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Journal of Monetary Economics 50 (2003) 889–913
Journal of MONETARY ECONOMICS
www.elsevier.com/locate/econbase

Why don't macroeconomic quantities respond to exchange rate variability?☆

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Received 1 May 2001; received in revised form 12 April 2002; accepted 20 May 2002

Abstract

Empirical studies comparing fixed and flexible exchange rate regimes document that countries moving from pegged to floating systems experience a systematic and dramatic rise in the variability of the real exchange rate. However, there is very little evidence that the behavior of other macroeconomic variables varies systematically with the exchange rate regime. This paper seeks to resolve this puzzle. We examine the effects of the exchange rate regime in a dynamic general equilibrium model with nominal goods prices set in the buyer's currency and incomplete asset markets. The model predicts a sharp increase in the volatility of the real exchange rate when moving from pegged to floating rates, while this pattern is not observed for other variables. The model also predicts a higher commovement of variables across countries under fixed rather than under flexible rates, a prediction that accords with recent empirical studies.

JEL classification: E32; F31; F33; F41

Keywords: Exchange rate regime; International business cycle; Nominal rigidities; Pricing to market; Incomplete asset markets

☆I would like to thank Alan Stockman for his advice and Rui Albuquerque, Gian Luca Clementi, Michael Dotsey, Per Krusell, Sylvain Leduc, and Pierre Sarte for useful comments. I would also like to thank Marianne Baxter and an anonymous referee for their suggestions. All errors are my own. The views expressed in this paper are those of the author and do not necessarily represent those of the Federal Reserve Bank of Richmond or the Federal Reserve System.

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0304-3932/03/$ - see front matter
doi:10.1016/S0304-3932(03)00035-7

1. Introduction

Empirical work comparing fixed and flexible exchange rate regimes has documented two basic empirical regularities. First, the behavior of exchange rates varies systematically with the exchange rate regime: Countries with moderate inflations that move from pegged to floating exchange rate regimes typically experience a dramatic increase in the short-run variability of the real exchange rate. Second, the behavior of other macroeconomic variables appears to be independent of the exchange rate regime. That is, pegging the nominal exchange rate appears to reduce substantially the volatility of real exchange rates but not to have much effect on other macroeconomic variables.

These empirical regularities pose a challenge to international business cycle models in which the international relative price of goods (that is, the real exchange rate) plays an important role in the allocation of real quantities across countries.[1] In such settings, one expects that quantities, such as output, consumption, or trade flows, would depend on the real exchange rate and thus behave differently under the two alternative systems. Moreover, if exchange rate instability is interpreted as a manifestation of underlying economic volatility, then one would expect that pegging the exchange rate would channel this volatility elsewhere in the economy, but would not, per se, reduce it. Therefore, the behavior of exchange rates and other macroeconomic variables across exchange rate regimes constitutes a significant puzzle in international economics.[2]

This paper addresses this puzzle by constructing a simple version of the standard two-country "new open-economy" model with nominal price rigidities based on the work of Obstfeld and Rogoff (1995). We show that such a model can account quantitatively for the stylized fact that exchange rate volatility differs systematically across exchange rate regimes while the volatility of other macroeconomic aggregates does not.

In the model, monopolistic competitive firms producing differentiated products are able to price discriminate across two markets and set prices in the buyers' currencies before the resolution of uncertainty. These features of the model imply that the law of one price does not hold and that, on impact, unexpected changes in the nominal exchange rate do not affect the relative price of domestic and imported goods.

We also assume that asset markets are incomplete and restrict agents to trading a nominal riskless bond denominated in home currency. When agents trade a complete set of state-contingent nominal bonds, the equilibrium real exchange rate is given by the ratio of marginal utilities of consumption across countries, a relation that ties down the volatility of the real exchange rate to the volatilities of marginal utilities of consumption. Because asset markets are incomplete in our model, the

[1] The real exchange rate between two countries is defined as the ratio of their price levels, measured in a common currency. It represents the international relative price of goods or the relative cost of a reference basket of goods.

[2] See, for example, the discussion in Backus et al. (1995, p. 349) or Stockman (1999).

real exchange rate also depends explicitly on a term capturing expected future marginal utilities of consumption and the future real exchange rate. This term creates a wedge between the real exchange rate and the ratio of current marginal utilities of consumption.

We study the business cycle properties of our model under the two polar alternatives of flexible and fixed nominal exchange rates.[3] The model is consistent with key regularities found in the data. We find that moving from pegged to floating rates generates a substantial increase in the volatility of the real exchange rate, but this pattern is not observed for other variables. Because nominal goods prices are fixed in the short run in the buyers' currencies, unanticipated changes in the nominal exchange rate, on impact, do not affect the relative price of domestic and foreign goods within each country. Instead, they only affect each country's revenues from exports. This feature limits the short-run response of consumption and other real variables to changes in the exchange rate and, consequently, limits the change in their volatilities as a country moves from a pegged to a floating regime.

Interestingly, the model also generates another prediction that is consistent with results of recent empirical studies: it predicts a higher commovement of variables across countries under fixed rates than under flexible rates. This feature results from the coordination of monetary policies across countries which is needed to peg the exchange rate under fixed rates.

There exists a very large body of literature devoted to the study of exchange rates in a flexible exchange rate regime. Recent theoretical contributions have progressed under the paradigm of dynamic general equilibrium models with nominal rigidities and have explored the implications of alternative pricing assumptions for exchange rate behavior. Betts and Devereux (2000) show that the presence of firms that can segment markets and preset prices in the buyers' currencies in a two-country model has important implications for exchange rate volatility and international macroeconomic transmission. Chari et al. (2000) calibrate a two-country model where all firms set prices in the buyer's currency and find that monetary shocks combined with nominal rigidities can generate exchange rates that are as volatile as in the data. Our paper contributes to this literature by focusing, instead, on the model's properties across alternative exchange rate regimes.

Devereux and Engel (1998) compare welfare across exchange rate regimes in a two-country model allowing firms to preset prices either in the sellers' or buyers' currencies. They do not question, however, whether either assumption helps match the evidence regarding the implications of the exchange rate regime for the volatility of exchange rates and other macroeconomic aggregates, including consumption, output, and trade flows. In the analysis below, we explore quantitatively the consequences of alternative regimes for the behavior of macroeconomic aggregates

[3] We assume that the fixed exchange rate system is perfectly credible. Thus, we abstract from the possibility of speculative attacks when the nominal exchange rate is pegged.

and show that a model where firms preset prices in the buyers' currencies can account for the stylized facts.[4]

This paper is organized as follows. The next section provides a review of the empirical findings on the effects of alternative exchange rate systems on the behavior of key macroeconomic aggregates. Section 3 describes the behavior of consumption and exchange rates in the context of a simple two-country model with preset prices in the buyers' currencies. The full model is described in Section 4 and the following section briefly reviews the numerical procedure used in approximating the equilibrium and the calibration of the model. Section 6 discusses the results and Section 7 concludes.

2. Exchange rates and exchange rate regimes

Stockman (1983) and Mussa (1986) established persuasively that countries moving from pegged to floating exchange rate systems experience a systematic and dramatic increase in the variability of nominal and real exchange rates.[5] Mussa documents that the short-term variability of the real exchange rate during a floating regime is generally 4–8 times larger than during a pegged regime. Mussa also showed that in periods of floating nominal rates, changes in real exchange rates are highly persistent, similar to the persistence exhibited by changes in nominal exchange rates, and that nominal and real exchange rates tend to be nearly perfectly correlated in the short run.

Most countries in the samples used in Stockman (1983) and Mussa (1986) adopted floating exchange rates in 1973 following the collapse of the Bretton Woods system and in the wake of a period characterized by major real disturbances: the oil price shocks. Both studies investigate whether an increase in frequency and volatility of real disturbances after 1973 could explain the observed increase in volatility of real exchange rates. If this were the case then the differences in the behavior of real exchange rates before and after 1973 would be wrongly attributed to changes in the exchange rate system. To this end, both studies look at the behavior of exchange rates for countries in which the exchange rate system did not change in 1973.[6] They both conclude that the behavior of the real exchange rate is strongly associated with the exchange rate system rather than with a particular time period.

[4] In related papers, Dedola and Leduc (1999) study this question in a two-country two-sector model with complete asset markets and Sopraseuth (2000) considers the implications of varying the fraction of firms in each country that set prices in the buyer's currency. Taking a different avenue, Jeanne and Rose (2002) address the same stylized facts in a microstructural model where exchange rate volatility is affected by the presence of "noise traders" in the foreign exchange market.

[5] Both papers use exchange rate and price data from industrialized countries with moderate inflations. See Obstfeld (1998), and the references therein, for a discussion about the evidence from high-inflation economies.

[6] Ireland, for example, kept the Irish pound pegged to the British pound until the end of 1978 and in January 1979 joined the joint float of the continental European countries. Another example is given by Canada: the Canadian dollar floated against the US dollar from the end of 1959 to the second quarter of 1962 and it resumed the float in 1970.

Table 1
Italian lira and German mark exchange rates

Period	Std($\hat{e}$)	Std($\hat{r}$)	Corr($\hat{e}, \hat{r}$)
Feb. 1957–Feb. 1973	0.0037	0.0041	0.886
Mar. 1973–Feb. 1979	0.0142	0.0144	0.981
Mar. 1979–Dec. 1989	0.0045	0.0047	0.898
Jan. 1990–Aug. 1992	0.0026	0.0040	0.829
Sept. 1992–Nov. 1996	0.0141	0.0143	0.994
Dec. 1996–Sept. 1998	0.0027	0.0029	0.902

Note: $\hat{e}(\hat{r})$ denotes the monthly log difference of the nominal (real) exchange rate between Italian lira and German mark.

The behavior of nominal and real exchange rates between the Italian lira and German mark provides a clear illustration of the systematic relationship between the volatility of exchange rates (and their correlation) and the exchange rate system.[7] Table 1 reports the standard deviations (and correlation) of nominal and real exchange rates between the lira and mark for each period characterized by a distinct international monetary arrangement between the two countries from February 1957 to September 1998.[8] Italy and Germany joined the European Monetary System (EMS) at its inception in March 1979. The EMS allowed for deviations of the nominal exchange rate within a $\pm 6\%$ band and following its creation the volatilities of exchange rates (and their correlation) fell dramatically, to levels near those observed during the Bretton Woods period of fixed parities (February 1957–February 1973). In December 1989, the EMS exchange rate band was reduced from $\pm 6\%$ to $\pm 2.25\%$, further reducing the volatilities of exchange rates. However, in September 1992 Italy abandoned the EMS, in response to significant pressure in currency markets. In the subsequent period of floating, the volatilities of exchange rates increased sharply to the levels of the post Bretton Woods period (March 1973–February 1979). Italy finally rejoined the EMS in November 1996, bringing about a reduction in exchange rate volatility to its previous level.

Nominal price rigidities represent the conventional explanation for the regularities described above. Models that assume slow adjustment of nominal goods prices along with rapid adjustment of the nominal exchange rate (under flexible rates) are one class of models that is consistent with the behavior of exchange rates and the ratio of national price levels under alternative exchange rate systems.[9] This point is clearly

[7] This example is taken from Obstfeld (1998).

[8] The nominal exchange rate is denoted by e and is expressed as the number of domestic currency units per unit of foreign currency. The real exchange rate, denoted by r, is computed as ep^*/p, where p and p^* denote home and foreign consumer price indices. The data used are measured at monthly frequency and are taken from the International Monetary Fund's *International Financial Statistics*. The sample period is 1957:1–1998:9.

[9] Stockman (1983) examines the conditions under which equilibrium models of exchange rates exhibit nominal exchange rate system neutrality with respect to the real exchange rate and how these models can be made consistent with the data.

made in Mussa (1986) and is shared by many others. See, for example, the discussions in Obstfeld and Rogoff (1996), Devereux (1997), Basu and Taylor (1999) and the references therein.

Baxter and Stockman (1989) extend the previous work by looking at the behavior of other macroeconomic variables across exchange rate regimes. They examine the volatility of output, consumption, trade variables, government spending, and the real exchange rate. They are "*unable to find evidence that the cyclic behavior of real macroeconomic aggregates depends systematically on the exchange-rate regime*," the only exception being the real exchange rate.

In later work, Flood and Rose (1995) find that traditional economic fundamentals of structural exchange rate models do not have the volatility characteristics needed to match those of exchange rates. In particular, they find that macroeconomic fundamentals lack the regime-varying volatility needed to match the systematic difference in exchange rate volatility across regimes.

However, more recent empirical studies have found evidence of a more subtle relationship between macroeconomic aggregates and the exchange rate regime, by investigating the relationship between the Exchange Rate Mechanism (ERM) of the EMS and the international transmission of business cycles. In two interesting studies, Artis and Zhang (1999) and Sopraseuth (2000) use data from a sample of OECD countries which includes both European and non-European countries, as well as countries participating and not participating in the ERM. The findings in Artis and Zhang (1999) suggest the emergence of a group-specific European business cycle since the formation of the ERM, which is independent of the US cycle.[10] Moreover, they present evidence linking the synchronization of business cycles to the lower exchange rate volatility. Sopraseuth (2000) finds that the EMS (characterized by lower volatility of exchange rates) is associated with higher commovements of output, consumption and investment between the participating countries.[11]

In summary, the evidence indicates that the exchange rate system affects the volatility of the real exchange rate, leaves the volatility of other macroeconomic aggregates roughly unchanged, and affects the cross-country correlation of macroeconomic aggregates. In this paper, we present a model that is consistent with all three of these empirical regularities.

3. Consumption and exchange rates in a simple model

In this section, we explore the basic intuition behind the behavior of consumption and exchange rates across exchange rate regimes in a simple two-country model with preset prices in the buyers' currencies. To keep the algebra to a bare minimum, we

[10] For example, Artis and Zhang report that for Belgium their measure of synchronization with the US cycle falls from 0.53 to 0.29 between the pre-ERM and ERM periods, while in the same period it rises from 0.58 to 0.74 with respect to the German cycle.

[11] Some empirical studies have uncovered higher cross-country correlations following the collapse of the Bretton Woods system. This conclusion, however, may be driven by the oil shocks (which induce a strong commovement among oil-importing countries) instead of the switch in regime.

assume that the utility function is additively separable in consumption, real money balances, and leisure and that both consumption and real money balances enter logarithmically. In this setup, the money demand function depends only on the agent's consumption and on the nominal interest rate. In addition, we assume that the nominal interest rate is constant in equilibrium.[12] Let the money demand function be written as

$$\frac{M_t}{P_t} = \frac{\chi C_t}{1 - 1/(1+i)}, \tag{3.1}$$

where M_t/P_t denotes real money balances, C_t denotes consumption, i is the nominal interest rate and χ is a preference parameter. Since prices of both domestic and imported goods are preset in the buyers' currencies, the price level P_t does not respond to changes in the nominal exchange rate and is not affected by either contemporaneous shocks to money or productivity. Since the equilibrium nominal interest rate is constant and prices are preset in the buyer's currency, Eq. (3.1) implies that domestic consumption is affected only by domestic monetary shocks; productivity or foreign monetary shocks do not affect domestic consumption contemporaneously.

Let us also assume that asset markets are complete and allow home and foreign agents to trade a complete set of state-contingent bonds denominated in home currency. The nominal exchange rate is then given by

$$e_t = \phi \frac{C_t P_t}{C_t^* P_t^*}, \tag{3.2}$$

where asterisks denote foreign variables and ϕ is a parameter that depends on initial conditions.[13] We assume, without loss of generality, that $\phi = 1$. The optimal risk sharing condition (3.2) simply equates the real exchange rate, $e_t P_t^*/P_t$, to the ratio of marginal utilities of consumption across countries, C_t/C_t^*. Using the money demand equation (3.1), the nominal exchange rate simplifies to

$$e_t = \frac{M_t}{M_t^*} \frac{1 - 1/(1+i)}{1 - 1/(1+i^*)}. \tag{3.3}$$

Therefore, both nominal and real exchange rates depend only on shocks to money supplies, since interest rates are constant and prices are preset in the buyers' currencies.

Let us assume that in the floating exchange rate regime the log of the money supply in each country follows independent random walk processes. However, in the fixed exchange rate regime, the foreign monetary authority pegs the nominal exchange rate by adjusting its money supply. From (3.3), this requires that $M_t = \delta M_t^*$, where δ is a constant. Let $\delta = 1$. These assumptions imply that home and

[12] Suppose the log of the money supply in each country follows a random walk, $m_t = m_{t-1} + v_t$, where $M_t = \exp(m_t)$ and v_t is a zero mean *i.i.d.* shock with variance σ_v^2. This assumption combined with the preference specification for real money balances implies that in equilibrium the nominal interest rate is constant and equal to $1/\beta\mu$, where $\mu = E_t[\exp(v_t)]$.

[13] See, for example, Chari et al. (2000).

foreign (log of) money supplies have the same conditional variance in both regimes, $var_{t-1}(m_t)$, and that their conditional correlation is zero in the flexible exchange rate regime and one in the fixed.

This simple model predicts that the conditional variance of the real exchange rate changes sharply across regimes. However, the conditional variance of consumption does not change across regimes. Since domestic consumption is affected only by domestic monetary shocks, the conditional variance of (the log of) consumption is the same across regimes and is equal to the conditional variance of (the log of) the money supply, $var_{t-1}(m_t)$. Moreover, note that the conditional correlation of consumption across countries is zero in the flexible exchange rate regime and one in the fixed exchange rate regime, due to the coordination of home and foreign money supplies associated with the fixed regime. From Eq. (3.3), it follows that nominal and real exchange rates have the same conditional variance because prices are preset in the buyer's currency and do not respond to changes in the nominal exchange rate. In the flexible exchange rate regime the conditional variance of (the log of) exchange rates is $2\,var_{t-1}(m_t)$, while in the fixed regime it is zero.

In this model, the optimal risk sharing equation (3.2) equates the real exchange rate to the ratio of consumption across countries. However, the volatility of home and foreign consumption does not vary across regimes, while the volatility of the real exchange rate does. This equation is consistent with the distinct behavior of consumption and real exchange rate volatilities across regimes because the cross-country correlation of consumption also varies across regimes. In particular, in the fixed exchange rate regime, home and foreign consumption are perfectly correlated, consistent with a constant real exchange rate.[14]

In the remainder of the paper, we focus on a fully specified two-country model and investigate whether it can account for the evidence presented in Section 2. Unlike the model described in this section, we assume that asset markets are incomplete. This assumption implies that the equilibrium real exchange rate is not given simply by the ratio of marginal utilities of consumption across countries. Instead, it depends also on a new term capturing the expectation of future variables. Moreover, unlike the model described above, we do not restrict the model to generate a constant nominal interest rate and we introduce an intertemporal dimension to the money demand function. The model is calibrated to the U.S. data; using the simulated data, we compute the unconditional moments for the variables of interest and compare them to the data.

4. The model

The world economy consists of two countries, denominated home and foreign. In each country, firms produce a continuum of varieties of a country-specific good. The

[14] The conditional variance of (the log of) the real exchange rate is given by $var_{t-1}(\ln q_t) = var_{t-1}(\ln c_t) + var_{t-1}(\ln c_t^*) - 2\,cov_{t-1}(\ln c_t, \ln c_t^*)$. Note that the last covariance term is zero in the flexible exchange rate regime and equal to $var_{t-1}(\ln c_t) = var_{t-1}(\ln c_t^*)$ in the fixed exchange rate regime.

representative household in each country consumes all varieties of the home and foreign goods. There are two sources of uncertainty in each country: shocks to the money supply and productivity.

In what follows, we describe the home country economy under the flexible exchange rate regime. The foreign country economy is assumed to have an identical structure. All foreign variables are denoted with an asterisk.

4.1. Households

4.1.1. Preferences

The home representative household maximizes its lifetime expected utility defined over random sequences of a consumption index (c_t), leisure ($1 - l_t$), and liquidity services from holding money (M_t/P_t),

$$U_0 = E_0\left[\sum_{t=0}^{\infty} \beta^t u\left(c_t, 1 - l_t, \frac{M_t}{P_t}\right)\right].$$

The parameter $\beta \in (0, 1)$ is the discount rate, u is the momentary utility function, assumed to be concave and twice continuously differentiable, and E_0 denotes the mathematical expectation conditional on information available in period $t = 0$.

4.1.2. Consumption and price indices

There is a continuum of varieties of the domestic good, indexed by $i \in [0, 1]$, and a continuum of varieties of the foreign good, indexed by $j \in [0, 1]$. The household consumes all varieties of both the domestic and foreign goods. Any two varieties of the same good are imperfect substitutes in consumption, with constant elasticity of substitution $\theta > 1$. Let $c_{h,t}(i)$ and $c_{f,t}(j)$ denote date t domestic consumption of the varieties i and j of the home and foreign goods, respectively. The consumption indices of home and foreign composite goods are defined as

$$c_{h,t} = \left(\int_0^1 c_{h,t}(i)^{(\theta-1)/\theta}\, di\right)^{\theta/(\theta-1)} \quad \text{and} \quad c_{f,t} = \left(\int_0^1 c_{f,t}(j)^{(\theta-1)/\theta}\, dj\right)^{\theta/(\theta-1)}.$$

Note that in this setup $c_{f,t}$ also represents date t imports of the home country.

The consumption index c_t is defined as

$$c_t = [\omega^{1/\gamma} c_{h,t}^{(\gamma-1)/\gamma} + (1 - \omega)^{1/\gamma} c_{f,t}^{(\gamma-1)/\gamma}]^{\gamma/(\gamma-1)}, \quad \gamma > 0 \text{ and } \omega \in (0, 1), \tag{4.1}$$

where the parameter γ represents the elasticity of substitution between the home and foreign composite goods, $c_{h,t}$ and $c_{f,t}$, and the weight ω determines the agent's bias for consumption of domestic good, $c_{h,t}$.

Let $P_{h,t}(i)$ and $P_{f,t}(j)$ be the home-currency prices of the varieties i and j of the home and foreign goods, respectively. Given these prices, the consumption-based money price index P_t is derived as

$$P_t = [\omega P_{h,t}^{1-\gamma} + (1 - \omega) P_{f,t}^{1-\gamma}]^{1/(1-\gamma)}, \tag{4.2}$$

where the price indices $P_{h,t}$ and $P_{f,t}$ for each composite good are[15]

$$P_{h,t} = \left(\int_0^1 P_{h,t}(i)^{1-\theta} \, di \right)^{1/(1-\theta)} \quad \text{and} \quad P_{f,t} = \left(\int_0^1 P_{f,t}(i)^{1-\theta} \, di \right)^{1/(1-\theta)}.$$

Given the structure of preferences, the agent's demand functions for varieties i and j of home and foreign goods, respectively, are given by

$$c_{h,t}(i) = \omega \left(\frac{P_{h,t}}{P_{h,t}(i)} \right)^{\theta} \left(\frac{P_t}{P_{h,t}} \right)^{\gamma} c_t \tag{4.3}$$

and

$$c_{f,t}(j) = (1-\omega) \left(\frac{P_{f,t}}{P_{f,t}(j)} \right)^{\theta} \left(\frac{P_t}{P_{f,t}} \right)^{\gamma} c_t. \tag{4.4}$$

4.1.3. The household's budget constraint

The home agent holds home currency, M_t, and trades a riskless discount bond with the foreign agent. This bond pays one unit of home currency with certainty one period after being issued. Let B_{t+1} denote the number of bonds held by the home agent between time t and $t+1$, and let Q_t denote the time t price of one discount bond.

The agent's intertemporal budget constraint, expressed in home-currency units, is

$$P_t c_t + M_t + Q_t B_{t+1} \leqslant P_t w_t l_t + M_{t-1} + B_t + \Pi_t + T_t,$$

where T_t is the government's money transfer in period t, Π_t represents profits of domestic firms (which we assume to be owned by the domestic household) and $P_t w_t l_t$ represents nominal labor earnings.[16]

The agent's optimization problem can now be summarized as

$$\max_{c_t, l_t, B_{t+1}, M_t} E_0 \left[\sum_{t=0}^{\infty} \beta^t u\left(c_t, 1-l_t, \frac{M_t}{P_t} \right) \right] \tag{4.5}$$

subject to

$$P_t c_t + M_t + Q_t B_{t+1} \leqslant P_t w_t l_t + M_{t-1} + B_t + \Pi_t + T_t, \tag{4.6}$$

$$B_{t+1} \geqslant -a_t, \tag{4.7}$$

B_0 *given.*

[15] The price indices P, P_h, and P_f are defined as the minimum expenditure necessary to buy one unit of composite goods c, c_h, and c_f, respectively, taking as given the prices for individual goods $P_h(i)$ and $P_f(j)$, $i, j \in [0, 1]$.

[16] In this paper, we treat the capital stock as fixed and assume that agents cannot accumulate capital. This simplifying assumption is not central to the main issue explored in this paper, namely, the difference in exchange rate volatility across regimes.

In this problem, Eq. (4.7) places an upper bound, a_t, on the number of one-period bonds that an agent can issue. This constraint on borrowing rules out equilibria which admit unbounded borrowing, or Ponzi schemes.[17]

4.2. Firms and market structure

The production function for each variety i is given by $z_t F(l_t(i))$, where $l_t(i)$ represents labor input, z_t is an aggregate (country-specific) productivity shock and F is a production function displaying decreasing returns to scale.

Because all varieties are imperfect substitutes in consumption, each individual firm has some market power determined by the parameter θ. Moreover, we assume that, due to high costs of arbitrage, home and foreign markets are segmented. Consequently, each individual monopolist can price-discriminate across countries. Furthermore, we assume that firms set prices one period in advance in the buyers' currencies. Thus, the home monopolist sets $P_{h,t}(i)$ and $P^*_{h,t}(i)$ optimally at the end of period $t-1$, and these prices are not revised until the end of the following period. These assumptions on the market structure are usually referred to in the literature as pricing-to-market or local currency pricing.[18]

The date t profit of monopolist i (in home currency units) is given by

$$\Pi_t(i) = P_{h,t}(i)c_{h,t}(i) + e_t P^*_{h,t}(i)c^*_{h,t}(i) - P_t w_t l_t(i),$$

where w_t denotes real wages in units of consumption good c. Note that $P_{h,t}(i)$ and $P^*_{h,t}(i)$ are denominated in units of home and foreign currency, respectively. The country's nominal exchange rate in period t, e_t, converts the revenues from sales in the foreign country into home currency.

The price setting problem of monopolist i is to maximize expected profits conditional on $t-1$ information, $E_{t-1}[\rho_t \Pi_t(i)]$, by choosing $P_{h,t}(i)$ and $P^*_{h,t}(i)$. That is

$$\max_{P_{h,t}(i), P^*_{h,t}(i)} \; E_{t-1}[\rho_t(P_{h,t}(i)c_{h,t}(i) + e_t P^*_{h,t}(i)c^*_{h,t}(i) - P_t w_t l_t(i))] \tag{4.8}$$

subject to $z_t F(l_t(i)) = c_{h,t}(i) + c^*_{h,t}(i)$ and the demand functions for $c_{h,t}(i)$ and $c^*_{h,t}(i)$. The term ρ_t (to be discussed below) denotes the pricing kernel used to value date t profits, which are random as of $t-1$.

Note from expression (4.8) that firms choose prices optimally in an explicitly stochastic environment, with a view towards hedging the risks they face. In

[17] Note that the borrowing constraint is time dependent, reflecting the fact that the model is non-stationary.

[18] With local currency pricing, the domestic price of imports does not change on impact with unexpected changes in the exchange rate and pass-through is zero. A large body of empirical studies have documented a low exchange rate pass-through at the consumer level or very little response of consumer prices to changes in the nominal exchange rate. This adjustment, however, seems to be higher at the importer level. See Devereux (1997) for a discussion of the empirical evidence on pricing-to-market and an exhaustive list of references. See also the discussions in Obstfeld and Rogoff (2000a, b) or Devereux and Engel (2000).

Betts and Devereux (2000) study how the degree of pricing-to-market affects the behavior of exchange rates in an open-economy model. Other recent models of exchange rates have assumed that all firms set prices in the buyers' currencies. See, for example, Kollmann (2001), Chari et al. (2000).

particular, we see that nominal exchange rate risk affects the pricing decision of firms, and thus will also affect output and other variables.

4.3. Government

The home country's government issues the domestic currency. The government runs a balanced budget and additions to the money stock are distributed to consumers through lump sum transfers, given by $T_t = M_t^s - M_{t-1}^s$. The money stock process is given by

$$M_t^s = (1 + g_t)M_{t-1}^s,$$

where g_t is stochastic.

4.4. Equilibrium

The solution to the consumer's problem (4.5) is characterized by the following standard efficiency conditions, in addition to Eqs. (4.6) and (4.7):

$$\frac{u_{1,t}}{u_{2,t}} = -\frac{1}{w_t}, \tag{4.9}$$

$$\frac{u_{3,t} - u_{1,t}}{P_t} + \beta E_t\left[\frac{u_{1,t+1}}{P_{t+1}}\right] = 0 \tag{4.10}$$

and

$$Q_t \geqslant \beta \frac{P_t}{u_{1,t}} E_t\left[\frac{u_{1,t+1}}{P_{t+1}}\right], \tag{4.11}$$

where $u_{i,t}$ represents the derivative of the momentary utility function u with respect to its ith argument in period t. Eq. (4.9) represents the agent's consumption-leisure choice and Eqs. (4.10) and (4.11) are the Euler equations with respect to money balances and bonds, respectively. Eq. (4.11) holds with equality when the borrowing constraint (4.7) does not bind.

The foreign consumer solves an analogous problem. Since the bond is denominated in home currency, the foreign agent's first-order condition with respect to bond holdings is given by

$$Q_t \geqslant \beta \frac{e_t P_t^*}{u_{1,t}^*} E_t\left[\frac{u_{1,t+1}^*}{e_{t+1} P_{t+1}^*}\right], \tag{4.12}$$

which holds with equality when the borrowing constraint $B_{t+1}^* \geqslant -a_t$ does not bind.

In states of the world when the borrowing constraint is binding for one agent, it cannot be binding for the other agent. Since there is no upper bound on the quantity of bonds that can be purchased and this asset is in zero net supply worldwide, the borrowing constraint will be non-binding at least for one household at all times. Suppose (4.7) is binding for the home agent. Then, $B_{t+1} = -a_t$ and Eq. (4.11) holds with a strict inequality; the bond price is uniquely defined by (4.12), which holds with equality. Similarly for the foreign agent. Therefore, at any given point in time, the bond's price is uniquely determined by the unconstrained agent's first-order condition.

Combining both agents' Euler equations for bond holdings, Eqs. (4.11) and (4.12), we obtain

$$e_t = \frac{P_t}{u_{1,t}} \frac{u^*_{1,t}}{P^*_t} \frac{E_t[u_{1,t+1}/P_{t+1}]}{E_t[u^*_{1,t+1}/e_{t+1}P^*_{t+1}]}, \tag{4.13}$$

which determines the evolution of the nominal exchange rate. This equation holds with a strict equality only when the borrowing constraint is not binding for any agent.

Note that, unlike standard general equilibrium models of exchange rates, the nominal exchange rate depends explicitly on expectations about future variables. This feature of the model is a consequence of both asset market incompleteness and product market segmentation. In a model with a complete set of state-contingent nominal bonds, the nominal exchange rate is determined every period by the optimal risk sharing condition $e_t = \phi(P_t/u_{1,t})u^*_{1,t}/P^*_t$, where ϕ is a parameter depending on initial conditions. Instead, if product markets are not segmented, then the equilibrium nominal exchange rate has to satisfy the law of one price every period (and is determined by the equilibrium in product markets). In our model, international trade in nominal bonds (that is, asset markets) determine the expected growth rate of the nominal exchange rate and its level is tied down by wealth effects of exchange rate changes on the households' budget constraints.

We now turn to the efficiency conditions for the firm's problem. The solution to problem (4.8) yields the following pricing functions for the home monopolist:

$$P_{h,t}(i) = \frac{\theta}{(\theta - 1)} \frac{E_{t-1}[\rho_t P_t w_t c_{h,t}(i) l_t(i)^{1-\alpha}/z_t]}{\alpha E_{t-1}[\rho_t c_{h,t}(i)]} \tag{4.14}$$

and

$$P^*_{h,t}(i) = \frac{\theta}{(\theta - 1)} \frac{E_{t-1}[\rho_t P_t w_t c^*_{h,t}(i) l_t(i)^{1-\alpha}/z_t]}{\alpha E_{t-1}[\rho_t e_t c^*_{h,t}(i)]}. \tag{4.15}$$

These expressions are a generalization of the standard optimal pricing rule in a model of monopolistic competition. In fact, in the deterministic version of our model with flexible prices these expressions become the standard markup over marginal cost. The expressions obtained simply extend this result to an explicit stochastic environment. They state that, up to a certainty equivalent approximation, each firm sets prices as a constant markup over expected marginal cost.

After the resolution of uncertainty, firms are willing to accommodate all demand at the pre-determined prices provided that the actual marginal cost does not rise above these prices. In all experiments we conduct, it is always optimal for firms to accommodate all demands at the preset prices. Thus, output is always demand determined.

Expressions (4.14) and (4.15) depend on ρ_t, the pricing kernel used to value date t profits, which are random as of $t-1$. As all home firms are owned by the home representative consumer, date t profits are valued according to the consumer's intertemporal marginal rate of substitution in consumption, $\rho_t = \beta(u_{1,t}/u_{1,t-1})P_{t-1}/P_t$.

Finally, from the above expressions for the price of the home good in the home and foreign markets, we see that, in general, the law of one price does not hold in this model. Moreover, depending on the nature of the uncertainty, ex ante price discrimination can go in either direction. In our model, deviations from PPP result only from deviations from the law of one price, that is, from movements in the price of similar goods across countries.

We focus on the symmetric and stationary equilibrium of the model. That is, the equilibrium in which all firms located in the same country make the same choices and the endogenous variables are stationary functions of the current state of the world (to be defined below). To make the economy stationary, all nominal variables are deflated by the level of the relevant money supply.[19] Let these variables be denoted with a hat. Moreover, we restrict attention to Markov stochastic processes for productivity and the growth rate of money stocks.

Since pricing decisions are made before the realization of uncertainty while consumption decisions are made afterwards, consumers and firms have different information sets at the moment they make their decisions. Moreover, because the stochastic processes are assumed to be Markovian, the history of each process is fully described by its last realization. Thus, the aggregate state of the world when the pricing decisions are made is fully characterized by the realization of the shocks in the previous period, $\lambda_{-1} \equiv (z_{-1}, z^*_{-1}, g_{-1}, g^*_{-1})$ and by the distribution of wealth between the two countries. The distribution of wealth is simply given by the home consumer's bond holdings, $\hat{B}$. Let $s^m \equiv (\lambda_{-1}, \hat{B})$ denote the aggregate state for the monopolists. Consumers make their choices after the realization of current period shocks. So, the relevant aggregate state of the world for their decisions also includes these shocks and is denoted by $s \equiv (s^m, \lambda)$.

A stationary and symmetric equilibrium for this economy is defined as a collection of:

- optimal decision rules for home and foreign consumers, $l(s)$, $\hat{B}'(s)$, $\hat{M}(s)$, $c_h(s)$, $c_f(s)$ and similarly for the foreign consumer;
- optimal pricing rules for home and foreign firms, $\hat{P}_h(s^m)$, $\hat{P}^*_h(s^m)$[20] and similarly for the foreign firm;
- equilibrium wage rates $w(s)$ and $w^*(s)$, bond price $Q(s)$, and nominal exchange rate $\hat{e}(s)$ that satisfy the following conditions:
    - consumers' decision rules solve the consumers' problem,
    - firms' pricing rules solve the firms' problem and
    - all markets clear.

[19] The nominal exchange rate is deflated by the ratio of foreign to home money supplies. In the stationary economy the borrowing constraint in Eq. (4.7) is constant.

[20] In the symmetric equilibrium, all firms located in the same country make the same pricing decisions. We therefore drop the firm index.

5. Calibration

We study the properties of our economy by approximating numerically the stationary equilibrium defined above. The solution algorithm used involves iterating on a mapping defined on the system of first-order conditions.

This section specifies the functional forms and parameter values used in solving the model. Our benchmark calibration assumes that the world economy is symmetric. Therefore, both countries share the same structure and parameter values. The model is calibrated for the U.S. data, with the exception of productivity shocks. These are calibrated using U.S. and Canadian Solow residuals. We assume that each time period in the model corresponds to one quarter, as is standard in the business cycle literature.

5.1. Preferences

Preference specifications are similar to Chari et al. (2000). The momentary utility function is given by

$$u\left(c, l, \frac{M}{P}\right) = \frac{1}{1-\sigma}\left[\left(ac^{\eta} + (1-a)\left(\frac{M}{P}\right)^{\eta}\right)^{\zeta/\eta}(1-l)^{1-\zeta}\right]^{1-\sigma},$$

where $\sigma > 0$, $\zeta \in (0, 1)$, $\eta > 0$ and $a \in (0, 1)$.

Mehra and Prescott (1985) estimate a reasonable range for the coefficient of risk aversion, σ, to be between 1 and 10. We set $\sigma = 2$, which is a relatively standard value in the literature. For the remaining parameters of the utility function, we follow the calibration procedure in Chari et al. (2000). Thus, we set $\zeta = 0.32$, $\eta = -1.56$ and $a = 0.73$. The intertemporal discount factor, β, is set equal to 0.99.

For the consumption index c_t defined in (4.1), we need to assign values to γ, the elasticity of substitution between home and foreign goods, and ω, which is related to the share of imports in total output. Most empirical studies seem to suggest that for the U.S. the elasticity of substitution between domestic and imported goods is between 1 and 2. We use γ equal to 1.5, which is standard in empirical trade models (see, for example, Chapter 5 in Whalley, 1985). Finally, in a symmetric steady-state across countries, the ratio $c_{\mathrm{h}}/c_{\mathrm{f}}$ can be expressed as $\omega/(1-\omega)$ as well as $(1-s)/s$, where s is the ratio of imports to GDP in the home country. We use an import share of 0.15, obtaining a value of ω equal to 0.85.

5.2. Technology and market structure

To completely specify the production technology, we need to choose a functional form for the production function and to specify the stochastic process for the productivity shocks. We assume that production takes place in each firm according to a decreasing returns to scale production function

$$F(l) = zl^{\alpha}, \quad 0 < \alpha < 1.$$

We set α equal to $\frac{2}{3}$.

The stochastic process for the world level of technology is assumed to follow a bivariate autoregressive process

$$\mathbf{z}' = A\mathbf{z} + \boldsymbol{\varepsilon}', \quad \boldsymbol{\varepsilon}' \ i.i.d.\ N(\mathbf{0}, \Sigma), \tag{5.1}$$

where $\mathbf{z} \equiv (z, z^*)$ and $\boldsymbol{\varepsilon} \equiv (\varepsilon, \varepsilon^*)$. A is a matrix of coefficients whose off-diagonal elements indicate the extent to which shocks to one country's technology spillover in later periods to the other country. We estimated A and Σ using estimates of Solow residuals for the U.S. and Canada. The logarithms of the Solow residuals are computed as $\log z = \log y - (1 - 0.36) \log n$ using aggregate data on output y and employment n.[21] Then, we estimate Eq. (5.1) by least squares. The estimates are

$$\hat{A} = \begin{bmatrix} 0.981\ (0.020) & 0.020\ (0.020) \\ 0.012\ (0.026) & 0.985\ (0.027) \end{bmatrix},$$

where standard errors are in parentheses. The estimated standard deviation of the innovations to productivity in the U.S. and Canada are 0.0058 and 0.0077, respectively.

In order to estimate a stochastic process with symmetric A and Σ matrices, consistent with the symmetric characterization of our model, we follow the procedure described in Backus et al. (1992). We obtain

$$\hat{A} = \begin{bmatrix} 0.9825 & 0.0155 \\ 0.0155 & 0.9825 \end{bmatrix}$$

and we set the standard deviation of both innovations to 0.00675.

Finally, we need to assign a value to θ, the elasticity of substitution between different consumption goods produced in the same location. This parameter determines each firm's market power. From Eq. (4.14), it follows that in the deterministic steady state, each firm's markup (the ratio of price to marginal cost) equals $\theta/(\theta - 1)$. Different empirical studies suggest that a reasonable range for firms' markup should be between 1.2 and 1.7.[22] We set $\theta = 3$, implying that the deterministic steady-state markup equals 1.5.

5.3. Monetary shocks

The growth rates of the money stock in each country are assumed to follow univariate autoregressive processes

$$g_{t+1} = \rho g_t + v_{t+1}, \quad v \sim N(0, \sigma_v). \tag{5.2}$$

The two processes are assumed to be independent as the correlation between the growth rates of money in the U.S. and Canada is close to zero. Moreover, because

[21] The output series are real GDP from the International Monetary Fund's *International Financial Statistics*. The labor input series are civilian employment from the U.S. Bureau of Labor Statistics and Statistics Canada. The sample period is 1976:1–1998:4.

[22] For a discussion on this evidence, see Rotemberg and Woodford (1995).

we assume the world economy to be symmetric, we use the same process for both countries.

We estimate this process using quarterly U.S. data for M1 from 1973:1 to 1999:1. The estimates are $\hat{\rho} = 0.81$ (0.0568) and $\hat{\sigma}_v = 0.0114$.

6. Results

In this section, we investigate whether the two-country model with segmented markets and local-currency pricing described above can account quantitatively for the evidence presented in Section 2.

We assume that in the fixed exchange rate regime, the foreign monetary authority unilaterally pegs the nominal exchange rate at the level $\bar{e}$. The model is otherwise identical to the theoretical economy with a flexible nominal exchange rate described in Section 4. That is, with fixed exchange rates, monetary policy in the foreign country is endogenously determined instead of being exogenously given by Eq. (5.2). Specifically, M^* is determined every period by the fixed exchange rate regime counterpart of Eq. (4.13):

$$\bar{e} = \frac{P_t}{u_{1,t}} \frac{u^*_{1,t}}{P^*_t} \frac{E_t[u_{1,t+1}/P_{t+1}]}{E_t[u^*_{1,t+1}/\bar{e}P^*_{t+1}]}.$$

Monetary policy in the home country is still given by Eq. (5.2).

6.1. Volatility across regimes

Table 2 reports the standard deviations of key variables under the two regimes in the presence of shocks to productivity and to the growth rate of money in both countries. The statistics presented are averages over 100 simulations of 100 periods each, after having logged and Hodrick–Prescott filtered the data generated by the model.[23]

The model successfully replicates the evidence presented in Section 2. It is clear from Table 2 that the real exchange rate is the variable most affected by a change in regime. The real exchange rate is eight times more volatile under flexible rates than under fixed rates. No other variable in the model is affected by the exchange rate regime nearly as much as the real exchange rate. In fact, the behavior of all other variables is relatively insensitive to the exchange rate regime: output, consumption, and trade flows are generally only slightly more volatile under fixed than under flexible rates.

Under flexible exchange rates, the model predicts that the standard deviation of home output is 1.86%. For the sample period 1970:1–1990:2, Backus et al. (1995) report that the volatility of U.S. output was 1.92%. The model predicts that nominal and real exchange rates are 2.4 and 1.9 times more volatile than home output. This

[23] All simulations start from a symmetric distribution of wealth across countries, that is, with $B_0 = 0$. The borrowing constraints never bind.

Table 2
Simulated standard deviations (in %)

Variable		Fixed rates	Flexible rates
Home:	Output	2.08	1.86
	Total consump.	2.07	2.09
	Local good	2.08	2.11
	Imports	2.14	2.15
Foreign:	Output	2.09	1.80
	Total consump.	2.07	2.02
	Local good	2.08	2.04
	Imports	2.13	2.09
Nominal exchange rate		—	4.39
Real exchange rate		0.42	3.37

Table 3
Simulated standard deviations (in %)

Variable		Monet. shock		Product. shock	
		Fixed	Flexib.	Fixed	Flexib.
Home:	Output	2.03	1.76	0.50	0.49
	Total consump.	2.03	2.02	0.39	0.38
	Local good	2.03	2.02	0.47	0.46
	Imports	2.03	2.02	0.67	0.66
Nominal exchange rate		—	4.32	—	0.01
Real exchange rate		—	3.31	0.42	0.42

result falls short of what we observe in the data: depending on the country, volatilities of real and nominal exchange rates can range from 3 to almost 8 times the volatility of output.[24]

Table 3 reports the standard deviations obtained from simulating the model assuming only one source of uncertainty at a time under each regime. Here we omit foreign variables. Productivity shocks have a small impact on the volatility of all variables and, in particular, on the volatility of the nominal exchange rate. This feature of the model is a result of prices being sticky for one quarter. Because firms set prices one period in advance, after the realization of uncertainty output is determined by demand. Therefore, on impact, the effect of productivity shocks works only through their effect on labor demand.

[24] The source is Chari et al. (2000). The sample period is 1972:1–1994:4. Chari et al. (2000) show that a two-country model with monetary shocks and firms that set prices in the buyer's currency can generate exchange rates that are as volatile as in the data when prices are held fixed for at least 1 year, risk aversion is high, and preferences are separable in leisure.

Regardless of the source of uncertainty, the model predicts that consumption and output are slightly more volatile under the fixed exchange rate regime. As the analysis below shows, our model predicts a larger adjustment for output and consumption in the fixed exchange rate regime in response to either a shock to productivity or to the money supply. Therefore, the model does not support Mundell–Fleming's result that different exchange rate regimes insulate economies from different types of shocks.

Since monetary shocks play the dominant role in determining the dynamics of our model, the response in each regime to a monetary shock allows us to gain intuition on how the model works. Let us consider the response to a positive and unexpected shock to the growth rate of money in the home country.

Since prices do not respond on impact to the monetary shock, the home consumer needs to hold more real balances. Thus, total consumption increases on impact and, therefore, also output and labor rise in the home country. In order to substitute intertemporally this temporary increase in wealth, the home consumer also reduces his debt to the foreign agent. However, this increase in bond holdings is small. As a consequence, the monetary shock does not induce significant permanent wealth effects.

Under flexible rates, the nominal exchange rate depreciates immediately to (approximately) its new long-run level. This adjustment in the nominal exchange rate is (approximately) the same as the long-run increase in the money supply. Since price levels are fixed in this period, both nominal and real exchange rates depreciate on impact.

Since nominal goods prices are set in the buyer's currency, the adjustment in the nominal exchange rate does not affect the relative price of home and foreign goods in either country, as Eqs. (4.3) and (4.4) show.[25] Thus, consumptions in the home country of home and foreign goods increase in the same proportion (and their response is identical to the response of total consumption) and higher home demand for foreign goods translates into a positive (but smaller) effect on foreign output, labor, and consumption. If, instead, prices were set in the seller's currency, nominal depreciation would decrease the relative price of home and foreign goods on impact in both countries[26] and both agents would substitute consumption towards the home good. Thus, having prices set in the buyer's currency eliminates, on impact, the expenditure switching effect associated with unexpected changes in the nominal exchange rate. Only a wealth effect remains, as revenues from exports (thus, firms' profits) increase in the home country and decrease in the foreign country. Because both agents have a bias towards the local good (determined by the parameter ω), this wealth effect on export revenues is quantitatively small.

When prices are preset in the buyer's currency, consumer demands do not depend on the nominal exchange rate and changes in this variable are dissociated, on impact,

[25] The responses of the prices of home and foreign goods in the home country are identical to the response of the price level.

[26] With seller's currency, this relative price in the home country would be $P_{h,t}/e_t P_{f,t}$, where $P_{f,t}$ is now expressed in units of foreign currency.

from allocation decisions. This feature shields the volatility of the variables in the model (except for the real exchange rate) from changes in the exchange rate regime.

One period after the shock, firms fully adjust the prices in the home country (that is, prices denominated in the home currency). Thus, prices adjust to their new long-run level[27] and all expansionary real effects of a positive monetary shock disappear after one period. Because of the small long-run effect on bond holdings, all real variables return roughly to their original levels. The real exchange rate, in particular, will not show any persistence in this model with only one quarter price stickiness.

Under fixed rates (and in the absence of other shocks), the foreign money supply has to mimic the home money supply in order to peg the currency. Therefore, the money supplies in both countries are always equal and, given the symmetric calibration of the model, the response to the home monetary shock is identical in both countries. In fact, bond holdings, net exports, and the real exchange rate are not affected by the monetary shock. The adjustment of all other home variables is qualitatively identical, but slightly greater, than under flexible rates. This difference is associated with the monetary expansion in the foreign country, which raises foreign demand for home goods.

Since the foreign monetary authority needs to mimic the home money supply in order to peg the exchange rate, the adjustment of output and consumption in response to a monetary shock is larger in the fixed exchange rate regime than in the flexible regime. The results in Table 3 indicate that also the adjustment of output and consumption in response to a productivity shock is larger in both countries under fixed rates than under flexible rates. However, in the case of a shock to productivity, the different response across regimes depends critically on asset market incompleteness.

Fig. 1 shows the responses to a positive productivity shock in the home country in period 2 (panel a), which represents a positive wealth shock for the home agent.[28] Since nominal goods' prices are set one period in advance and only adjust one period after the shock, home labor supply falls on impact (panel c) in response to the shock. In the flexible exchange rate regime and due to asset market incompleteness, the home agent accumulates bonds and his labor supply remains below the steady-state level as the shock dies out. In the new steady state, the agent has a higher level of bond holdings which is consistent, from the agent's budget constraint, with a lower nominal exchange rate level.

In the fixed exchange rate regime, the foreign monetary authority increases the money supply in order to maintain the peg, counterbalancing the positive home wealth shock associated with the productivity shock. Therefore, under fixed rates the response to the productivity shock resembles the response that would be obtained with optimal risk sharing, even though asset markets are incomplete: In equilibrium, after the initial fall in the period of the shock, the home (high productivity) agent's

[27] The change in prices is approximately the same as the long-run increase in the money supply.

[28] To construct these figures, we approximate the stochastic process for the growth rate of home money supply by a three-state Markov chain, using Tauchen and Hussey's (1991) method. The figures depict the average response of the system across all instances in which the shock transited from its mean value to its high value, in a 75,000 period simulation of the model. These figures are analogous to impulse response functions. This procedure is proposed in Gomes et al. (2001).

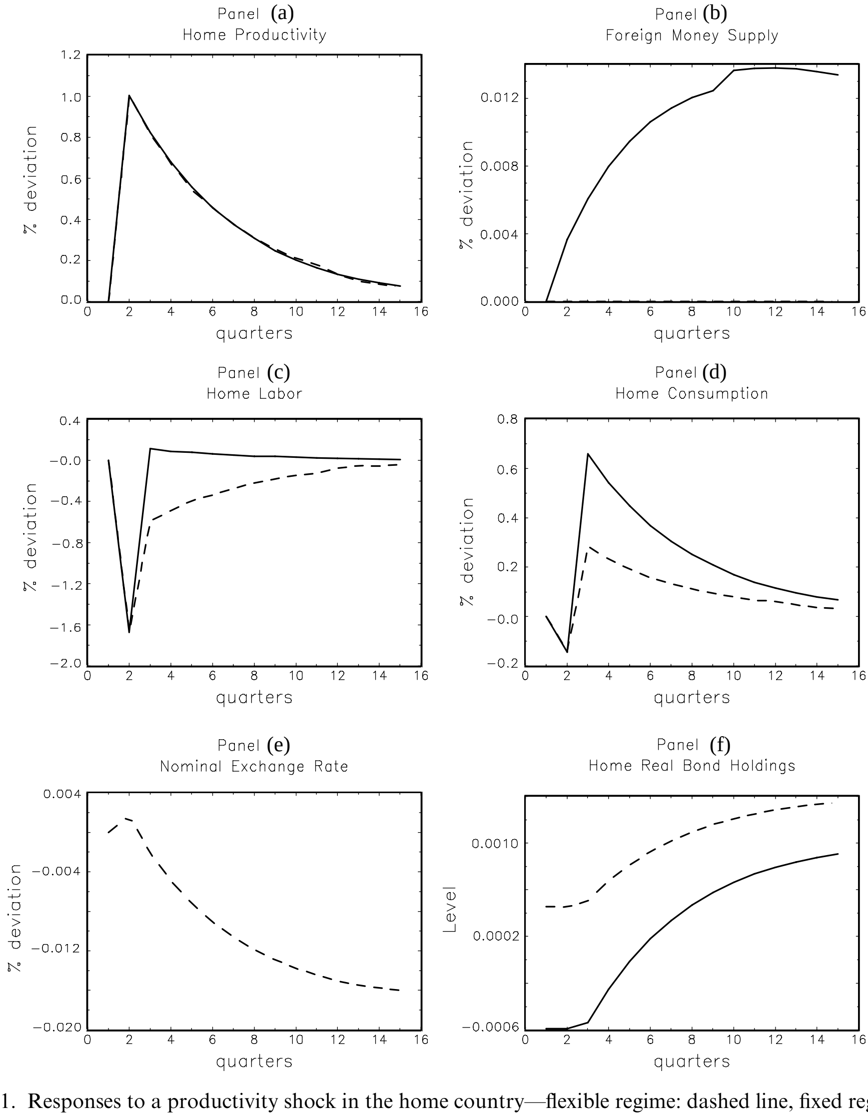

Fig. 1. Responses to a productivity shock in the home country—flexible regime: dashed line, fixed regime: solid line.

labor supply stays above steady state, instead of remaining below steady state, as the shock dies out. Because of this agent's higher productivity, the adjustment of all variables is larger in the fixed regime than in the flexible regime.

6.2. Cross-correlations across regimes

The model predicts that the volatility of the real exchange rate is the variable most affected by a change in regime, while the effect of this change on the volatilities of all

Table 4
Simulated cross-correlations

	Fixed rates	Flexible rates
Cross-correlation		
Home and foreign outputs	0.94	0.35
Home and foreign consump.	0.98	0.06
Nominal and real exchange rates	—	0.31

other variables is small. In Section 4, Eq. (4.13) expressed the nominal exchange rate in period t as a function of contemporaneous and next period's marginal utilities of consumption and price levels in both countries. Rewriting this equation in terms of the real exchange rate gives

$$q_t = \frac{u^*_{1,t}}{u_{1,t}} \frac{E_t[u_{1,t+1}/P_{t+1}]}{E_t[u^*_{1,t+1}/q_{t+1}P_{t+1}]}, \tag{6.1}$$

where the real exchange rate is expressed as the ratio of marginal utilities of consumption times a term of expected values. Given that the volatility of the real exchange rate (in the left-hand side of Eq. (6.1)) is markedly different across regimes and the volatilities of the variables in the right-hand side are not, we need to reconcile Eq. (6.1) with the results obtained.

Table 4 reports the cross-correlations for selected variables across regimes, for simulations with both types of shocks. In this table, we observe that moving from pegged to flexible exchange rates decreases substantially the cross-correlation between home and foreign outputs and consumptions. As in the simple model presented in Section 3, this feature is a result of the coordination of home and foreign monetary policies, required to keep the peg under fixed exchanges rates. As noted before, under flexible rates the monetary policies in the two countries are independent, while under fixed rates they are correlated. This implies that the cross-country correlations of all variables is higher under fixed than under flexible exchange rates and is consistent with the evidence presented in Section 2.

It is therefore the difference in the commovement of variables across countries[29] that allows Eq. (6.1) to hold across regimes. The additional expectation term in Eq. (6.1), implied by asset market incompleteness, has a negligible role in creating a wedge between the volatility of the real exchange rate and the volatility of the ratio of marginal utilities of consumption. This result is in line with the findings in Engel (2001).

In this paper, we have developed a simple version of the new open-macroeconomics model aimed at explaining the puzzling empirical results discussed in Section 2. Consequently, our model has abstracted from features that are inessential for that purpose but that would be necessary to characterize other features of the data, in particular, capital accumulation or a higher degree of price

[29] In particular, the higher commovement between home and foreign marginal utilities of consumption in the fixed exchange rate regime.

stickiness. Table 4, for example, shows that our model predicts a correlation between real and nominal exchange rates of 0.31, which falls short of the correlation in the data. This feature results partly from the very simple price-setting structure used in the model: all firms set prices one period in advance. Consequently, monetary shocks have real effects for only one period, after which firms fully adjust their nominal prices. Therefore, real variables show no persistence. This property of the response to a monetary shock translates into the correlation between real and nominal exchange rates and auto-correlations of real variables in the simulated model, given the relative importance of monetary shocks in our model. With longer-term price setting, including possibly staggered price setting, our model would predict a higher correlation between real and nominal exchange rates. Similarly, our model has abstracted from capital accumulation. Consequently, our model predicts very small auto-correlations of real macroeconomic aggregates and it predicts that the first-order auto-correlation of the nominal exchange rate (under a floating-rate regime) is only 0.7.[30] Both longer-term, staggered price setting and capital accumulation would induce persistence in the model and raise predicted auto-correlations, without affecting the intuition for the results in the paper.

7. Conclusion

Empirical studies show that countries moving from pegged to floating exchange rate regimes experience a dramatic increase in the volatility of exchange rates, while the volatility of other macroeconomic aggregates is barely affected. Moreover, business cycles tend to be more synchronized across countries under fixed rates than flexible rates. We explain these empirical regularities by developing a two-country dynamic general equilibrium model. The most important features of our model are sticky prices in the buyers' currencies and asset market incompleteness.

The model successfully generates a sharp increase in the volatility of the real exchange rate following a switch from fixed to flexible rates, without a similar pattern for the volatilities of output, consumption, or trade flows. Because prices are set in advance in the buyers' currencies, allocation decisions are dissociated, on impact, from unexpected changes in the nominal exchange rate. This feature restricts the effect of the exchange rate regime on the volatilities of output, consumption, or trade flows.

Another contribution of the paper is the prediction of higher cross-correlations of variables across countries under fixed rates than under flexible rates. This implication results from the coordination of monetary policies across countries needed to peg the exchange rate under fixed rates.

[30] The model predicts that the first-order auto-correlation of output is only −0.04 under fixed exchange rates and −0.05 under flexible rates. Instead, the model predicts a first-order auto-correlation of 0.55 for the real exchange rate under a fixed rate regime. This result is determined by the persistence in productivity shocks, given that in the model with monetary shocks only the real exchange rate is constant.

The most natural extension of our work is the analysis of the welfare implications of alternative exchange rate regimes. This welfare analysis has important policy implications and is at the core of the policy debate involving currency areas, such as the Euro zone.

Using the framework developed in this paper, we can evaluate the welfare costs of exchange rate volatility in a general equilibrium setup which is quantitatively consistent with the data. There are, however, three reasons that prevent us from conducting this welfare analysis in the present paper. First, variables in the model display very low persistence when compared with the data. As discussed in the text, the present model could be extended by introducing capital accumulation or longer-term price setting structures. Second, the model only considers exogenous money supply rules. It would be important to study the welfare costs of exchange rate volatility when money is endogenous. Finally, the model abstracts from the credibility issues associated with the fixed exchange rate regime. Given that the risk of a speculative attack is typically considered one of the most important costs of pegged rates, the credibility of the fixed regime is a crucial issue in any model used for the welfare analysis of exchange rate volatility.

References

Artis, M., Zhang, W., 1999. Further evidence on the international business cycle and the ERM: is there a European business cycle? Oxford Economic Papers 51, 120–132.

Backus, D., Kehoe, P., Kydland, F., 1995. International business cycles: theory and evidence. In: Cooley, T. (Ed.), Frontiers of Business Cycle Research. Princeton University Press, Princeton, NJ, pp. 331–356.

Basu, S., Taylor, A., 1999. Business cycles in international historic perspective. Journal of Economic Perspectives 13, 45–68.

Baxter, M., Stockman, A., 1989. Business cycles and the exchange rate regime: some international evidence. Journal of Monetary Economics 23, 377–400.

Betts, C., Devereux, M., 2000. Exchange rate dynamics in a model of pricing-to-market. Journal of International Economics 50, 215–244.

Chari, V.V., Kehoe, P., McGrattan, E., 2000. Can sticky prices models generate volatile and persistent real exchange rates? Federal Reserve Bank of Minneapolis Research Department Staff Report 277.

Dedola, L., Leduc, S., 1999. On exchange rate regimes, exchange fluctuations, and fundamentals. Federal Reserve Bank of Philadelphia Working Paper no. 99-16.

Devereux, M., 1997. Real exchange rates and macroeconomics: evidence and theory. Canadian Journal of Economics 30, 773–808.

Devereux, M., Engel, C., 1998. Fixed vs. floating exchange rates: how price setting affects the optimal choice of exchange-rate regime. NBER Working Paper no. 6867.

Devereux, M., Engel, C., 2000. Monetary policy in the open economy revisited: price setting and exchange rate flexibility. NBER Working Paper no. 7665.

Engel, C., 2001. Optimal exchange rate policy: the influence of price setting and asset markets. Journal of Money, Credit and Banking 33, 518–541.

Flood, R., Rose, A., 1995. Fixing exchange rates: a virtual quest for fundamentals. Journal of Monetary Economics 36, 3–37.

Gomes, J., Greenwood, J., Rebelo, S., 2001. Equilibrium unemployment. Journal of Monetary Economics 48, 109–152.

Jeanne, O., Rose, A., 2002. Noise trading and exchange rate regimes. Quarterly Journal of Economics 117, 537–569.

Kollmann, R., 2001. The exchange rate in a dynamic-optimizing current account model with nominal rigidities: a quantitative investigation. Journal of International Economics 55, 243–262.

Mehra, R., Prescott, E., 1985. The equity premium: a puzzle. Journal of Monetary Economics 15, 145–161.

Mussa, M., 1986. Nominal exchange rate regimes and the behavior of real exchange rates: evidence and implications. Carnegie–Rochester Conference Series on Public Policy 25, pp. 117–214.

Obstfeld, M., 1998. Open-economy macroeconomics: developments in theory and policy. Scandinavian Journal of Economics 100, 247–275.

Obstfeld, M., Rogoff, K., 1995. Exchange rate dynamics redux. Journal of Political Economy 103, 624–660.

Obstfeld, M., Rogoff, K., 1996. Foundations of International Macroeconomics. MIT Press, Cambridge, MA.

Obstfeld, M., Rogoff, K., 2000a. New directions for stochastic open economy models. Journal of International Economics 50, 117–153.

Obstfeld, M., Rogoff, K., 2000b. The six major puzzles in international macroeconomics: is there a common cause? In: Bernanke, B., Rogoff, K. (Eds.), NBER Macroeconomics Annual 2000. MIT Press, Cambridge, MA, pp. 339–390.

Rotemberg, J., Woodford, M., 1995. Dynamic general equilibrium models with imperfectly competitive product markets. In: Cooley, T. (Ed.), Frontiers of Business Cycle Research. Princeton University Press, Princeton, NJ, pp. 243–293.

Sopraseuth, T., 2000. Exchange rate regimes and international business cycles. Unpublished Paper, Department of Economics, University of Paris I.

Stockman, A., 1983. Real exchange rates under alternative nominal exchange rate systems. Journal of International Money and Finance 2, 147–166.

Stockman, A., 1999. Choosing an exchange-rate system. Journal of Banking & Finance 23, 1483–1498.

Tauchen, G., Hussey, R., 1991. Quadrature-based methods for obtaining approximate solutions to nonlinear asset pricing models. Econometrica 59, 371–396.

Whalley, J., 1985. Trade Liberalization Among Major World Trading Areas. MIT Press, Cambridge, MA.