)H$, at the nominal wages W^m and W^T, where $0 < \phi < 1$. Similarly, the household supplies a fraction, ν, of capital to the monopolistic sector and a fraction, $(1-\nu)$, to the competitive sector at the nominal rental rates R^m and R^T. In addition to the factor payments, the wealth of the household comprises the nominal money balances, M, contingent one-period nominal bonds denominated in the home currency, $B(s)$, which pay one unit of home currency if state $s^{'}$ occurs and 0 otherwise, profits from the monopolistic firms, $\int_0^k \Pi^m(j)dj$, and a governmental lump-sum tax or transfer T. The household must decide how much of its wealth to allocate to the consumption of the homogeneous and differentiated goods and how much to invest and save in the form of bonds and nominal money balances, facing the following nominal budget constraint:

$$P^T C^T + P^m C^m + P^T I + \int_{s^{'}} P_b(s^{'}, s) B(s^{'}) ds^{'} + M^{'} = \Omega \tag{2.21}$$

where $P_b(s^{'}, s)$ is the price of the bond contingent on the state $s^{'}$ occurring at time $t+1$, given the state of the world, s, today. The agent's wealth follows the law of motion:

$$\begin{aligned} \Omega^{'} &= W^{m^{'}} \phi^{'} H^{'} + W^{T^{'}} (1-\phi^{'}) H^{'} + R^{m^{'}} \nu^{'} K^{'} + R^{T^{'}} (1-\nu^{'}) K^{'} \\ &\quad + B(s^{'}) + M^{'} + \int_0^k \Pi^{m^{'}}(j) dj + P^{T^{'}} T^{'} \end{aligned} \tag{2.22}$$

The household's problem can be written as the following dynamic programming problem:

$$V(\Omega; s) = \max_{C^m, C^T, B(s^{'}), M^{'}, H, I, K^{'}, \nu, \phi} \left\{ U\left(C^T, C^m, \frac{M^{'}}{P}, (1-H) \right) + \beta E\left[V(\Omega^{'}; s^{'}) \right] \right\} \tag{2.23}$$

subject to (2.21), (2.22), and the law of motion for capital given by (2.7).

2.6. Government

Each period the government makes a lump-sum transfer or collects a lump-sum tax (expressed in units of the tradable good) given by:

$$T = \left(\overline{M}^{'} - \overline{M} \right) \tag{2.24}$$

The money supply evolves according to:

$$\overline{M}^{'} = (1+g)\overline{M} \tag{2.25}$$

where g is a random variable.

2.7. Equilibrium

2.7.1. Definition

We focus on the equilibrium characterized by symmetry in the monopolistically competitive sector, defined as follows:

- a set of decision rules for the representative household and the foreign equivalent,[10] $C^T(\Omega; s)$, $C^m(\Omega; s)$, $B(\Omega; s^{'})$, $M^{'}(\Omega; s)$, $h(\Omega; s)$, $I(\Omega; s)$, $K'(\Omega; s)$, $\nu(\Omega; s)$, and $\phi(\Omega; s)$, solving the household's problem;
- a capital demand rule, $K^m(p^m_{-1h,h}(j), p^m_{-1f,h}(j); s)$, a labor demand rule $H^m(p^m_{-1h,h}(j), p^m_{-1f,h}(j); s)$, and a pricing function $p^m_{h,h}(p^m_{-1h,h}(j), p^m_{-1f,h}(j); s)$ and $p^m_{f,h}(p^m_{-1h,h}(j), p^m_{-1f,h}(j); s)$ solving the monopolistic firm's problem;
- a capital demand rule, $K^T(s)$ and a labor demand rule $H^T(s)$ solving the competitive firm's problem, taking prices, $P^T(s)$, $W^T(s)$ and $R^T(s)$, as given.
- $p^m_{h,h}(p^m_{-1h,h}(j), p^m_{-1f,h}(j); s) = p^m_{h,h}(p^m_{-1h,h}, p^m_{-1f,h}; s)$ and $p^m_{f,h}(p^m_{-1h,h}(j), p^m_{-1f,h}(j); s) = p^m_{f,h}(p^m_{-1h,h}, p^m_{-1f,h}; s)$ for all $j \in [0, k]$.
- $p^m_{h,h}(p^m_{-1h,h}(j), p^m_{-1f,h}(j); s)$, $p^m_{f,h}(p^m_{-1h,h}, p^m_{-1f,h}; s)$, $P_b(s^{'}, s)$, $P^T(s), W^T(s)$, $R^T(s)$, $W^m(s)$, and $R^m(s)$ are such that the goods, money, bonds, and input markets clear.

Since the traded good is perfectly traded on world markets, the law of one price holds:

$$P^T(s) = e(s)P^{T^*}(s). \tag{2.26}$$

The real exchange rate is therefore given by:

$$z(s) = \frac{e(s)P^*(s)}{P(s)}. \tag{2.27}$$

[10] In order to save on notation the foreign conditions are not shown.

Because some firms price-discriminate across countries, changes in the real exchange rate come from movements in the deviations from the LOP for monopolistic goods.

Household A solution to the household's problem satisfies:

$$U_1\left(C^T, C^m, \frac{M'}{P}, (1-H)\right) = \lambda P^T \tag{2.28}$$

$$U_2\left(C^T, C^m, \frac{M'}{P}, (1-H)\right) = \lambda P^m \tag{2.29}$$

$$\lambda P_b(s', s) = S(s', s)\beta V_1(\Omega'; s') \tag{2.30}$$

$$\lambda = U_3\left(C^T, C^m, \frac{M'}{P}, (1-H)\right) + \beta E\left(V_1(\Omega'; s')\right) \tag{2.31}$$

$$\lambda(W^m\phi + W^T(1-\phi)) = U_4\left(C^T, C^m, \frac{M'}{P}, (1-H)\right) \tag{2.32}$$

$$\chi\psi'(I/K) = \lambda P^T \tag{2.33}$$

$$\chi = \beta E\left[\lambda'(\nu R^{m'} + (1-\nu)R^{T'})\right] + \beta E\left[\chi'(\psi(I/K) - \psi'(I/K)(I/K) + (1-\delta)\right] \tag{2.34}$$

$$W^m = W^T \tag{2.35}$$

$$R^m = R^T \tag{2.36}$$

$$V_1(\Omega; s) = \lambda \tag{2.37}$$

where U_i and V_i represent the partial derivative of the utility function and the value function with respect to their ith argument, and χ is the multiplier associated with the capital evolution equation (2.7). $S(s', s)$ denotes the transition function governing the state of the world. It gives the probability of state s' occurring at time $t+1$, given that the world is in state s at time t.

Firms Similarly, the problem of the monopolistic firm yields the following conditions:

$$\rho W^m = \eta A(1-\alpha)\left(K^m(j)\right)^{\alpha}\left(H^m(j)\right)^{-\alpha} \tag{2.38}$$

$$\rho R^m = \eta A\alpha\left(K^m(j)\right)^{\alpha-1}\left(H^m(j)\right)^{1-\alpha} \tag{2.39}$$

$$\begin{aligned} \rho(1-\theta)\left(\frac{p^m_{h,h}(j)}{P^m}\right)^{-\theta} C^m \quad = \quad & -\rho P^T \varphi_1\left(p^m_{h,h}(j), p^m_{-1h,h,}(j)\right) \\ & -E\left[\rho' P^{T'} \varphi_2\left(p^{m'}_{h,h}(j), p^m_{h,h}(j)\right)\right] \\ & -\eta \frac{\theta}{P^m}\left(\frac{p^m_{h,h}(j)}{P^m}\right)^{-\theta-1} C^m \end{aligned} \tag{2.40}$$

$$\begin{aligned} \rho(1-\theta)\left(\frac{p^m_{f,h}(j)}{P^{m*}}\right)^{-\theta} C^{m*} \quad = \quad & -\rho P^T \varphi_1\left(p^m_{f,h}(j), p^m_{-1f,h}(j)\right) \\ & -E\left[\rho' P^{T'} \varphi_2\left(p^{m'}_{f,h}(j), p^m_{f,h}(j)\right)\right] \\ & -\eta \frac{\theta}{P^{m*}}\left(\frac{p^m_{f,h}(j)}{P^{m*}}\right)^{-\theta-1} C^{m*} \end{aligned} \tag{2.41}$$

where η is the multiplier related to the distribution of output across home and foreign markets (2.18), and φ_i is the partial derivative of the cost function with respect to its ith argument.

Conditions (2.38) and (2.39) are the standard conditions stipulating that the firm hires labor and capital until the marginal revenue of hiring one more unit equals its marginal cost. Equations (2.40) and (2.41) indicate that the firm selects prices $p^m_{h,h}(j)$ and $p^m_{f,h}(j)$ so that the marginal benefit of raising a price equals the marginal cost. In a symmetric equilibrium, these price-setting conditions become:

$$\begin{aligned} \rho(1-\theta)\left(\frac{p^m_{h,h}}{P^m}\right)^{-\theta} C^m \quad = \quad & -\rho P^T \varphi_1\left(p^m_{h,h}, p^m_{-1h,h}\right) - E\left[\rho' P^{T'} \varphi_2(p^{m'}_{h,h}, p^m_{h,h})\right] \\ & -\eta\theta\left(\frac{p^m_{h,h}}{P^m}\right)^{-\theta} \frac{C^m}{P^m} \end{aligned} \tag{2.42}$$

and

$$\rho(1-\theta)\left(\frac{p^m_{f,h}}{P^{m^*}}\right)^{-\theta} C^{m^*} = -\rho P^T \varphi_1\left(p^m_{f,h}, p^m_{-1f,h}\right) - E\left[\rho' P^{T'} \varphi_2\left(p^{m'}_{f,h}, p^m_{f,h}\right)\right] -\eta\theta\left(\frac{p^m_{f,h}}{P^{m^*}}\right)^{-\theta} \frac{C^{m^*}}{P^{m^*}} \tag{2.43}$$

By raising its price, the monopolistic firm benefits from the higher value of its output but bears the current and future costs of changing its price, as well as a lower current demand for its product.

3. Calibration

Preferences We simulate the model economy using a utility function of the form:

$$\frac{\sigma-1}{\sigma}\ln\left[\left(\left(C^T\right)^{\omega}\left(C^m\right)^{1-\omega}\right)^{\frac{\sigma}{\sigma-1}} + \left(\frac{M'}{P}\right)^{\frac{\sigma}{\sigma-1}}\right] + \upsilon\ln(1-H). \tag{3.1}$$

The interest elasticity of money demand, σ, is known to be small but positive. We use Ireland's (1997) estimate and set it equal to 0.159. υ is calibrated such that the agent spends 30 percent of his time working in steady state. Since we are not aware of any satisfactory way to pin down ω, the relative share of the flexible-price, competitive good on steady state consumption, as a natural benchmark value we set this parameter to 0.5, middle ground between complete price stickiness and perfect price flexibility.[11] We set the discount factor to 0.9901, which implies a quarterly real interest rate of 1 percent.

Production We set θ=6.17. This gives a value of 1.19 for the steady state markup, which is the value estimated by Morrison (1990). This value is standard in the literature.

We assume the following quadratic form for the cost of price-adjustment function:

$$\frac{d}{2}\left(\frac{p^m_{h,h}}{p^m_{-1h,h}} - 1\right)^2. \tag{3.2}$$

Therefore, there are costs to adjusting prices in steady state as in Ireland (1997) and Aiyagari and Braun (1997). Following the latter, we use empirical results from

[11] In section 4.2.2 we analyze the implications of different values of this parameter.

the VAR literature to calibrate the adjustment cost parameter, d. We choose d such that the maximal response of employment to a one-standard-deviation impulse to the growth rate of money is the same as that reported by Christiano, Eichenbaum, and Evans (1996). Using a nonstructural VAR in which monetary shocks are identified by innovations to nonborrowed reserves, they find that a contractionary one-standard-deviation monetary innovation leads to a 0.149 percent decline in employment. This yields a value of the adjustment-cost parameter, d, equal to 6, which implies that, in steady state, the economies spend 0.1% of world output adjusting prices.

Since all the goods are traded, we used Stockman and Tesar's (1995) estimate of the labor share in the production of tradable goods and set $(1-\gamma)$ and $(1-\alpha)$ to 0.61.

Real Shocks The economy-wide technology shocks are assumed to follow a bivariate autoregressive process:

$$\mathbf{z}^{'} = \boldsymbol{\lambda}_1 + \boldsymbol{\lambda}_2 \mathbf{z} + \boldsymbol{\epsilon}^{'} \tag{3.3}$$

where $\mathbf{z} \equiv (z, z^*)^{'}$, $\boldsymbol{\epsilon} \equiv (\epsilon, \epsilon^*)^{'}$ and $\boldsymbol{\lambda}_1$ is a vector of constants and $\boldsymbol{\lambda}_2$ is a matrix of coefficients. We compute the Solow residuals from aggregate quarterly data on output and employment for the U.S. and Germany, taken from the Federal Reserve System database, for the period 1973:1-1998:3 (i.e., the floating period). As is standard in the literature, the Solow residuals are constructed as $log\ y$-$(1-0.39)logn$, without including a measure of the capital stock. We used data on civilian employment instead of hours worked, since Germany does not compile statistics on the latter. The estimates are

$$\boldsymbol{\lambda}_2 = \begin{bmatrix} 0.975 & 0.004 \\ -0.015 & 0.985 \end{bmatrix}.$$

The standard deviations of the U.S. and German productivity shocks are 0.0037 and 0.0067, respectively, and the correlation between the innovations is 0.028.[12]

[12] These values are on the lower side with respect to those usually assumed in the literature. For instance, Backus et al. (1995) set the standard deviation of productivity shocks in both the home and the foreign country, and their cross-correlation to 0.00852 and 0.258 respectively. Our choice affects the *absolute* level of volatility of real variables in our model, as shown in the following section. However, since our main focus is on *relative* volatility *across regimes*, adopting the above mentioned values would not change our main results.

Monetary Shocks We assume that the monetary growth rates in the two countries follow two independent autoregressive processes. We assume independence because monetary innovations are not highly correlated across countries. We estimate the following process for the U.S. and Germany using quarterly data on M1 for the (floating) period 1973:1-1998:3

$$\log g^{'} = (1 - \rho_g) \log \overline{g} + \rho_g \log g + u^{'}, \tag{3.4}$$

where $u^{'}$ is a normally distributed error term with a standard deviation σ_u. For the U.S., we obtain the following, rather standard, estimates: $\rho_g = 0.544$, $\overline{g} = 1.0142$, and $\sigma_u = 0.007$.[13] In contrast, the estimation on German data yielded $\rho_g = 0.445$, $\overline{g} = 1.0189$, and $\sigma_u = 0.008$.

4. Findings

We now assess the business cycle properties of our model economy under the two different exchange rate regimes by studying the effects of both real and monetary shocks. We begin by computing impulse-response functions to grasp some intuition on the working of our two-sector, two-country model; subsequently, in the spirit of the equilibrium business cycle literature, we analyze the second moment properties of the model, focusing on the difference in the volatility of key variables across exchange rate regimes. Throughout all the exercises but the last one, we define the fixed exchange rate regime as the one in which the foreign country (credibly) pegs its currency to that of the home country.

4.1. Impulse Responses

The impulse-response experiments consist of shocking the driving process once at date 0, when both countries are at their deterministic steady state. We discuss first responses of the home and foreign economies to an unexpected increase in the home growth rate of money (equivalent to a permanent unexpected increase in the home money stock), followed by an investigation of the responses to an unexpected positive aggregate real shock to the home country.

Monetary Shock Figures 1a and 1b depict the responses, under each exchange rate regime, of key variables in each country (aggregate, tradable and PTM output, aggregate consumption, labor supply, relative price of PTM goods, inflation,

[13] Cooley and Hansen (1995) set the value of ρ and σ to 0.5 and 0.01, respectively.

and the nominal interest rate), as well as the nominal and the real exchange rate, to a one standard deviation shock to the growth rate of money (amounting to an increase of 0.6 percentage point). In all figures, the solid line corresponds to the peg and the dashed line corresponds to the flexible exchange rate regime. While the initial shock is unanticipated, the future path of the money stock is known with certainty by households, because money growth follows a known autoregressive law of motion. This means that in our model, as we mentioned above, monetary policy has real effects even when anticipated. On impact, because of the presence of the price-adjustment cost, the home nominal price of monopolistic goods reacts less than the nominal price of the perfectly competitive good, making the mark up and relative price of the former fall. As a consequence, households choose to substitute out of the competitive good into home and foreign PTM goods, since the two commodities are fairly good substitutes (the elasticity of substitution is unity in our baseline Cobb-Douglas utility), thus shifting the factors of production toward these goods in both countries. The production of monopolistic goods increases while that of competitive goods shrinks; at the aggregate level both home output and home consumption rise. The increase in consumption is due to a fall in the real interest rate, although the nominal interest rate slightly rises, following the jump in expected inflation. In subsequent periods, the anticipated inflation effect brings about an increase in the real rate, depressing consumption. Investment falls on impact, and the aggregate capital stock in the following periods declines because of the assumption that capital is a flexible price good. In our model, price stickiness, as already pointed out by Ohanian, Stockman, and Kilian (1995), imposes only an intratemporal distortion without affecting the intertemporal choice between consumption today and tomorrow, as would be the case if capital were a sticky price good, as in standard one-sector models with nominal rigidities (e.g., Kim (1995)).

As we anticipated beforehand, with pricing-to-market and perfect capital mobility (complete asset markets), a floating exchange rate does not perfectly insulate the foreign country from the monetary shock occurring in the home country. Indeed, home demand for the foreign produced monopolistic goods increases too. This triggers an increase in labor supply in the foreign country in order to meet world demand, as well as a shift of resources from the competitive to the monopolistic sector. The foreign agent has to produce more while consuming roughly the same: nominal and real interest rates are barely affected. As a consequence, aggregate consumption displays little correlation across countries, while as in the home country, the aggregate level of output rises in the foreign country. The decrease in world production of perfectly traded commodities also puts downward pressure on the foreign relative price of PTM goods, though to a much lesser extent than in the home country. Following the monetary shock both the real and nominal exchange rates depreciate. The persistence of the nominal exchange rate movements closely mimics the persistence of the monetary shock, since the nominal exchange rate is determined by the LOP in the flexible-price sector. However, the persistence of the real exchange rate is significantly higher. The real exchange rate response to a monetary shock has a half-life of about seven quarters, slightly lower than what is found empirically.

Under a fixed exchange rate regime, the propagation of the monetary shock is quite different. Since its currency is pegged, the foreign monetary authority has to increase the rate of money growth following a monetary expansion in the home country. Thus it imports the home monetary policy and now behaves identically like the home economy. The responses of all variables in both countries are generally larger in absolute value under a fixed exchange rate regime, with the exception of the real exchange rate. This result does not seem to support the Mundell-Fleming view that fixed exchange rates are preferable (in the sense that output is less volatile) when the source of the shocks is mainly monetary.[14]

Real Shock In contrast to monetary shocks, the transmission of economy-wide, country-specific real shocks is practically the same under either a fixed or a flexible exchange rate regime, as in this case the full insurance mechanism that complete markets entail is at work. The impulse-responses are presented in Figures 2a and 2b. Following a positive shock to home aggregate productivity, the inflation rate falls on impact in both countries.[15] The relative price of monopolistic goods rises in the two countries as a result of the price-adjustment cost borne by firms in this sector. Consequently, the world consumption of PTM goods falls on impact.[16] The foreign production of tradable goods falls on impact as the foreign agent works less (this effect is again due to complete markets) and continues decreasing as investment (not shown) flows toward the home country. In the aggregate, consumption in the two countries increases, whereas home output increases and the foreign output falls. Under floating exchange rates, both the nominal and the

[14] In terms of utility, however, the welfare benefit of a fixed exchange rate system can be quite different.

[15] For simplicity, we assume the real shocks to be uncorrelated across countries for this experiment.

[16] The response of tradable consumption is not shown, but it obviously increases.

real exchange rates appreciate on impact following the real shock, although the magnitude of the appreciations is quite small. The real appreciation is the result of the fall in the foreign relative price of monopolistic goods relative to the home one.

It is interesting to note that the fixed exchange rate regime brings about a decrease in the volatility of the real exchange rate, with all the other variables reacting in the same way as under a float. Under a real shock, the exchange rate regime does not provide a way of shielding from its consequences, mainly affecting the real exchange rate response. As we just pointed out, this is in contrast to monetary shocks, in which case a fixed exchange rate regime amplifies the response of most variables, except that of the real exchange rate. However, it is still possible that the exchange rate regime affects mainly the real exchange rate when an economy is hit by a combination of both real and monetary shocks. We turn to this question in the next section in which we quantifies the impact of the exchange rate regime on the volatility and the persistence of the principal macroeconomic variables in our model.

4.2. Business Cycle Properties

As we mentioned earlier, Stockman (1983), Mussa (1986), Baxter and Stockman (1989), and Flood and Rose (1995) find that most variables have approximately the same statistical properties under either Bretton Woods or the current floating exchange rate system. The one exception is the real exchange rate. This finding is at odds with the received view that the decrease in the volatility of the real exchange rate brought about by fixed exchange rates should be reflected in increases in the volatilities of other macroeconomic variables. This section first quantifies the effect of a change in the exchange rate arrangement on the statistical properties of key macroeconomic variables in the model. We compute all the statistics by logging and filtering the data using the Hodrick and Prescott filter and averaging moments across 100 simulations, each running for as many periods as the actual fixed and floating historical periods (*i.e.*, 52 and 116 quarters respectively).

To give a simple idea of the extent of the puzzle, Table 1 reports the average standard deviations of inflation, ouput, consumption, investment, labor, net exports (NX) and exchange rates for the G7 countries. We report both the trade-weighted exchange rates and the exchange rates against the dollar (z/$ and e/$). The table clearly shows that while the real and the nominal exchange rates became much more volatile in the post-Bretton Woods era, we do not observe a similar change in the volatility of the other macroeconomic variables reported in the table. For instance, the average standard deviations of output and inflation are roughly the same under the two eras. Moreover, while consumption, investment, and employment have become more volatile, on average, since 1973, this increased volatility pales compared to the increase in the standard deviation of the real exchange rate. Finally, the standard deviation of net exports slightly fell after the demise of Bretton Woods.

Using our simulated data, Table 2 reports the standard deviation of the real and nominal exchange rates, as well as that of home inflation, output,consumption, investment, labor, and net exports. Table 3 describes the volatility of the foreign variables under the two regimes.

Table 2 shows that the variability of output under a flexible exchange rate regime is 0.8 percent, roughly one half of the variability of the G7 average output, while the volatility of aggregate consumption is 40 percent of that in the data, during the flexible exchange rate period. The standard deviation of investment is 5.7 times larger than that of output, higher than what it is in the actual data. Aggregate output in the foreign country is more volatile than in the home country, while foreign aggregate consumption is as volatile as in the home country. Foreign aggregate output is more volatile than home aggregate output because of the higher standard deviation of the foreign real shock, under our calibration. Similarly, foreign investment is also more volatile than home investment. Table 3 also shows that the standard deviation of the foreign output is roughly 2/3 of that in the data.

As we previously mentioned, both real and nominal exchange rates have been highly volatile under the current flexible exchange rate system. In fact, table 1 reports that the standard deviation of either exchange rate is approximately between 2.5 and 4 times that of output, depending on the type of exchange rate (trade-weighted or bilateral). Under our calibration, the model with a floating exchange rate regime produces variability of the real and nominal exchange rates that are 1.3 and 3.2 times the variability of home output, respectively. Therefore, the model succeeds in generating a volatile nominal exchange rate, yet this does not completely translate into a very large variability of the real exchange rate relative to aggregate output.

Comparing volatilities of variables under either a fixed or a flexible exchange rate regime, Tables 2 and 3 show that the real exchange rate is clearly the variable most affected by a change in regime. All other variables are barely influenced by the change of regime, and none experienced changes in volatility as large as that of the real exchange rate.[17] In this sense, the model is able to account for the empirical fact that more variability in the real exchange rate does not get transmitted to other macroeconomic variables. We provide some intuiton behind the result in the following section.

To gauge the contribution of monetary shocks to this finding, we computed the same across-regime volatilities with only real shocks. Tables 4 and 5 show the results for the home and foreign country, respectively. Now, all the variables are less volatile than in the case in which both money and real shocks are present. However, it remains that the variables most affected by the change in the exchange rate regime are the nominal and the real exchange rates. For instance, the real exchange rate is twice as volatile when the nominal exchange rate floats, while the volatility of the remaining variables (except the nominal exchange rate, of course) are unaffected by the exchange rate regime. Note, also, that both exchange rates are now much less volatile than aggregate output. This suggests monetary shocks play an important role in determining the variability of the real exchange rate when prices are sticky. This is in stark contrast to results found in open-economy flexible-price models. Our result is also consistent with findings in the VAR literature measuring the effects of monetary shocks in an open economy. Both Clarida and Galì (1994) and Eichenbaum and Evans (1996), using VAR data representations under very different identifying assumptions, found a significant portion of the forecast error's variance in exchange rates to be due to monetary shocks.

Finally, in Table 6 we report the impact of the exchange rate arrangement and of real and monetary shocks on the serial and cross-correlation of selected variables. The first three lines show the serial correlation of the real and nominal exchange rate and their cross-correlation. In our model, under a float, both exchange rates are less persistent than in the actual data, and monetary shocks have a dampening impact on the persistence of the real exchange rate, reflecting the fact that monetary shocks are less autocorrelated than productivity shocks. This points to a weakness in the propagation mechanism of monetary shocks in our model. Note also that under the flexible exchange rate regime, the real and the nominal exchange rates are highly correlated when the simulations include all the shocks. That correlation, however, falls by approximately a half when only

[17] The volatility of sectoral output and consumption did not change dramatically either, across exchange rate regime. Relative to the fixed exchange rate regime, the ratios of standard deviations of home tradable and nontradable consumption under the flexible exchange rate arrangement were 0.88 and 0.99; that of tradable and nontradable output were 0.98 and 0.7.

real shocks are included. Again, this points to the importance of monetary shocks in our framework.

The last four lines of Table 6 show the correlation of the real exchange rate to the ratio of home and foreign aggregate output, the cross-country correlation of aggregate consumption, aggregate output, and the nominal money supply. The first statistics is consistent with the data for the case with both real and monetary shocks, as the real exchange rate displays basically no correlation with the ratio of output (Stockman (1998)). The model's consumption correlation across countries decreases going from a fixed to a flexible exchange rate regime. Moreover, that correlation is approximately zero when the exchange rate is allowed to float in the model and both types of shocks affect the economies. This result is due to the joint presence of monetary shocks and pricing-to-market, as was highlighted by Betts and Devereux (1998). As could be seen from the impulse response functions, a monetary shock, under a flexible exchange rate regime, raises home consumption while foreign consumption remains approximately unchanged. In contrast, domestic and foreign consumptions move together in response to a real shock. Thus, the presence of monetary shocks lowers the consumption correlation so much that it is roughly zero under the flexible exchange rate regime. Note, however, that the correlation of domestic and foreign output is negative in the model. Finally, as expected, the cross-country correlation of nominal money supply decreases under floating exchange rates.[18]

4.3. Understanding the Mechanism

4.3.1. The Behavior of Relative Prices Across Countries

Why are the variances of most macroeconomic series in our model, except that of the real exchange rate, unaffected by the exchange rate regime? One immediate reason is that the change in the exchange rate system mainly impinges on the covariance between domestic and foreign relative prices. Define q (q^*) as the domestic (foreign) relative price of the imperfectly competitive goods in term of the perfectly competitive one:

$$q = \frac{P^m}{p^T}. \tag{4.1}$$

[18] The cross-correlations of consumtpion and money, under a fixed exchange rate regime, are much higher in the model than in the data. This can be partly due to the fact that, contrary to our fixed exchange rate regime, Bretton Woods was not a system of perfectly pegged currencies.

Recalling that LOP holds in our model for the competitive good, the real exchange rate can be written as a power of the ratio of relative prices in the two countries:

$$z = \frac{eP^*}{P} = \left(\frac{q^*}{q}\right)^{1-\omega}. \tag{4.2}$$

where ω is the weight of the competitive good in the consumption aggregator. Therefore, the variance of the logarithm of the real exchange rate can be decomposed in the following way:

$$Var(\log z) = (1-\omega)^2 \left[Var(\log q^*) + Var(\log q) - 2Cov(\log q^*, \log q)\right]. \tag{4.3}$$

As the impulse-response functions documented, under a flexible exchange rate regime, the domestic and foreign relative prices are barely correlated in response to a monetary shock and perfectly correlated in response to a real shock. Since the foreign country imports the home monetary policy when it pegs its nominal exchange rate, relative prices become perfectly correlated in response to both real and monetary shocks. Therefore, the covariance and the correlation of relative prices increase under a fixed exchange rate regime. Under a fixed exchange rate system, the covariance between domestic and foreign relative prices increases to such an extent that the variance of the real exchange rate is approximately zero. Table 7 presents the ratios of the standard deviation and the covariance of domestic and foreign relative prices under the two exchange rate regimes.

The table shows that while the standard deviations of the domestic and foreign relative price is approximately the same under the two exchange regimes, the covariance between these two relative prices is five times higher when the nominal exchange rate is fixed. The fact that the volatility of relative prices is barely affected by the exchange rate regime explains why consumption and output are nearly as volatile when the exchange rate is fixed or not. The increase in the covariance between domestic and foreign prices under the fixed exchange rate regime also explains why the correlation of consumption in Table 6 increases going from a flexible to a fixed exchange rate.

In our framework, this change in the covariance structure between domestic and foreign relative prices clearly points towards the advantage to adopting a two-country general equilibrium model, as opposed to a small or semi-small open economy in which foreign relative prices are exogenous, to study the effects of exchange rate regimes. In the latter instance, all variations in the real exchange rate will be due to movements in domestic relative prices, because the covariance between domestic and foreign relative prices as well as the variance of the latter will be zero. Since more variable domestic prices will bring about more volatile domestic consumption through the first-order condition for consumption, it has to be the case that a more volatile real exchange rate in such an environment results in an increase in the volatility of consumption. However, in a general equilibrium context, an increase in the variability of the real exchange rate does not necessarily have to come along with an increase in the volatility of consumption or other macroeconomic series, as our results demonstrate.

4.3.2. The Role of Pricing-to-market and Two Sectors

Intuitively the higher volatility of the real exchange rate under the flexible exchange rate regime should have an impact on the volatility of net exports. In our baseline calibration, this does not happen, mainly because of the presence of firms pricing-to-market and because of a significant share of the competitive good. Figures 3 and 4 shed some light on the contribution of these two features of the model. Figure 3 shows the standard deviation of the real exchange rate relative to output with respect to the share ω of the purely competitive, flexible-price good when monopolistic firms price-to-market or not. As Betts and Devereux (1998) pointed out, it is apparent that local currency pricing increases the volatility of the real exchange rate relative to that of output. It also shows that the impact of pricing-to-market is greater the more important is the monopolistic sector. Figure 4, on the the hand, shows the standard deviation of net export under the flexible exchange rate regime relative to the standard deviation of net exports when the exchange rate is fixed. This ratio is shown as function of ω, with and without pricing-to-market: pricing-to-market clearly dampens this ratio. Therefore, pricing-to-market is an important feature of the model as it increases the volatility of the real exchange rate with respect to output and it decreases the effects of that volatility on the variability of net exports. Basically, the combination of pricing-to-market and price rigidity in the buyer's currency mitigates the expenditure switching effect, since movements in nominal exchange rates do not fully pass-through to the prices consumers face. As a result, large variations in exchange rates are not necessarily associated with large movements in net exports. The figures show that the presence of a perfectly competitive sector is important too. If the economies were composed solely of pricing-to-market monopolistic firms, under a flexible exchange rate regime the model would counterfactually generate net exports almost twice as volatile as when the foreign currency is fixed. In this case, a larger share of the home country's exports is subject to foreign monetary policy shocks.

5. The Flood and Rose (1995) Experiment Revisited

In this section we set out to replicate the main experiment Flood and Rose (1995) conducted on a panel of eight OECD countries. They start with the observation that exchange rates are significantly more volatile under flexible exchange rate regimes than under fixed ones. They also find that the volatility of other macroeconomic variables does not change much across exchange arrangements. As a result, they argue that models based on fundamentals will likely be unsuccessful at explaining exchange rates' movements.

Their experiment is as follows. Take a standard monetary model of exchange rate determination, first assuming perfectly flexible prices. Using a structural money-market equilibrium condition and *PPP*, the logarithm of the exchange rate can be written as:

$$e_t = (m_t - m_t^*) - \beta(y_t - y_t^*) + \alpha(i_t - i_t^*) - (\varepsilon_t - \varepsilon_t^*) - \upsilon_t \tag{5.1}$$

where e_t is the nominal exchange rate, m_t denotes the money stock, y_t represents real income, i_t is the nominal interest rate, and ε_t is a money demand shock. Foreign variables are denoted with an asterisk and υ_t is a stationary random deviation from *PPP*. β and α are structural parameters representing the income and interest elasticities of money demand, respectively. Denote "traditional fundamentals" by relative money stocks and real income across countries:

$$TF_t \equiv (m_t - m_t^*) - \beta(y_t - y_t^*). \tag{5.2}$$

Finally, define as "virtual fundamentals":

$$VF_t \equiv e_t - \alpha(i_t - i_t^*). \tag{5.3}$$

Under the assumption of price stickiness, a similar expression relating virtual and traditional fundamentals can be derived using a Phillips-curve equation:

$$\begin{aligned} e_t - \alpha(i_t - i_t^*) &= TF_t - \frac{\phi}{\theta} r_t - \frac{\phi}{\theta^2} E_t(r_{t+1} - r_t) \\ &\quad -\theta^{-1} E_t\left[(e_{t+1} - e_t) + (p_{t+1}^* - p_t^*)\right] + \theta^{-1}(p_{t+1} - p_t), \end{aligned} \tag{5.4}$$

where r_t is the ex ante real interest rate while θ and ϕ are parameters characterizing the price-adjustment process. The right-hand side of the equation defines the traditional fundamentals under price stickiness:

$$\begin{aligned} TFS_t \equiv\ & TF_t - \frac{\phi}{\theta} r_t - \frac{\phi}{\theta^2} E_t(r_{t+1} - r_t) \\ & -\theta^{-1} E_t \left[(e_{t+1} - e_t) + (p^*_{t+1} - p^*_t) \right] + \theta^{-1}(p_{t+1} - p_t). \end{aligned} \tag{5.5}$$

As Flood and Rose (1995) stipulate, both traditional and virtual fundamentals are two different ways of measuring the same latent variable. Therefore, we should expect TF_t (TFS_t) and VF_t to behave similarly provided the model is a good representation of the data. However, virtual and traditional fundamentals behave very differently across exchange rate regimes. Flood and Rose (1995) show that the volatility of virtual fundamentals is much higher under the Bretton Woods system than under the current managed float, while that of traditional fundamentals does not change significantly. To statistically test for a change in volatility across exchange rate regimes, the authors assume that the change in traditional and virtual fundamentals, ΔTF_t (ΔTFS_t) and ΔVF_t, are normally distributed, so that the ratio of regime-specific sample variances is distributed as F under the null hypothesis of equal variance across exchange rate regimes. For each definition of fundamentals, Table 8 reports the ratio of the sample standard deviation under floating exchange rates relative to the sample standard deviation under Bretton Woods. In the column labeled "Data," we report the same statistic computed with German and U.S. quarterly data. We use data from 1960Q2 to 1972Q4 for the Bretton Woods era and from 1973Q1 to 1998Q3 for the post-Bretton Woods era. The table shows that while the null hypothesis of equal standard deviation across regimes cannot be rejected at the 5 percent confidence level for traditional fundamentals (with or without price stickiness), this is not the case for virtual fundamentals.[19] The variance of virtual fundamentals increases more than three times across regimes.

The second and third columns of Table 8 report the results from the simulated series of our model under all shocks and only real ones, respectively. As in Flood and Rose (1995), we set $\beta = 1$ and $\theta = \phi = 0.1$.

[19] The critical values are 1.59 and 1.94 at the 5% and 10% confidence level. In Table 8, two asterisks indicate that the null hypothesis of equal volatility cannot be rejected at the 5% confidence level; one aterisk indicates that the hypothesis can be rejected at the 5% but not at the 1% confidence level.

We ran the following experiment. We simulate our model under both the flexible and the fixed exchange rate regime. Since under a *perfect* peg the volatility of the virtual fundamentals will be exactly zero, and therefore, the ratio across regimes will be infinite, we introduce some variability in the nominal exchange rate by adding a shock to the nominal exchange rate. We calibrate this shock so that the standard deviation of the simulated VF under the fixed exchange rate regime is the same as that found in the data for the Breton Woods period (roughly 1%). We then endogenously derive the consistent process for the foreign growth rate of money. Real shocks in both countries and home money supply shocks were set to their benchmark values. Looking at column 2 for all shocks, the results in Table 7 show that the simulated series from our model give a very similar picture to that in the actual data. In fact, the behavior of the volatility of traditional fundamentals across regimes is so close in our model that the null hypothesis of equal variance would not be rejected in our simulated data. Moreover, the model captures the increase in the variability in virtual fundamentals going from a fixed to a flexible exchange rate regime: the volatility ratio of VF is 3.58 in the data while our model generates a ratio of 3.16. The third column sheds some light on this result: the change of regime is not able to account for the change in volatility when there are only productivity shocks, as the ratio of volatility of the virtual fundamentals now falls below one going from a fixed to a flexible exchange rate regime. As the previous analysis of the variables' second moments in the model showed, monetary shocks play an important role in the dynamics of the model, allowing the model's implications to be closer to the data along important dimensions.

6. Conclusions

Recently Devereux (1997), drawing together the relevant evidence from both empirical and theoretical research, concluded that there is some hope for a "traditional" macroeconomic approach to the real exchange rate. Following this lead, this paper developed a rather standard general equilibrium model, featuring deviations from the law of one price and nominal price rigidities. We found it capable to go some way in accounting for both the dramatic increase in the relative volatility of the nominal and real exchange rates occurring after the demise of the Bretton Woods system, as well as the relative stability in the volatility of most other macroeconomic variables. One of the main mechanisms behind this result is the combination of pricing-to-market and price rigidity in the buyer's currency, as fluctuations in nominal exchange rates are not fully passed-through to prices consumers face. Consequently, large variations in exchange rates are not necessarily associated with large movements in quantities. This feature is quantitatively crucial, since it increases the volatility of the real exchange rate and decreases that of net exports. Moreover, different speeds of price-adjustments across sectors are also important, since a world economy solely composed of monopolistic firms pricing-to-market would counterfactually generate net exports that are significantly more volatile in a flexible *vis-à-vis* a fixed exchange rate regime.

Our findings seem to have an obvious policy implication: if there is no significant trade-off between exchange rate stability and macroeconomic volatility, then floating exchange rates may be excessively volatile. However, in order to make explicit policy recommendations our analysis should be extended in at least two ways. First, a thorough assessment of the welfare impact of exchange rate volatility should be undertaken. Second, the management of the exchange rate implies that monetary policy has to give up on goals related to internal stabilization. The exploration of this aspect requires that money supply be modeled in a way reflecting those goals, rather than as following some exogenous stochastic process. These are avenues we are currently pursuing.

Clearly this analysis is not devoid of problems; for example our equilibrium model is still unable to generate an adequate persistence and absolute level of volatility of the real exchange rate. As pointed out by Devereux (1997), one likely reason is that there are other important goods market frictions, e.g., transport costs (Dumas (1992)), alternative market structures (Lapham (1995)), or search costs (Head and Shi (1996)), not included in our setup that could potentially generate more movements in real exchange rates. Finally, in our model the increase in the variability of the real exchange rate, under a flexible exchange rate regime, is due to a fall in the covariance of within-country relative prices of goods priced-to-market: the exchange rate regime has barely any effect on the variance of these relative prices. Therefore, providing direct evidence on the specific relationships among exchange rate arrangements, sectoral market structure, and the properties of relative price movements is an important task for future research.

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Table 1. Economic Fluctuations Across Exchange Rate Regimes (in %) - Average of G7 Countries[20]

Sys.	*St. Dev.*									
	z	e	z/$	e/$	π	Y	C	I	H	NX
Bretton Woods	n.a.	1.90	2.74	2.25	0.70	1.81	1.22	4.10	1.62	2.77
Post Bretton Woods	7.26	7.55	5.01	4.45	0.71	1.82	1.65	4.53	2.23	2.46

[20] Series are quarterly, logged (with exception of net exports and inflation) and passed through the HP filter. The Bretton Woods period is taken to run from 1957:1 to 1972:4 (or shorter subject to data availability); the Post Bretton Woods from 1974:1 to 1997:4. Data were taken from the IMF International Financial Statistics: Y is real GDP (industrial production for France); C is nominal total private consumption expenditures deflated using the GDP deflator (CPI for France); I is change in nominal stocks deflated using the GDP deflator; H is industrial employment; NX is defined as in Kollman (1997), page 34; π is quarterly CPI inflation; z and e are real and nominal effective exchange rates computed by the IMF (REU and NEU, respectively); $e/\$$ and $z/\$$ are nominal and real exchange rates *vis-á-vis* the U.S. dollar (the latter based on relative CPI).

Table 2. Simulated Second Moments of Home Variables (in %)

Sys.	*St. Dev.*							
	z	e	π	Y	C	I	H	NX
Fix	0.009	n.a	0.86	0.82	0.58	4.69	0.68	1.30
	(0.0001)		0.002	(0.007)	(0.002)	(0.004)	(0.001)	(0.002)
Float	1.04	2.54	0.80	0.80	0.66	4.59	0.65	1.10
	(0.004)	(0.005)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)

Table 3. Simulated Second Moments of Foreign Variables (in %)

Sys.	*St. Dev*				
	π	Y	C	I	H
Fix	0.86	1.23	0.57	5.87	0.78
	(0.002)	(0.0063)	(0.0019)	(0.0059)	(0.0025)
Float	0.80	1.21	0.63	5.85	0.73
	(0.0014)	(0.0024)	(0.0018)	(0.0062)	(0.0004)

Table 4. Simulated Second Moments of Home Variables (in %) - Only Real Shocks

Sys.	*St. Dev.*							
	z	e	π	Y	C	I	H	NX
Fix	0.002	n.a	0.15	0.77	0.25	4.48	0.59	0.92
	(0.0001)		0.002	(0.007)	(0.002)	(0.004)	(0.001)	(0.0013)
Float	0.005	0.01	0.16	0.77	0.25	4.48	0.59	0.91
	(0.004)	(0.005)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.0014)

Table 5. Simulated Second Moments of Foreign Variables (in %) - Only Real Shocks

Sys.	*St. Dev*				
	π	Y	C	I	H
Fix	0.15	1.19	0.25	5.74	0.68
	(0.002)	(0.0063)	(0.0019)	(0.0059)	(0.0025)
Float	0.16	1.19	0.25	5.76	0.68
	(0.0014)	(0.0024)	(0.0018)	(0.0062)	(0.0004)

Table 6. Empirical and Simulated Correlations of Selected Variables[21]

Correlations	Data		*Model*			
			All Shocks		*Real Shocks*	
	Bretton Woods	Post Bretton Woods	*Fix*	*Float*	*Fix*	*Float*
$\rho(z)$	0.85	0.81	0.89	0.68	0.87	0.91
$\rho(e)$	0.81	0.85	n.a.	0.73	n.a.	0.73
$\rho(z,e)$	0.85	0.95	n.a.	0.90	n.a.	0.42
$\rho(z,\frac{y}{y^*})$	0.20	0.12	0.17	-0.02	0.49	0.40
$\rho(C,C^*)$	0.33	0.24	1	-0.09	1	1
$\rho(Y,Y^*)$	0.18	0.45	-0.30	-0.35	-0.41	-0.41
$\rho(M,M^*)$	0.21	0.07	1	0.11	1	1

[21] The empirical data are averages over the G7 countries. M is M1 money stock; see footnote 16 for explanations about the other series. Bilateral correlations are with the U.S.

Table 7. Ratio of Second Moment of Relative Prices Across Exchange Rate Regimes (in %)

	All Shocks			Real Shocks		
	$\sigma(q^*)$	$\sigma(q)$	$cov(q^*, q)$	$\sigma(q^*)$	$\sigma(q)$	$cov(q^*, q)$
Fix vs Float	1.14	1.04	5.66	0.95	0.98	0.93

Table 8. Volatility Ratios of First Differenced "Fundamentals" Across Exchange Rate Regimes

	Data	*All Shocks*	*Real Shocks*
VF	3.58	3.16	0.46^{*}
Flexible-price model			
TF	1.19^{**}	1.29^{**}	0.92^{**}
Sticky-price model			
TFS	1.16^{**}	1.15^{**}	0.70^{**}

Figure 1a: Responses to a Home Monetary Shock Under a Fixed and a Flexible Exchange Rate

Flexible Rates - - - Fixed Rates ——

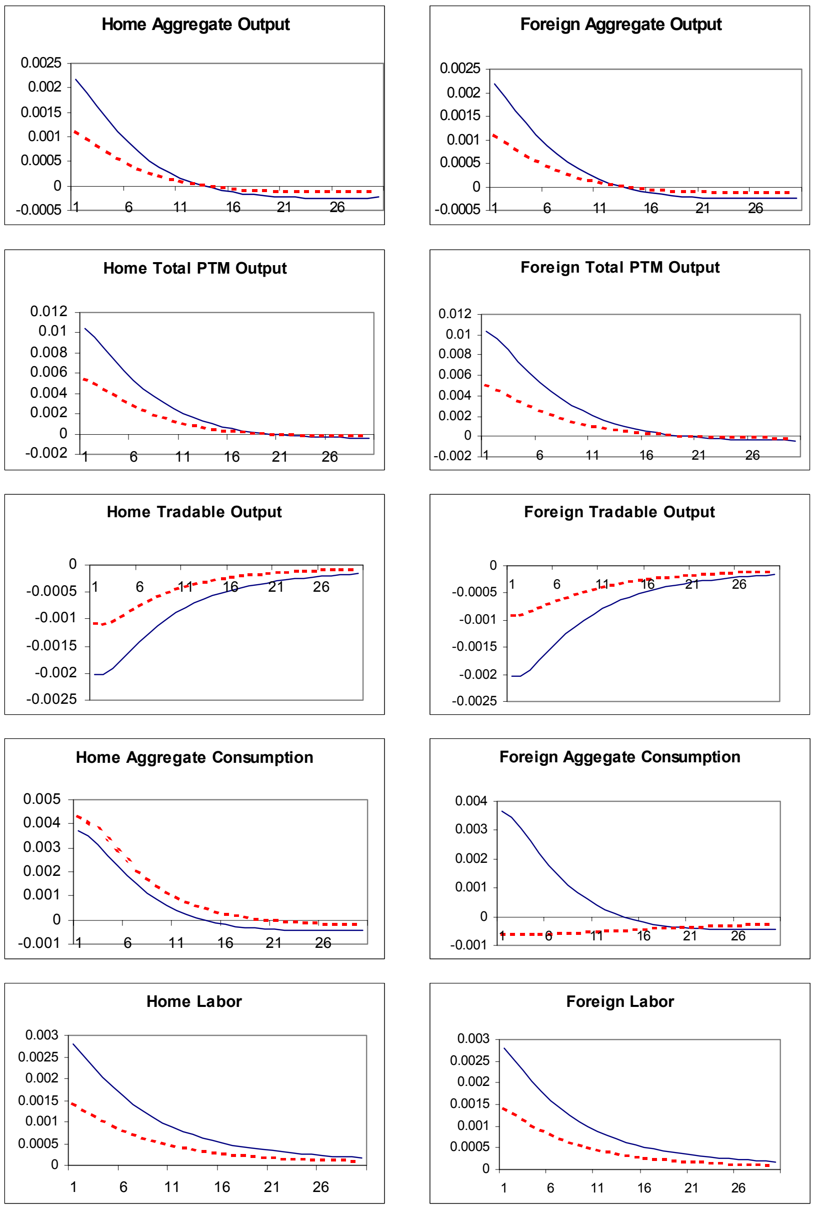

Figure 1b: Responses to a Home Monetary Shock Under a Fixed and a Flexible Exchange Rate
Flexible Rates - - - Fixed Rates ——

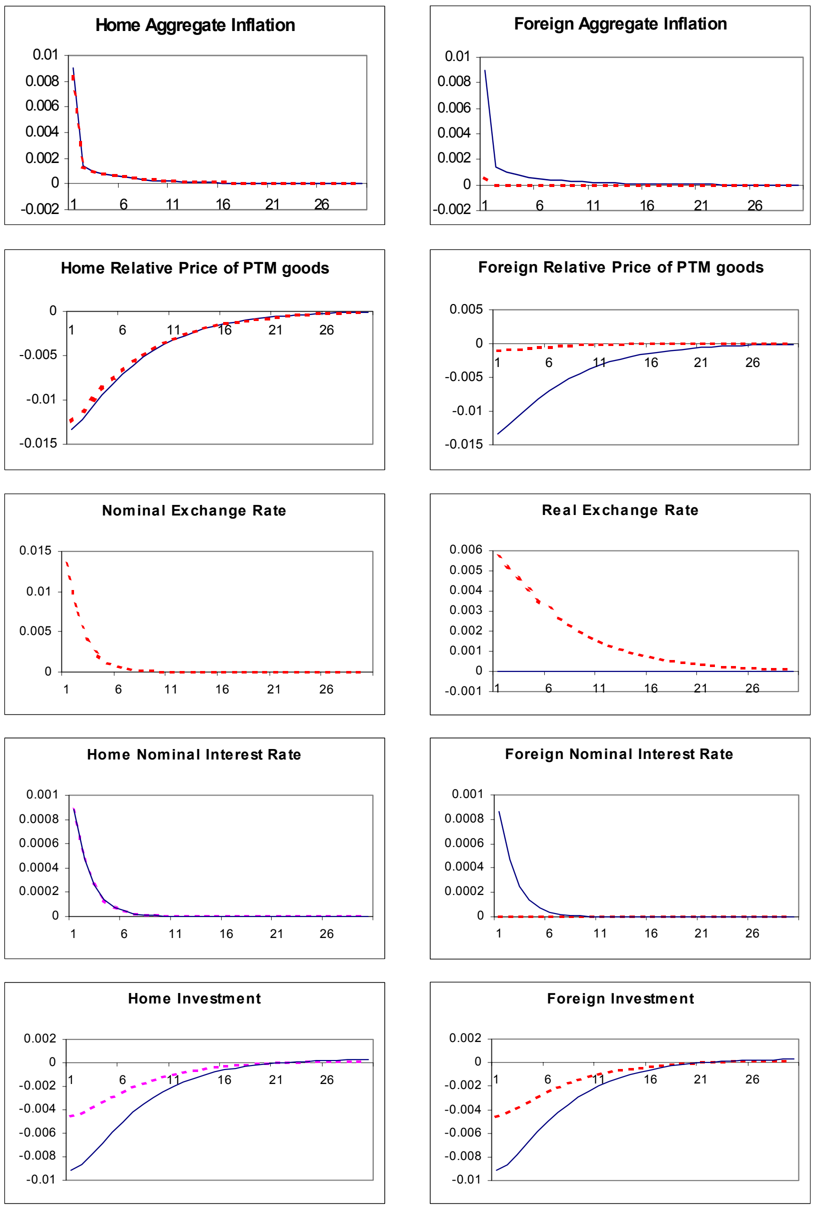

Figure 2a: Responses to a Home Real Shock Under a Fixed and a Flexible Exchange Rate

Flexible Rates - - - Fixed Rates ——

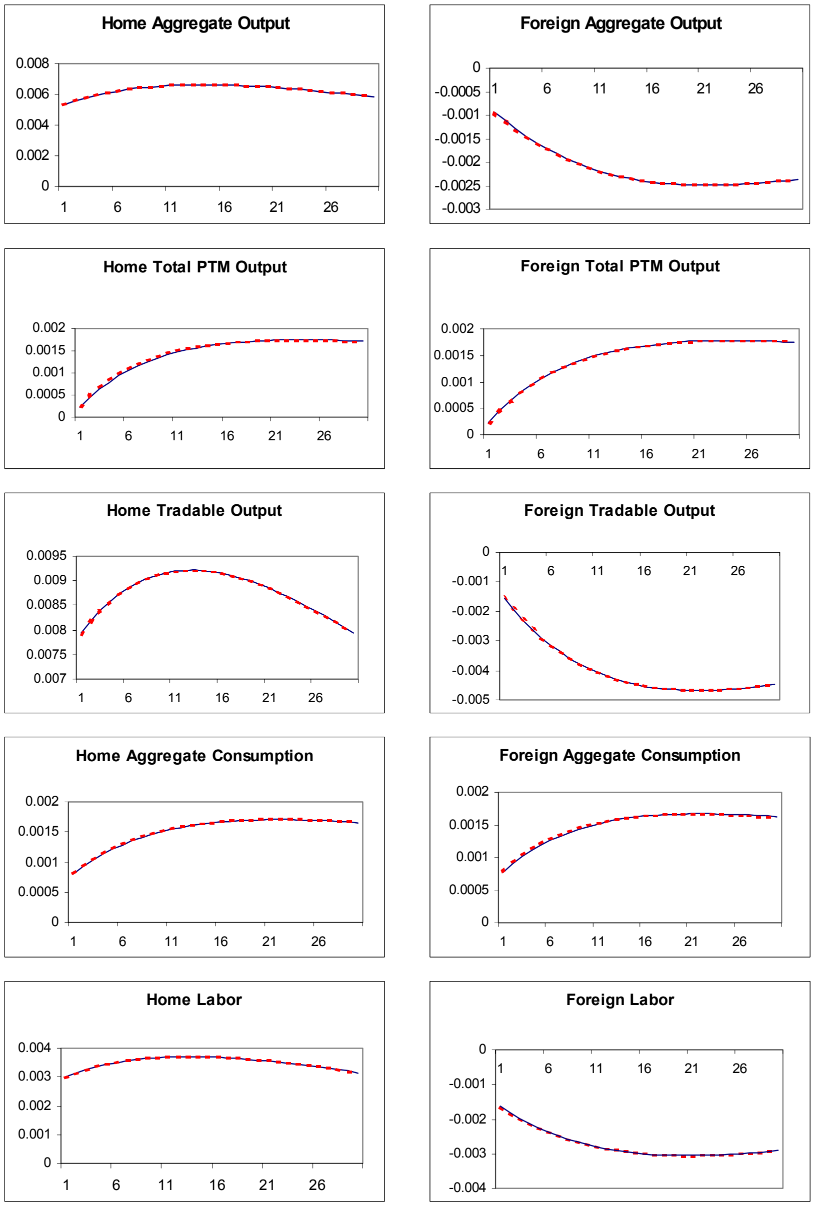

Figure 2b: Responses to a Home Real Shock Under a Fixed and a Flexible Exchange Rate
Flexible Rates - - - Fixed Rates ——

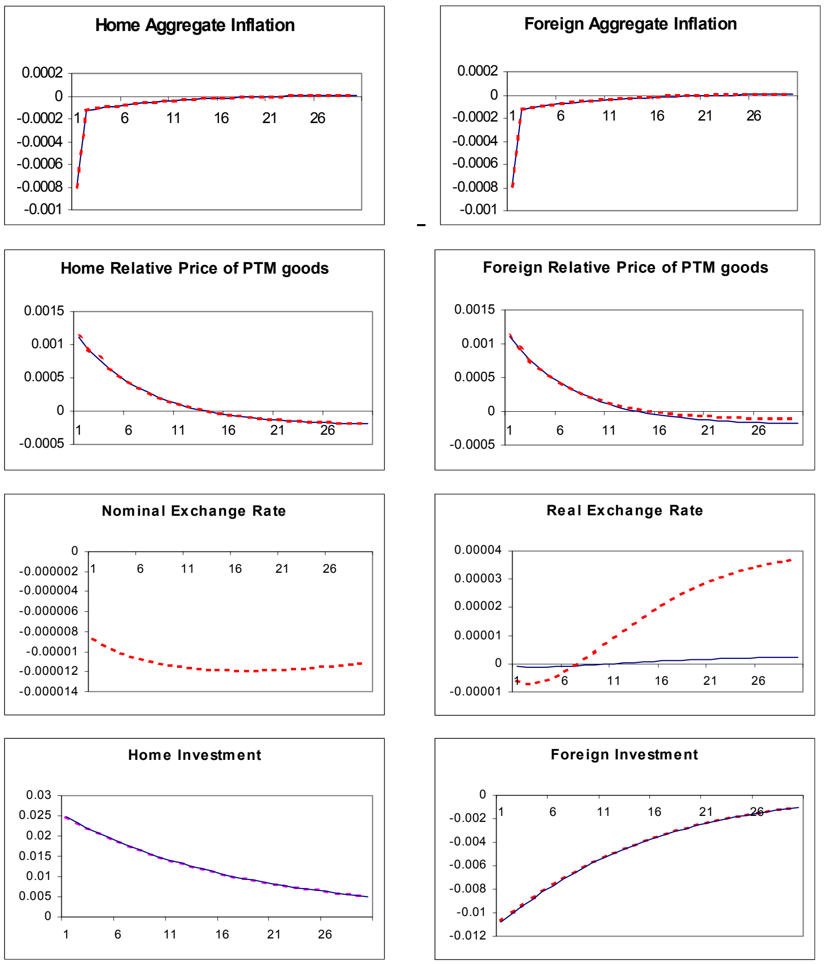

Figure 3: Standard Deviation of the Real Exchange Rate Relative to that of Output Under a Flexible Exchange Rate Regime

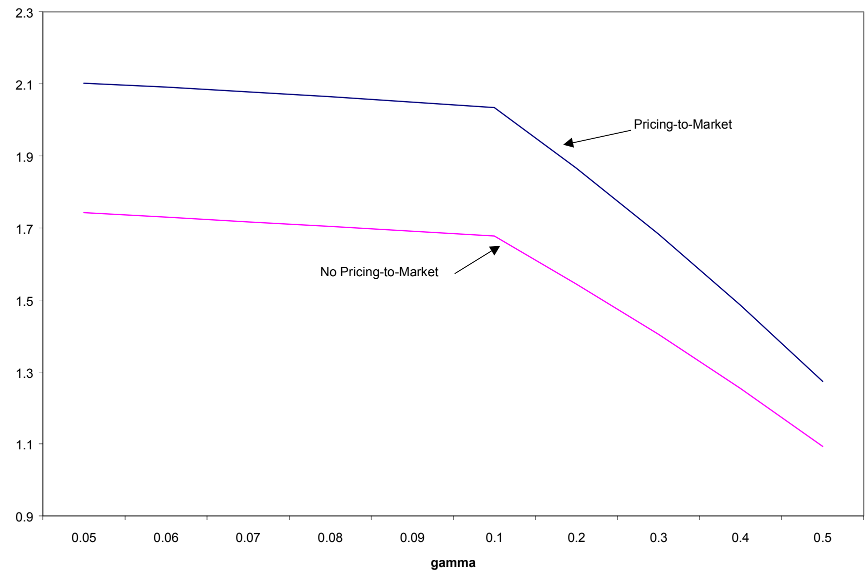

Figure 4: Ratio of Standard Deviations of Net Exports Across Exchange Rate Regimes