Macroeconomic Effects of Nominal Exchange Rate Regimes: New Insights into the Role of Price Dynamics

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This paper analyzes the effects of pegged and floating exchange rates using a two-country dynamic general equilibrium model that is calibrated to the U.S. and a European aggregate. The model assumes shocks to money, productivity and the interest parity condition. It captures the fact that the sharp increase in nominal exchange rate volatility after the abandonment of the Bretton Woods (BW) system was accompanied by a commensurate rise in *real* exchange rate volatility, but had no pronounced effect on the volatility of U.S. and European output. This holds irrespective of whether flexible or sticky prices are assumed--which casts doubt on the widespread view that the roughly equal rise in nominal *and* real exchange rate volatility reflects price stickiness. Flex-prices variants of the model capture better the fact that the cross-region output correlation has been higher in the floating-rate era.

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1. Introduction

The macroeconomic effect of the nominal exchange rate regime is a key question in economics. The volatility of nominal exchange rates and of real exchange rates (defined as relative national price levels, expressed in a common currency) between the major currency blocs (U.S., Europe, Japan) has risen sharply after the end of the Bretton Woods (BW) pegged-exchange rate system. By contrast, the *volatility* of real GDP showed little change after the end of BW, but the cross-region *correlation* of GDP increased markedly.

For example, the standard deviation of Hodrick-Prescott filtered log quarterly nominal and real exchange rates between the U.S. and an aggregate of the three largest continental European economies (EU3: Germany, France, Italy) rose from less than 1% under BW to about 8% in the post-BW era. The standard deviation of U.S. and EU3 GDP was between 1% and 2%, in both eras; the U.S.-EU3 GDP correlation rose from -0.18 (BW) to 0.48 (post-BW).

This paper analyzes these facts using a quantitative two-country dynamic general equilibrium (DGE) model. Interest centers on what light these facts shed on a central and controversial issue in macroeconomics: the relevance of price stickiness for explaining (international) macroeconomic data. The rise in *real* exchange rate volatility that accompanied the rise in *nominal* exchange rate volatility after the end of the BW system, is widely viewed as reflecting price stickiness--and used to justify (Keynesian) sticky-prices macro models, see; e.g., Mussa (1986), Dornbusch and Giovannini (1990), Caves et al. (1993), and Obstfeld and Rogoff (1996).

The results presented in this paper cast doubt on this view. A flexible-prices variant of the model here--that features shocks to the interest parity condition, see discussion below--can capture the key facts discussed in the first and second paragraph. A sticky-prices variant can capture the post-BW rise in nominal and real exchange rate volatility, but fails to explain the rise in the cross-country output correlation. Thus, the simultaneous rise in nominal *and* real exchange rate volatility after the end of the BW system *cannot* be interpreted as evidence for price stickiness (flex- and sticky-prices variants *both* capture this phenomenon).

The widespread view discussed above seems to be based on the assumption that monetary shocks are the main source of exchange rate fluctuations (standard theory predicts that money shocks have no effect on the real exchange rate under price flexibility, but induce real exchange rate movements that closely track the nominal exchange rate when prices are (sufficiently) sticky). However, econometric attempts to predict post-BW short-run exchange rate movements from changes in money and other macroeconomic fundamentals (productivity, fiscal policy) have so far had little success (Meese and Rogoff (1983), Rogoff (2000)). Also, structural economic models driven by these fundamentals tend to generate *predicted* exchange rate variability that is *much* smaller than that seen in the post-BW data. This applies both to flex-prices models in the Real Business Cycle (RBC) tradition, as well as to sticky-prices models.[1] Therefore, models that rely solely on traditional fundamentals are not well suited for analyzing a floating-rate regime.

In order to generate more realistic exchange rate volatility, this paper considers an additional type of shock: a stationary shock to the

[1]E.g., the Backus et al. (1995) RBC model captures only about one tenth of the standard deviation of post-BW real exchange rates. Sticky-prices models may generate more volatile exchange rates than RBC models (possibility of Dornbusch-style exchange rate overshooting) but require unrealistically long price adjustment lags to match post-BW volatility (Kollmann (2002), Chari et al. (2000)).

uncovered interest parity (UIP) condition. This specification is motivated by the well-documented strong and persistent empirical departures from UIP (e.g., Lewis (1995)). The UIP shock can be interpreted as reflecting distorted exchange rate forecasts (Frankel and Froot (1989), i.a., document biases in exchange rate forecasts).

Variants of the model that assume a pegged and a floating exchange rate are calibrated to the U.S. and the EU3. The calibration uses estimates of the time series process of the UIP shock. A flex-prices version of the model and a sticky prices version are considered. The latter assumes staggered price setting à la Calvo (1983); the average duration between price changes is set at 4 quarters--as often assumed in Keynesian models.

Simulations of the floating rate variant suggest that UIP shocks are a powerful source of nominal and real exchange rate fluctuations--much more than money and productivity shocks. The variant with UIP shocks captures about 80% of the standard deviations of post-BW nominal and real U.S.-EU3 exchange rates. Due to the small volume of U.S.-EU3 trade, relative to GDP (under 2%), nominal exchange rate movements induced by UIP shocks have only a limited effect on national price levels--thus, these movements are accompanied by (roughly) equiproportional variations of the *real* exchange rate; also, these exchange rate movements only have a weak effect on aggregate output. The model thus captures the fact that the sharp rise in dollar exchange rate volatility after the end of BW did not greatly affect the volatility of U.S. and EU3 output. These results hold irrespective of whether sticky or flexible prices are assumed.

By contrast, flex- and sticky-prices versions yield sharply differing predictions regarding the effect of the exchange rate regime on the *cross-country output correlation*. Monetary policy affects output under sticky prices, but is neutral under flexible prices. As a pegged exchange rate regime requires international synchronization of monetary policy, the sticky-prices variant predicts that the cross-country output correlation is higher in a pegged-rate regime than in a floating-rate regime. That prediction is inconsistent with the fact that the U.S.-EU3 output correlation was lower (and actually *negative*) under BW. Flex-prices variants of the model, by contrast, capture that fact, provided one allows for asymmetric country-specific productivity shocks during the BW era (empirically, innovations to total factor productivity were *negatively* correlated across the U.S. and the EU3, during the BW era).

In the industrialized world, the rise in exchange rate volatility after the end of the BW system has been strongest among the major currency blocs--which motivates the focus of the paper on the U.S.-EU3 exchange rate. Trade flows among theses blocs are weak, relative to GDP.

The model predicts that the effect of UIP shocks on real GDP is stronger in more open economies. The sensitivity to openness is most pronounced when import prices (in buyer currency) are flexible (this is the case when *all* prices are flexible, or when prices are sticky in terms of producer currency)--and when, hence, nominal exchange rate movements are immediately and fully passed through into import prices. The sensitivity to openness is less perceptible when import prices are sticky, because of price setting in buyer currency ("pricing to market"). (With complete pass through, nominal exchange rate movements induce noticeably stronger responses of national price levels, and hence of expected real interest rates and thus of output, the greater is the degree of openness; price stickiness in buyer currency dampens considerably the price level responses.) The model suggests that more open economies have a stronger incentive to peg their exchange rate--especially under complete pass through. Empirically, the likelihood of adopting a peg is positively linked to openness; e.g., Edwards (1996). A structure with flexible import prices can better rationalize this fact than a structure with sticky import prices.

The work here is related to the Keynesian literature of the 1960s and 1970s that provided theoretical analyses of fixed and floating exchange rate regimes, under the assumption that prices (or wages) are sticky (e.g., Mundell (1968), Dornbusch (1980)); that literature predicts that the exchange rate regime affects macroeconomic behavior, but provides only limited quantitative/empirical results. Methodologically, that literature lacks the explicit micro-foundations that characterize the dynamic-optimizing approach adopted here. Recent DGE open economy models (see Obstfeld and Rogoff (1996) for a survey) typically assume a floating exchange rate. Exceptions include Obstfeld and Rogoff (2000), Devereux and Engel (2000), Bacchetta and van Wincoop (2000) who compare pegged and floating exchange rate regimes, using highly stylized models, for which *exact* closed form solutions can be derived; these authors focus on welfare effects of the exchange rate regime. In contrast, the paper here considers a richer *business cycle* model that is solved numerically and used to analyze key features of historical data.

Section 2 discusses the model. Sect. 3 reports macroeconomic stylized facts for the BW and post-BW periods. Sect. 4 presents simulation results. Sect. 5 concludes.

2. The Model

A world with two countries, called Home and Foreign, is considered. In each country there are firms, a representative household and a government that issues a national currency. Each country produces a single non-tradable final good and a continuum of tradable intermediate goods indexed by $s\in[0,1]$. Each country's final good is produced by perfectly competitive firms that use local and imported intermediate goods as inputs; it can be consumed or used for investment. There is monopolistic competition in the markets for intermediate goods--each intermediate good is produced by a single firm. Intermediate goods producers use domestic capital and domestic labor as inputs--capital and labor are immobile internationally. Each country's household owns all domestic firms and the domestic capital stock, which it rents to firms; it also supplies labor to firms. The markets for rental capital and labor market are competitive.

The following description focuses on the Home country. The Foreign country is a mirror image of the Home country (preferences and technologies are symmetric across countries). Foreign variables are denoted by an asterisk.

2.1. Final good production

The Home final good is produced using the aggregate technology

$$Q_t = \{(\alpha^d)^{1/\vartheta}\cdot(Q_t^d)^{(\vartheta-1)/\vartheta} + (\alpha^m)^{1/\vartheta}\cdot(Q_t^m)^{(\vartheta-1)/\vartheta}\}^{\vartheta/(\vartheta-1)}, \qquad (1)$$

with $\alpha^d,\alpha^m>0$, $\alpha^d+\alpha^m=1$, $\vartheta>0$. Q_t is Home final good output at date t. Q_t^d, Q_t^m are quantity indexes of Home and Foreign produced intermediate goods, respectively: $Q_t^i=\{\int_0^1 q_t^i(s)^{(\nu-1)/\nu}\,ds\}^{\nu/(\nu-1)}$, with $\nu>1$, for i=d,m, where $q_t^d(s)$ and $q_t^m(s)$ are quantities of the Home and Foreign produced type 's' intermediate goods. Let $p_t^d(s)$ and $p_t^m(s)$ be the prices of these goods, in Home currency. Cost minimization in Home final good production implies:

$$q_t^i(s)=(p_t^i(s)/\mathcal{P}_t^i)^{-\nu}\,Q_t^i, \quad Q_t^i = \alpha^i\,(\mathcal{P}_t^i/P_t)^{-\vartheta}\,Q_t, \text{ for } i=d,m, \qquad (2)$$

with $\mathcal{P}_t^i\equiv\{\int_0^1(p_t^i(s))^{1-\nu}\,ds\}^{1/(1-\nu)}$, $\quad P_t\equiv\{\alpha^d\,(\mathcal{P}_t^d)^{1-\vartheta}+\alpha^m\,(\mathcal{P}_t^m)^{1-\vartheta}\}^{1/(1-\vartheta)}$.

$\mathcal{P}^d_t$ [$\mathcal{P}^m_t$] are price indices for Home [Foreign] intermediate goods. Perfect competition in the final good market implies that the good's price equals P_t (its marginal cost is: $\{\alpha^d\ (\mathcal{P}^d_t)^{1-\vartheta}+\alpha^m\ (\mathcal{P}^m_t)^{1-\vartheta}\}^{1/(1-\vartheta)}$).

2.2. Intermediate goods producers

The technology of the firm that produces Home intermediate good 's' is:

$$y_t(s) = \theta_t\ (\mathcal{K}_t(s))^{\psi}\ (\mathcal{L}_t(s))^{1-\psi},\quad \text{with } 0<\psi<1. \tag{3}$$

$y_t(s)$ is the firm's output at date t. θ_t is an exogenous productivity parameter that is common to all Home intermediate goods producers. $\mathcal{K}_t(s)$ and $\mathcal{L}_t(s)$ are the amounts of capital and labor used by the firm.

Let R_t and W_t be the Home rental rate of capital and wage rate. Cost minimization implies: $\mathcal{L}_t(s)/\mathcal{K}_t(s) = \psi^{-1}\ (1-\psi)\ R_t/W_t$. The firm's marginal cost is $\mathfrak{G}_t\equiv(1/\theta_t)(R_t)^{\psi}\ (W_t)^{1-\psi}\ \psi^{-\psi}\ (1-\psi)^{-(1-\psi)}$.

The firm's good is sold in the domestic market and exported: $y_t(s)= q^d_t(s)+q^{m*}_t(s)$, where $q^d_t(s)$ [$q^{m*}_t(s)$] is Home [Foreign] demand. The Foreign demand function is analogous to the Home demand function (2):

$$q^{m*}_t(s) = (p^{m*}_t(s)/\mathcal{P}^{m*}_t)^{-\nu}\ Q^{m*}_t,$$

where $p^{m*}_t(s)$ is the firm's export price, in Foreign currency, and $\mathcal{P}^{m*}_t \equiv\{\int_0^1 (p^{m*}_t(s))^{1-\nu}\ ds\}^{1/(1-\nu)}$.

The firm's profit, π_t, is:

$$\pi_t(p^d_t(s),p^{m*}_t(s))\equiv(p^d_t(s)-\mathfrak{G}_t)(p^d_t(s)/\mathcal{P}^d_t)^{-\nu}Q^d_t\ +(e_t p^{m*}_t(s)-\mathfrak{G}_t)(p^{m*}_t(s)/\mathcal{P}^{m*}_t)^{-\nu}Q^{m*}_t,$$

where e_t is the nominal exchange rate, defined as the Home currency price of Foreign currency.

Intermediate good producers can price discriminate between the domestic market and the export market: $p^d_t(s)\neq e_t p^{m*}_t(s)$ is possible (when prices are flexible, firms set $p^d_t(s)=e_t p^{m*}_t(s)$, as the price elasticities of their demand schedules are identical in both markets). Intermediate goods prices are set in a staggered fashion, à la Calvo (1983), in buyer currency: firms cannot change prices, in buyer currency, unless they receive a random "price-change signal". The probability that the price (in buyer currency) of a give intermediate good can be changed in any particular period is $1-\delta$, a constant. Thus, the mean price-change-interval is $1/(1-\delta)$. Firms are assumed to meet all demand at posted price.

Consider a Home intermediate good producer that, at t, sets a new price in the Home market, $p^{d}_{t,t}$ and in the Foreign market, $p^{m*}_{t,t}$. With probability δ^{τ}, these prices are still in force at $t+\tau$. The firm sets

$$\{p^{d}_{t,t},p^{m*}_{t,t}\} = \text{Arg} \underset{pd,pm}{\text{Max}} \sum_{\tau=0}^{\tau=\infty}\delta^{\tau}E_{t}\{\rho_{t,t+\tau}\ \pi_{t+\tau}(pd,pm)/P_{t+\tau}\},$$

where $\rho_{t,t+\tau}$ is a pricing kernel (for valuing date $t+\tau$ pay-offs) that is assumed to equal the Home household's intertemporal marginal rate of substitution in consumption: $\rho_{t,t+\tau}=\beta^{\tau}\cdot U_{C,t}/U_{C,t+\tau}$, where $U_{C,t+\tau}$ is the household's marginal utility of consumption at date $t+\tau$ (household preferences are described in Section 2.3).

The solution of the firm's decision problem regarding $p^{d}_{t,t}$, $p^{m*}_{t,t}$ is:

$$p^{d}_{t,t}=(\nu/(\nu-1))\left\{\sum_{\tau=0}^{\tau=\infty}\delta^{\tau}E_{t}\{\Xi^{d}_{t,t+\tau}\ \mathfrak{G}_{t+\tau}\}\right\}\Big/\left\{\sum_{\tau=0}^{\tau=\infty}\delta^{\tau}E_{t}\Xi^{d}_{t,t+\tau}\right\},$$

$$p^{m*}_{t,t}=(\nu/(\nu-1))\left\{\sum_{\tau=0}^{\tau=\infty}\delta^{\tau}E_{t}\{\Xi^{m*}_{t,t+\tau}\ \mathfrak{G}_{t+\tau}\}\right\}\Big/\left\{\sum_{\tau=0}^{\tau=\infty}\delta^{\tau}E_{t}\{\Xi^{m*}_{t,t+\tau}\ e_{t}\}\right\},$$

with $\Xi^{d}_{t,t+\tau}\equiv\rho_{t,t+\tau}\ Q^{d}_{t+\tau}\ (\mathcal{P}^{d}_{t+\tau})^{\nu}/P_{t+\tau}$, $\Xi^{m*}_{t,t+\tau}\equiv\rho_{t,t+\tau}\ Q^{m*}_{t+\tau}\ (\mathcal{P}^{m*}_{t+\tau})^{\nu}/P_{t+\tau}$. These expressions imply that, up to a certainty equivalent approximation, prices set at t equal a weighted average of current and expected marginal costs, multiplied by the markup factor $\nu/(\nu-1)>1$.

The price indices $\mathcal{P}^{d}_{t}$ and $\mathcal{P}^{m*}_{t}$ evolve according to:

$$(\mathcal{P}^{d}_{t})^{1-\nu}=\delta(\mathcal{P}^{d}_{t-1})^{1-\nu}+(1-\delta)(p^{d}_{t,t})^{1-\nu},\qquad (\mathcal{P}^{m*}_{t})^{1-\nu}=\delta(\mathcal{P}^{m*}_{t-1})^{1-\nu}+(1-\delta)(p^{m*}_{t,t})^{1-\nu}.$$

2.3. The representative household

The preferences of the Home household are described by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \, U(C_t, \mathcal{M}_t/P_t, L_t). \tag{4}$$

E_0 denotes the mathematical expectation conditional on information available in period t=0. $0<\beta<1$ is a subjective discount factor. C_t and L_t are period t consumption and labor effort. $\mathcal{M}_t$ is the household's stock of Home money at the end of period t. U is a utility function of the following form:

$$U(C, \mathcal{M}/P, L) = \ln\{[C^{\sigma} + \kappa\, (\mathcal{M}/P)^{\sigma}]^{1/\sigma}\} - L. \tag{4a}$$

As indicated earlier, the Home household owns all Home firms and it accumulates Home physical capital. The law of motion of capital is:

$$K_{t+1} + \phi(K_{t+1}, K_t) = K_t\,(1-d) + I_t, \tag{5}$$

where I_t is gross investment. $0<d<1$ is the depreciation rate of capital and ϕ is an adjustment cost function: $\phi(K_{t+1}, K_t) = 0.5\,\Phi\,\{K_{t+1} - K_t\}^2/K_t$, $\Phi>0$.

The household can also hold nominal one-period Home and Foreign currency bonds. The period t budget constraint of the Home household is:

$$\begin{aligned} \mathcal{M}_t + A_t + e_t B_t + P_t(C_t + I_t) = \mathcal{M}_{t-1} + T_t + A_{t-1}(1+r_{t-1}) + \\ e_t B_{t-1}(1+r^*_{t-1}) + R_t K_t + \int_0^1 (\pi_t^d(s) + \pi_t^x(s))ds + W_t L_t. \end{aligned} \tag{6}$$

A_{t-1} and B_{t-1} are the household's (net) stock of Home and Foreign currency bonds that mature in period t. r_{t-1} and r^*_{t-1} are the nominal interest rate on these bonds. T_t is a government cash transfer. The last two terms on the right-hand side of (5) are the household's dividend and labor income.

The household chooses a strategy $\{\mathcal{M}_t, A_t, B_t, K_{t+1}, C_t\}_{t=0}^{t=\infty}$ to maximize its expected lifetime utility (4), subject to constraints (5), (6). Ruling out Ponzi schemes, the following equations are first-order conditions of this decision problem:

$$1 = (1+r_t)\,\beta\, E_t\{(U_{C,t+1}/U_{C,t})\,(P_t/P_{t+1})\}, \tag{7}$$

$$1 = (1+r^*_t)\,\beta\, E_t\{(U_{C,t+1}/U_{C,t})\,(P_t/P_{t+1})\,(e_{t+1}/e_t)\}, \tag{8}$$

$$1 = \beta\, E_t\{(U_{C,t+1}/U_{C,t})\,(R_{t+1}/P_{t+1} + 1-d + \phi_{2,t+1})/(1 + \phi_{1,t})\}, \tag{9}$$

$$U_{m,t} = (r_t/(1+r_t))\ U_{C,t}, \tag{10}$$

$$W_t/P_t = 1/U_{C,t}. \tag{11}$$

Here, $U_{C,t} \equiv \partial U(C_t,..)/\partial C_t$, $U_{m,t} \equiv \partial U(C_t,..)/\partial(\mathcal{M}_t/P_t)$, $\phi_{1,t} \equiv \partial\phi(K_{t+1},K_t)/\partial K_{t+1}$, $\phi_{2,t} \equiv \partial\phi(K_{t+1},K_t)/\partial K_t$. (7)-(9) are Euler equations; (10) can be viewed as a money demand condition; (11) says that the household equates the marginal rate of substitution between consumption and leisure to the real wage rate.

2.4. Uncovered Interest Parity

Up to a (log-)linear approximation, (7) and (8) imply interest parity (UIP): $E_t \ln(e_{t+1}/e_t) \cong r_t - r_t^*$. Given the well-documented strong and persistent empirical departure from UIP (see, e.g., Lewis (1995)), variants of the model are explored in which the Euler condition for foreign currency bonds (8) is disturbed by a stationary exogenous stochastic shock, φ_t ("UIP shock", henceforth) whose unconditional mean is unity ($E\varphi_t=1$):

$$1 = \varphi_t\ (1+r_t^*)\ \beta\ E_t\{(U_{C,t+1}/U_{C,t})\ (P_t/P_{t+1})\ (e_{t+1}/e_t)\}. \tag{8a}$$

(Log-)linearizing (7) and (8a) yields:

$$E_t \ln(e_{t+1}/e_t) = r_t - r_t^* - \ln(\varphi_t). \tag{12}$$

The UIP shock can be interpreted as reflecting biased exchange rate forecasts or a time-varying "risk premium".[2] [3]

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[2]Assume that household *beliefs* at t about e_{t+1} are given by a probabi= lity density function, p_t^S, that differs from the *true* pdf, p_t, by a factor $1/\varphi_t$: $p_t^S(e_{t+1},\Omega)=p_t(e_{t+1}/\varphi_t,\Omega)/\varphi_t$ (Ω is any other random variable). The Home Euler equation for Foreign bonds is then given by (8a) (Foreign Euler equation for Home bonds: $1=\varphi_t^{-1}(1+r_t)\beta E_t(U^*_{C,t+1}/U^*_{C,t})(P^*_t/P^*_{t+1})(e_t/e_{t+1})$).

[3]Several recent studies have assumed UIP shocks (these papers do not study the issues addressed here: a quantitative analysis of differences in macroeconomic behavior across the BW and post-BW periods; the role of price dynamics). See, for example Miller and Williamson (1988), Mark and Wu (1998) and Jeanne and Rose (2000) who interpret the shocks as "fads", and McCallum and Nelson (1999, 2000) and Taylor (1993) who refer to them as a "risk premium".

2.5. Monetary policy

Let M_t be the Home money stock at the end of period t. The government pays increases in the money stock out to the household, as a transfer, T:

$$M_t = M_{t-1} + T_t.$$

Variants of the model with a pegged and a floating exchange rate are considered. In the pegged-rate regime, Home money is exogenous, while Foreign money follows a path that ensures that the nominal exchange rate equals a fixed parity, $\bar{e}$: $e_t=\bar{e}$; in the floating-rate regime, by contrast, the money stocks in both countries are exogenous.

2.6. Market clearing conditions

Supply equals demand in intermediate goods markets as producers of intermediate goods meet all demand at posted prices. Market clearing in the Home markets for the final good, labor and rental capital requires:

$$Z_t = C_t + I_t, \quad L_t = \int_0^1 \mathcal{L}_t(s)\, ds, \text{ and } K_t = \int_0^1 \mathcal{K}_t(s)\, ds,$$

where Z_t, L_t and K_t are the supplies of the final good, labor and rental capital; $\int_0^1 \mathcal{L}_t(s)ds$ and $\int_0^1 \mathcal{K}_t(s)ds$ is total demand for labor and capital (by intermediate good producers). Each country's currency is only held by its residents; Home money market equilibrium requires, thus:

$$M_t = \mathcal{M}_t,$$

where M_t and $\mathcal{M}_t$ are the money supply and the household's desired money balances. Market clearing in bond markets requires:

$$A_t + A_t^* = 0 \quad \text{and} \quad B_t + B_t^* = 0,$$

where A_t^* [B_t^*] is the Foreign-owned stock of Home [Foreign] currency bonds.

2.7. Solution method

An approximate model solution is obtained by taking a linear approximation of the equations listed above (and of counterparts of these equations for the Foreign country), around a deterministic steady state that is symmetric across countries, and in which each country's trade balance and its net stock of foreign currency bonds are zero. (Log-)linear stochastic processes are specified for the exogenous variables (see below). The resulting linear dynamic system is solved using the Anderson and Moore (1985) method (using MATLAB programs written by G. Anderson and V. Wieland; http://www.bog.frb.fed.us/pubs/).

2.8. Parameter values

The subjective discount factor is set at $\beta=1/1.01$; the implied steady state real interest rate, r, is 1%, as $\beta\cdot(1+r)=1$ holds in steady state (business cycle models that are calibrated to quarterly data commonly assume r=0.01, which corresponds roughly to the long run average return on capital).

Equation (10) implies $\mathcal{M}_t/P_t=C_t(r_t(1+r_t)^{-1}\kappa^{-1})^{1/(\sigma-1)}$. Hence, the elasticity of money demand with respect to the interest rate (evaluated at the steady state interest rate) is $emi\equiv\beta/(\sigma-1)$. Based on Fair's (1987) estimates of emi for the U.S. and the EU3 countries (Germany, France, Italy), I set emi=-0.05. The preference parameter κ determines the steady state consumption velocity. It appears that the key model predictions are not very sensitive to changes in κ. In the simulations, κ is set at a very small (positive) number, which implies that changes in real money balances have no (perceptible) effect on the marginal utility of consumption; this entails that money is (essentially) neutral when prices are flexible.

The price elasticity of a country's aggregate import demand function is given by ϑ (see (2)). For the U.S. and Germany, Hooper and Marquez (1995) report median estimates of ϑ of 1.05 and 0.55, respectively; for France and Italy, Hooper et al. (1998, p.7) report an estimate of 0.4. The simulations set ϑ=0.75. [4] The ratio of U.S. imports from the EU3 divided U.S. GDP averaged about 0.4% during the BW period, and about 1% during the post-BW period; the ratio of EU3 imports from the U.S. divided by EU3 GDP was about 1.2% during BW and 1% during post-BW (data source: IMF Direction of Trade Statistics). In the baseline model, α^m (see (1)) is set so that each country's imports/GDP ratio is 1% (for both exchange rate regimes).

The steady state markup of price over marginal cost for intermediate goods is set at $1/(\nu-1)=0.2$, consistent with the findings of Martins et al. (1996) for the U.S. and the EU3 countries. The technology parameter ψ (see (3)) set at ψ=0.2, which entails a 2/3 steady state labor income/GDP ratio, consistent U.S. and EU3 data. Aggregate data indicate a quarterly capital depreciation rate of roughly 2.5%; thus, d=0.025 is assumed. The capital adjustment cost parameter Φ is set at Φ=8, in order to match the fact that the standard deviation of investment is approximately 4 times larger than that of output, in the U.S. and in the EU3.

Micro evidence on the frequency of price changes is sketchy and inconclusive, and it mainly pertains to the U.S.--I am not aware of evidence for the EU3. Retail prices are quite flexible--e.g., the Levy et

[4]The assumption in the model that the elasticity of substitution is identical across countries is made for simplicity of exposition only. When Home and Foreign elasticities, denoted ϑ and ϑ^*, differ, combinations of ϑ and ϑ^* for which the mean $(\vartheta+\vartheta^*)/2$ is identical, are observationally equivalent, for the variables discussed below. Computing a weighted average (using GDP weights) of the estimates of ϑ for Germany, France and Italy reported above and then taking the arithmetic mean of this weighted average and of the estimate for the U.S. yields an elasticity of 0.75.

al. (1998) study of U.S. supermarkets finds that 15% of prices are changed every *week*. A survey of top management at about 200 major U.S. firms by Blinder et al. (1998) reports a median frequency of 1.4 price changes per year; however, the median price-adjustment lag following a demand or cost change is quite short: 1 quarter. It appears that in many sectors non-price attributes (delivery lags, warranties, after-sale services etc.) are quite responsive to changes in market conditions--changes in these attributes might thus act as a substitute for short term price changes (Carlton (1986)).

The simulations consider a variant of the model with an average price-change-interval of 4 quarters, δ=0.75 (a value widely used in New Keynesian macro models; e.g., Erceg et al. (2000)), and a variant with flexible prices, δ=0 (as assumed in RBC models).

Productivity and the UIP shock follow these processes:

$$z_t^{\theta} = R^{\theta} z_{t-1}^{\theta} + \varepsilon_t^{\theta}, \qquad \text{for } z_t^{\theta} \equiv (\ln(\theta_t), \ln(\theta_t^*))', \tag{13}$$

$$\ln(\varphi_t) = \rho^{\varphi} \ln(\varphi_{t-1}) + \varepsilon_t^{\varphi}. \tag{14}$$

In the pegged-rate regime, Home money evolves according to:

$$\ln(M_{t+1}/M_t) = \rho^{m} \ln(M_t/M_{t-1}) + \varepsilon_t^{m}. \tag{15}$$

In the floating-rate regime, the law of motion of Home and Foreign money is:

$$z_{t+1}^{\mu} = R^{\mu} z_t^{\mu} + \varepsilon_t^{\mu}, \qquad \text{for } z_{t+1}^{\mu} \equiv (\ln(M_{t+1}/M_t), \ln(M_{t+1}^*/M_t^*))'. \tag{16}$$

ε_t^{θ}, ε_t^{φ}, ε_t^{m} and ε_t^{μ} are independent (vector) white noises.

Estimates of these processes for 1959Q1-70Q4 and 73Q1-94Q4 are shown in Table 1. The processes have differed markedly across these two periods. Estimates for the 59-70 [73-94] period are used to simulate the pegged-exchange-rate [floating-rate] variant of the model.

The autocorrelation of U.S. productivity (about 0.85) and the standard deviation of U.S. productivity innovations (0.6%) were roughly similar across both periods. By contrast, the autocorrelation of EU3 productivity was much lower during the BW period (0.17) than during the post-BW era (0.81), while the standard deviation of the EU3 productivity innovation was higher during the BW era (0.87% vs. 0.54%); this reflects a series of sharp but brief shocks to EU3 output during the 1960s (reflecting, e.g., the French general strike of 1968). The correlation between U.S. and EU3 productivity innovations was *negative* in the BW era (-0.28) and positive in the post-BW era (0.18).

The autocorrelation of the UIP shock and the standard deviation of the innovation to that shock were 0.24 and 0.58% during 59Q1-70Q4, compared to 0.50 and 3.30% during 73Q1-94Q4.[5] The UIP shock has thus been more persistent during the post-BW period and--as might be expected--*much* more volatile (clearly there is much more scope for irrational exchange rate forecasts when exchange rates float than when they are pegged).

The autocorrelation of U.S. money growth was the same during both periods (0.39), but the standard deviation of U.S. money supply innovations was higher during the post-BW era. The autocorrelation of post-BW EU3 money growth was likewise positive (0.18). Spillovers between the U.S. and EU3 money supply processes were weak under BW (off-diagonal elements of R^{μ} matrix close to zero); also, the correlation between U.S. and EU3 money supply innovations has been close to zero, during that period.

Note that the estimated post-BW money and productivity processes are roughly symmetric across the two countries; to simplify the discussion, the floating-rate variant of the model uses 'symmetrized' versions of those

[5]Note that $\ln(\varphi_t)=E_t\ln(\varphi'_t)$, with $\ln(\varphi'_t)\equiv\ln(e_{t+1}/e_t)+r^*_t-r_t$. I regressed $\ln(\varphi'_t)$ on a constant and on variables known at date t (lags 1-4 of $\ln(\varphi'_t)$; U.S. and EU3 interest rates, inflation and linearly detrended log GDP at dates t,...,t-4); (14) was then estimated using the fitted $\ln(\varphi'_t)$ series.

processes: $R^m=\begin{bmatrix} .29 & .03 \\ .03 & .29 \end{bmatrix}$, $E(\varepsilon_t^m \varepsilon_t^{m\prime}) = .0112^2 \cdot \begin{bmatrix} 1 & -.02 \\ -.02 & 1 \end{bmatrix}$, $R^\theta=\begin{bmatrix} .81 & .03 \\ .03 & .81 \end{bmatrix}$, $E(\varepsilon_t^\theta \varepsilon_t^{\theta\prime})=.0058^2 \cdot \begin{bmatrix} 1 & .17 \\ .17 & 1 \end{bmatrix}$.

3. Stylized facts about economic fluctuations (BW and post-BW era)

Table 2 reports statistics on the cyclical behavior of key U.S. and EU3 quarterly time series for the periods 59Q1-70Q4 and 73Q1-94Q4. The EU3 time series are weighted averages of German, French and Italian data (weights: shares in 1980 EU3 GDP). All series have been logged, with the exception of interest rates, and Hodrick-Prescott (HP) filtered. Table 2 shows that:

(1) The standard deviations of nominal and real exchange rates were smaller than 1% under BW and exceeded 8% during the post-BW era. The correlation between nominal and real exchange rates was close to unity (0.99) during the post-BW era--markedly higher than under BW (0.43). During the post-BW era, nominal and real exchange rates have been much more volatile than GDP, the money stock and the price level.

(2) Standard deviations of money stocks, price levels and nominal interest rates were likewise higher in the post-BW era, especially in the U.S. (U.S.: increase by factor of roughly 3). The volatility of EU3 real macro aggregates shows no systematic differences across the two periods, but that of real U.S. aggregates was higher during the post-BW era (the standard deviation of U.S. GDP increased from 1.22% (BW era) to 1.82% (post-BW era)). However, the increase in the volatility in money, prices, interest rates and real quantities, relative to the BW era, was much weaker than that of exchange rate volatility.

(3) Cross-country correlations of real macro aggregates, of productivity and of the price level were markedly higher in the post-BW era

than under BW; for example, the cross-country correlation of GDP increased from -0.18 (BW) to 0.48 (post-BW). In both periods, the cross-country correlation of the nominal interest rate (roughly 0.5) was sizable and highly statistically significant.

(4) In both periods and in both countries, consumption and total factor productivity have been less volatile than GDP, while investment and net exports have been more volatile.

(The empirical regularities highlighted here hold also for other industrialized countries--see, e.g. Mussa (1986), Baxter and Stockman (1989), Flood and Rose (1995), Gerlach (1988), Backus et al. (1995)).

4. Model predictions

Simulation results are reported in Tables 3-4. The countries' output and price level are measured by their real GDP and the final good price (P_t, P^*_t); the real exchange rate is defined as $RER_t \equiv e_t P^*_t / P_t$. Model statistics pertain to variables that have been logged (with the exception of the interest rate) and HP filtered. Variants are considered in which each of the 3 types of shocks occurs separately, as well as variants with the 3 simultaneous shocks.

4.1. Baseline model--floating exchange rate (Table 3)

Table 3 shows results for the floating exchange rate variant. Money supply shocks have no effect on real variables when prices are flexible (δ=0; see Column (1)). In contrast, money shocks have a sizable effect on real variables in the sticky-prices structure (δ=0.75; Col. (5)) -- predicted standard deviations of output and the real exchange rate: 1.95% and 1.71%, respectively. The predicted standard deviation of the *nominal* exchange rate

(2.7%) is roughly the same in the flex-prices and sticky- prices structures. In the sticky-prices structure, money shocks induce a cross-country correlation of output (0.08) that is positive, but much smaller than that seen in the U.S.-EU3 data (0.48).

For understanding the effect of shocks on the exchange rate, it is useful to note that log-linearizing (7) and (10) yields a difference equation in the Home nominal interest rate and money that has this solution:

$$r_t - r = (1-\zeta)^{-1}\sum_{k=0}^{k=\infty}\zeta^k E_t \ln(M_{t+1+k}/M_{t+k}), \quad \text{with } 0<\zeta\equiv emi/(emi-r)<1, \tag{17}$$

where emi<0 is the interest rate elasticity of money demand. Hence, the Home nominal interest rate is an increasing function of expected future Home money growth rates. Interestingly, productivity shocks and UIP shocks have *no* effect on the nominal interest rate; also, the behavior of the *nominal* interest rate does *not* depend on the degree of price stickiness.

Solving (12) forward allows to express the nominal exchange rate as a function of (the expected path of) the Home-Foreign nominal interest rate differential and of the UIP shock.

$$\ln(e_t) = -\sum_{k=0}^{k=\infty} E_t\{r_{t+k} - r^*_{t+k} - \ln(\varphi_{t+k})\} + \lim_{k\mapsto\infty} E_t \ln(e_{t+k}). \tag{18}$$

For the sticky-prices structure, Panel (a) of Figure 1 (to be included in future versions of the paper) shows dynamic effects of a 1% Home money supply innovation. The shock induces a nominal and real exchange rate depreciation and a gradual increase in the Home price level. The shock raises the Home nominal interest rate as it raises the expected growth rate of money; this explains why, on impact, the nominal exchange rate undershoots its long run response (see (18)).[6] Also, the expected Home *real*

[6]These responses of the nominal interest rate and the nominal exchange rate hinge on the unit intertemporal elasticity of substitution in consumption (iec) and the unit elasticity of money demand with respect to

interest rate, in terms of the Home final good, falls (not shown in Figure), as the expected Home inflation rate increases. This raises Home consumption and investment demand--thus Home output rises. Foreign output rises likewise (as Home demand for Foreign goods rises), though by markedly less than Home output.

<u>Productivity shocks</u> have a sizable effect on output, but only a very weak effect on the nominal exchange rate. When prices are flexible, the predicted standard deviations of nominal and real exchange rates are 0.06% and 0.83%, respectively (Col. (2)). Price stickiness dampens the effect of productivity shocks on output and the real exchange rate (Col. (6)). When there are just productivity shocks, the floating-exchange-rate variant of the model predicts that macroeconomic aggregates are positively correlated across countries, which is mainly due to the fact that--in the floating-rate variant--the cross-country correlation of productivity (0.21) is positive.

The preceding shows that money and productivity shocks cannot explain the high volatility of (nominal and real) exchange rates seen during the post-BW era--irrespective of whether flexible or sticky prices are assumed.

<u>UIP shocks</u> have a much stronger effect on the nominal and real

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consumption (emc) implied by the log-CES preference specification (4a) (which was adopted to simplify the presentation). Kollmann (2001a, 2001b) considers a more general specification that allows to set iec≠1, emc≠1. When iec<1, emc<1 and prices are sticky, the nominal interest rate may fall--and hence, there may be Dornbusch (1976) style exchange rate overshooting--in response to a positive money supply shocks. However, unless price adjustment lags are implausibly long (in the range of four *years*), predicted exchange rate volatility remains below that seen in the post-BW data (Kollmann (2001a)). The nominal interest rate is affected by productivity shocks and UIP shocks, when iec, emc≠1; however, that effect is weak, and the key predictions regarding the effect of money and UIP shocks discussed below continue to hold when iec, emc≠1.

exchange rate: when just UIP shocks are assumed, the predicted standard deviation of nominal and real exchange rates is about 6.5%. This is so irrespective of whether prices are flexible or sticky. By contrast, UIP shocks have only a minor effect on the standard deviations of the other variables considered in the Table, with the exception of net exports.

As discussed above, UIP shocks have *no* effect on the nominal interest rate. As UIP shocks do not alter the money supply (which is exogenous), they have little long-run effect on the (Home and Foreign) price level, and hence little long-run effect on the nominal exchange rate. Thus, with just UIP shocks (see (18)):

$$\ln(e_t) \cong \sum_{k=0}^{k=\infty} E_t \ln(\varphi_{t+k}) = (1-\rho^{\varphi})^{-1}\ln(\varphi_t). \tag{19}$$

Panel (c) in Figure 1 shows dynamic effects of a 1% UIP shock. In accordance with the preceding formula, a 1% UIP shock induces a nominal depreciation of the Home currency by about 2%, on impact; in subsequent periods, the nominal exchange rate appreciates and moves back towards its pre-shock value.

The Home currency depreciation lowers the Home import price index $\mathcal{P}^m$, which lowers the Home price level P. However, the response of P is very weak (+0.004%, on impact), as the weight of import prices in the domestic price index (which equals the imports/GDP ratio: 1%) is low. (Foreign responses are a mirror image of Home responses.)

The weak responses of P and P^* implies that the behavior of the *real* exchange rate ($e_t P_t^*/P_t$) mimics very closely that of the nominal rate, when just UIP shocks are assumed: the correlation between nominal and real exchange rates is 0.99; the standard deviation of the real exchange rate is close to that of the nominal exchange rate. This is the case irrespectively of whether prices are flexible (δ=0) of sticky (δ=0.75).

The weak effect of UIP shocks on (expected) inflation rates (and their zero effect on nominal interest rates) implies also that their effect on expected *real* interest rates (in terms of Home and Foreign final goods) is likewise weak. This explains why these shocks have little effect on consumption, investment and aggregate output.[7] In terms of % standard deviations, (net) exports (NX) are the only quantity variable that is significantly affected by UIP shocks, especially when prices are flexible--predicted standard deviation of NX: 10.33% with flexible prices, and 1.78% with sticky prices.[8] The lower variability of NX in the sticky-prices structure is due to the weaker response of import prices (in buyer currency) to the nominal exchange rate change, under price stickiness.

The recent literature (e.g., Betts and Devereux (2000), Devereux and Engel (2000)) has stressed that the predictions of sticky-prices models may be sensitive to whether prices are set in buyer currency ("pricing to market", PTM)--as assumed in the baseline case--or set in producer currency. Producer currency price setting (PCP) implies that exchange rate movements are immediately and fully passed through into import prices, in terms of buyer currency. I studied a variant of the model with PCP (not

[7]As the nominal exchange rate depreciates on impact, and then gradually appreciates, in response to a positive UIP shock, the Home price level rises on impact, and gradually falls thereafter; the shock thus reduces the Home expected inflation rate, and raises the Home expected real interest rate; hence, Home consumption, investment and output fall (Foreign responses are a mirror image of Home responses). The rise in the Home imports price index (and fall in Foreign imports price index) induced by a positive UIP shock reduces Home net exports.

[8]In Table 3, NX is defined as $NX \equiv Q^{m*}/Q^{m}$, where Q^{m*} [Q^{m}] is a quantity index of Home exports [imports] (see (1)). Due to the small trade/GDP ratio, the high volatility of HP filtered logged NX is consistent with the low volatility of HP filtered logged output, consumption and investment.

reported in Table) and found that its predictions resemble those of the PTM model (with one exception: in the PCP variant, net exports are about as volatile as in the flex-prices variant, as in both variants import prices, in buyer currency, exhibit a sharp and immediate response to a UIP shock).[9] When the trade share is low (as in the baseline case), the distinction between PTM and PCP is thus irrelevant for real GDP and the real exchange rate. (As discussed below, the distinction matters when trade shares are higher.)

When the three types of shocks are used simultaneously (Table 3, Cols. (4) and (8)), the flex-prices and sticky-prices variants of the floating-rate model generate predicted standard deviations of nominal and real exchange rates of about 7%--these variants capture, thus, about 80% of the standard deviation of post-BW U.S.-EU3 nominal and real exchange rates. Both variants yield high predicted correlations between nominal and real exchange rates (correlation in sticky-prices [flex-prices] variant: 0.97 [0.92]). In terms of capturing the standard deviations of the quantity variables, both variants seem broadly consistent with the post-BW data. Both variants underpredict the post-BW correlation between U.S. and EU3 GDP (0.48) (the cross-country GDP correlation is higher under flexible prices (0.23) than under sticky prices (0.09).

The rise in *real* exchange rate volatility that accompanied the rise in *nominal* exchange rate volatility after the end of the BW system, and the almost perfect correlation between post-BW nominal and real exchange rates,

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[9]Under PCP, $p_t^d(s)=e_t p_t^{m*}(s)$ holds at all times. A Home intermediate good producer that, at t, gets to change its price sets:

$$p_{t,t}^d = \text{Arg} \underset{pd}{\text{Max}} \sum_{\tau=0}^{\tau=\infty} \delta^\tau E_t\{\rho_{t,t+\tau}\, \pi_{t+\tau}(pd, pd/e_{t+\tau})/P_{t+\tau}\},$$

is widely viewed as reflecting price stickiness--and used to justify (Keynesian) sticky-prices macro models with, in which monetary shocks have real effects (e.g., Mussa (1986), Dornbusch and Giovannini (1990), Caves et al. (1993), and Obstfeld and Rogoff (1996)). The results presented here cast doubt on this view--as sticky-prices and flexible-prices variants of the model both capture this fact. This view seems to based on the assumption that monetary shocks are the main source of exchange rate fluctuations (as money shocks have no effect on the real exchange rate under price flexibility, but induce high nominal-real exchange rate correlations when prices are sufficiently sticky). However, the simulations suggest that money shocks only explain a relatively small part of post-BW (nominal and real) exchange rate fluctuations.

By contrast, UIP shocks have a sizable effect on the nominal exchange rate *and* on the real exchange rate, as these shocks have little effect on the national price level--even when prices are flexible. Hence, the high correlation between the nominal and the real exchange rate does not permit to draw conclusions regarding price stickiness.

4.2. Baseline model--pegged exchange rate (Table 4)

Table 4 presents results for the variant of the model with a pegged exchange rate (these results are based on the structure of exogenous shocks estimated from BW era data).[10]

In the fixed-exchange rate variant, Home money shocks induce a

[10]The pegged-rate variant discussed here builds on Kollmann (1996). A paper by Dedola and Leduc (2000) also uses a calibrated DGE model to compared pegged- and floating-rate regimes. The model and the focus of the analysis here differ from theirs.

response of Foreign money that mimics the path of Home money. When prices are sticky, output, prices and interest rates are thus perfectly correlated across countries, when just Home money shocks are assumed. With just productivity shocks, the predicted cross-country output correlation is *negative* (-0.08), when prices are flexible, because of the assumed *negative* cross-country correlation of productivity; by contrast, the cross-country correlation is positive (0.25) in the sticky-prices version (a positive shock to Home productivity requires a *rise* in the Foreign money stock, to prevent a depreciation of the Home currency; with sticky prices, this raises Home *and* Foreign output). In the fixed-exchange rate regime, UIP shocks trigger a significant response of the Foreign interest rate and money supply, to stabilize the nominal exchange rate; with sticky prices, this has a noticeable effect on Foreign real activity (standard deviation of Foreign output when there are just UIP shocks: 1.05%). UIP shocks have, hence, a more destabilizing effect in a pegged-rate regime than in a floating-rate regime.

When the pegged-exchange rate structure is simultaneously subjected to the three types of shocks, that structure generates predicted standard deviations that are broadly consistent with the Bretton Woods data. Note, especially, that the model is consistent with the fact that while the volatility of nominal and real exchange rates has changed markedly between the BW and post-BW eras, the variability of real economic activity has changed comparatively little. This is so irrespective of whether flexible or sticky prices are assumed. However, the sticky-prices version of the fixed-exchange rate model generates yields a high positive cross-country output correlation (0.73)--while the actual cross-country correlation was negative during the BW era (-0.18). The flex-prices version of the BW model, by contrast, generates a *negative* cross-country correlation (-0.06).

4.3. Extension: higher trade shares (Table 5)

In the industrialized world, the rise in exchange rate volatility after the end of the BW system has been strongest among the major currency blocs--which motivates the focus of the present paper on the U.S.-EU3 exchange rate. Trade flows among theses blocs are weak, relative to GDP. Can the results be transposed to situations with stronger trade links (such as those observed *among* EU countries)? A detailed empirical/calibration analysis of such situations is beyond the scope of this paper. Table 5 merely consider versions of the floating-rate model in which the steady state trade share (imports/GDP ratio), denoted by α, is set at a markedly higher value than in the baseline case: α=0.25 (baseline: α=0.01). (All other parameters are kept unchanged.)

When there are just money and productivity shocks, the predicted standard deviations of macroeconomic variables are not very sensitive to α. Table 5 and the discussion below focus thus on the effect of UIP shocks.

The nominal-real exchange rate correlation induced by UIP shocks is close to unity (0.99), irrespective of the trade share (and of whether prices are flexible or sticky). Predicted *nominal* exchange rate variability does not depend on the trade share. However, *real* exchange rate variability is inversely related to openness, while price level and output variability is positively linked to openness. This sensitivity to openness is most pronounced when nominal exchange rate movements are completely and immediately passed through into import prices (in buyer currency)--which is the case in the flex-prices structure and in a sticky-prices structure with producer currency price setting (PCP). The sensitivity to openness is much less perceptible in the baseline sticky-prices structure with buyer currency price setting ("pricing to market", PTM). With full pass through, nominal exchange rate movements induce noticeably stronger responses of national price levels (and hence stronger responses of expected real interest rates and thus of consumption and output, but weaker responses of the real exchange rate), the greater the trade shares (PTM dampens considerably the response of price levels). When α=0.25, the predicted standard deviations of the real exchange rate, the price level and GDP are 3.23%, 1.71%, and 0.43% under price flexibility (and 3.34%, 1.67%, 0.53% under PCP), compared to 6.29%, 0.29%, 0.09% under PTM. (Corresponding statistics in the baseline case with α=0.01: 6.47%, 0.13%, 0.02% [flex-prices]; 6.51%, 0.13%, 0.02% [PCP]; 6.67%, 0.02%, 0.01% [PTM].) Hau (2000) shows that a clear inverse relationship between post-BW real exchange rate volatility and openness exists, across OECD countries.

The model here suggests that--especially under complete pass through--more open economies have a stronger incentive to peg their exchange rate (vis-à-vis their main trading partner(s)), in order to avoid the destabilizing effects of volatile nominal exchange rates. Empirically, the likelihood of adopting an exchange rate peg is positively linked to openness (e.g., Edwards (1996)). This might be viewed as indirect evidence for a high degree of pass through (and, thus, for a flex-prices structure *or* a sticky-prices structure with producer currency pricing)--the model predicts that, in very open economies, the destabilizing effect of exchange rate volatility is much stronger under complete pass through.

5. Conclusion

This paper has compared business cycle stylized facts across the Bretton Woods (BW) pegged exchange rate period and the post-Bretton Woods era, for the U.S. and an aggregate of European economies (EU3). Nominal and real exchange rate volatility was much higher under floating; the volatility of aggregate output was hardly affected by floating, but the U.S.-EU3 output correlation was markedly higher during the post-BW period.

Based on a two-country dynamic general equilibrium (DGE) model, the paper argues that a flexible-prices structure (in which money is neutral) can capture all the facts described above; the sticky-prices structure can capture the rise in nominal-real exchange rate volatility after the end of BW but fails to explain the rise in the cross-country output correlation.

The model assumes shocks to money supplies and to productivity, as well as shocks to the uncovered interest parity (UIP) condition. Standard DGE models (with just money and productivity shocks) fail to capture the high volatility of the U.S. dollar exchange rate during the post-BW era. The model here (with UIP shocks) generates much more volatile exchange rates than standard models--it captures about 80% of the standard deviations of post-BW U.S.-EU3 nominal and real exchange rates. In contrast to conventional wisdom (e.g., Mussa (1986), Dornbusch and Giovannini (1990), Caves et al. (1993), and Obstfeld and Rogoff (1996)), the model here suggests that price stickiness is not the key to explaining why the substantial rise in *nominal* exchange rate volatility between the major currency blocs after the end of the BW system was accompanied by a commensurate rise in *real* exchange rate volatility: when trade flows are weak, relative to GDP (as is the case between the major currency blocs), nominal exchange rate movements induced by UIP shocks are accompanied by roughly parallel *real* exchange rate movements, irrespective of whether prices are flexible or sticky; also, these exchange rate movements have little effect on GDP.

The model suggests that, by contrast, the degree of price flexibility matters in situations with strong trade links: there, nominal exchange rate movements (induced by UIP shocks) have a weaker effect on the real exchange rate, and a markedly stronger effect on real GDP, *when* nominal exchange rate movements are fully passed through into import prices (compared to a setting with pricing to market). The simulation results suggest that--especially under complete pass through--highly open economies have a stronger incentive to peg their exchange rate, in order to avoid the destabilizing effects of volatile nominal exchange rates.

DATA APPENDIX

The **data** are quarterly and (unless otherwise indicated) are from International Financial Statistics [IFS] published by the IMF. **GDP**: real GDP. **Consumption**: real total private consumption. **Investment**: gross fixed capital formation plus change in stock of inventories (nominal series deflated using CPI). **Net exports**: *exp/imp*, where *exp (imp)* is volume index of exports (imports) of goods and services. **Money stock**: M1 (from OECD Main Economic Indicators [MEI]; 59-70 series for EU3 M1 are taken from Darby et al. (1983)). **Price level**: CPI. **Nominal interest rate**: short term rates from Citibase, expressed on a quarterly basis (series FYUSCD, FYGECM, FYFRCM, FYITBY; for Italy: bond yield, credit institutions). **Nominal exchange rate**: domestic currency prices of U.S. dollar. **Real exchange rate**: based on relative CPIs.

Productivity (θ): total factor productivity index defined as $\ln(\theta)\equiv\ln(Y)-0.208\ln(K)-(1-0.208)\ln(L)$, where Y, K and L are real GDP, capital and labor (EU3 series for 59-70: $\ln(\theta)\equiv\ln(Y)-(1-0.208)\ln(L)$, due to lack of data on K); the weight on log capital (0.208) corresponds to the value in the theoretical model. *Labor*: For the U.S., total employee hours (Citibase series LPMHU) are used; the EU3 series for 1959-70 is total employment (from OECD Main Economic Indicators) while the series for 1973-95 is total hours, from Bulletin of Labor Statistics (International Labor Office). *Capital*: The U.S. capital stock is taken from Survey of Current Business (U.S. Department of Commerce); for EU3 countries, capital stock series do not seem to be readily available, for 1959-70; for 73-94, EU3 capital stock series are taken from the OECD publication 'Flows and Stocks of Fixed Capital'; these capital stock series are annual; quarterly series are constructed by linear interpolation of the annual series.

Aggregate EU3 series are geometric weighted averages of German, French and Italian series (for interest rate: arithmetic average); weights: 0.41, 0.35, 0.24 (shares in 1980 EU3 GDP). Germany series are for *West* Germany.

Starting dates for GE Consumption (C) & Investment (I): 60Q1; FR C & I: 65Q1; IT C: 70Q1; IT I: 60Q1. The aggregate EU3 C series starts in 60Q1; it equals GE C for 60Q1-64Q4 and a weighted average of GE and FR C, for 65Q1-69Q4 (series for sub-periods spliced together multiplicatively). Aggregate EU3 I series constructed analogously.

TABLE 1. Fitted laws of motion of money, productivity and UIP shock

(a) 1959:Q1-1970:Q4

$$\Delta\ln(M^{US}_{t+1}) = \underset{(0.14)}{0.39}\ \Delta\ln(M^{US}_{t}) + \varepsilon^{m,US}_{t}, \quad \sigma(\varepsilon^{m,US}_{t}) = 0.0067.$$

$$\begin{bmatrix}\ln(\theta^{US}_{t}) \\ \ln(\theta^{EU3}_{t})\end{bmatrix} = \begin{bmatrix}\underset{(0.06)}{0.93} & \underset{(0.11)}{-0.06} \\ \underset{(0.09)}{0.03} & \underset{(0.15)}{0.17}\end{bmatrix} \cdot \begin{bmatrix}\ln(\theta^{US}_{t-1}) \\ \ln(\theta^{EU3}_{t-1})\end{bmatrix} + \begin{bmatrix}\varepsilon^{\theta,US}_{t} \\ \varepsilon^{\theta,EU3}_{t}\end{bmatrix},$$

$$\sigma(\varepsilon^{\theta,US}_{t}) = 0.0065, \quad \sigma(\varepsilon^{\theta,EU3}_{t}) = 0.0087, \quad \rho(\varepsilon^{\theta,US}_{t}, \varepsilon^{\theta,EU3}_{t}) = \underset{(0.09)}{-0.28}.$$

$$\ln(\varphi_t) = \underset{(0.15)}{0.24}\ \ln(\varphi_{t-1}) + \varepsilon^{\varphi}_{t}, \quad \sigma(\varepsilon^{\varphi}_{t}) = 0.0058.$$

(b) 1973:Q1-1994:Q4

$$\begin{bmatrix}\Delta\ln(M^{US}_{t+1}) \\ \Delta\ln(M^{EU3}_{t+1})\end{bmatrix} = \begin{bmatrix}\underset{(0.10)}{0.39} & \underset{(0.09)}{-0.00} \\ \underset{(0.11)}{0.07} & \underset{(0.10)}{0.18}\end{bmatrix} \cdot \begin{bmatrix}\Delta\ln(M^{US}_{t}) \\ \Delta\ln(M^{EU3}_{t})\end{bmatrix} + \begin{bmatrix}\varepsilon^{m,us}_{t} \\ \varepsilon^{m,EU3}_{t}\end{bmatrix},$$

$$\sigma(\varepsilon^{m,US}_{t}) = 0.0106, \quad \sigma(\varepsilon^{m,EU3}_{t}) = 0.0119, \quad \rho(\varepsilon^{m,US}_{t}, \varepsilon^{m,EU3}_{t}) = \underset{(0.08)}{-0.02}.$$

$$\begin{bmatrix}\ln(\theta^{US}_{t}) \\ \ln(\theta^{EU3}_{t})\end{bmatrix} = \begin{bmatrix}\underset{(0.06)}{0.81} & \underset{(0.06)}{-0.03} \\ \underset{(0.05)}{0.09} & \underset{(0.05)}{0.81}\end{bmatrix} \cdot \begin{bmatrix}\ln(\theta^{US}_{t-1}) \\ \ln(\theta^{EU3}_{t-1})\end{bmatrix} + \begin{bmatrix}\varepsilon^{\theta,US}_{t} \\ \varepsilon^{\theta,EU3}_{t}\end{bmatrix},$$

$$\sigma(\varepsilon^{\theta,US}_{t}) = 0.0063, \quad \sigma(\varepsilon^{\theta,EU3}_{t}) = 0.0054, \quad \rho(\varepsilon^{\theta,US}_{t}, \varepsilon^{\theta,EU3}_{t}) = \underset{(0.08)}{0.18}.$$

$$\ln(\varphi_t) = \underset{(0.09)}{0.50}\ \ln(\varphi_{t-1}) + \varepsilon^{\varphi}_{t}, \quad \sigma(\varepsilon^{\varphi}_{t}) = 0.0330.$$

Notes: An intercept was included in all regressions (a linear time trend was also included in regression equation for productivity). Figures in parentheses are standard errors. σ [ρ]: standard deviations of [correlations between] innovations. See Appendix for description of data.

Table 2. Historical statistics

	1959Q1-1970Q4		1973Q1-1994Q4	
	U.S.	EU3	U.S.	EU3
	(1)	(2)	(3)	(4)
Standard deviations (in %)				
GDP	1.22 (.10)	1.05 (.11)	1.82 (.22)	1.16 (.14)
Consumption	1.04 (.08)	1.18 (.13)	1.46 (.16)	0.88 (.08)
Investment	3.97 (.57)	4.83 (.51)	7.20 (.90)	5.05 (.63)
Net exports	6.10 (.78)	4.09 (.58)	7.93 (.80)	3.07 (.30)
Productivity	0.71 (.05)	0.87 (.11)	0.87 (.11)	0.63 (.05)
Money	0.87 (.10)	1.31 (.11)	2.36 (.39)	1.49 (.17)
Price level	0.62 (.10)	0.74 (.04)	1.67 (.26)	1.21 (.15)
Nominal interest rate	0.13 (.03)	0.16 (.03)	0.48 (.07)	0.35 (.04)
Nominal $ exchange rate	0.46 (.10)		8.75 (1.1)	
Real $ exchange rate	0.98 (.09)		8.11 (1.0)	
Cross-country correlations				
GDP	-0.18 (.15)		0.48 (.14)	
Consumption	-0.34 (.18)		0.30 (.18)	
Investment	-0.25 (.13)		0.27 (.19)	
Productivity	0.00 (.13)		0.28 (.12)	
Money	0.12 (.18)		0.04 (.18)	
Price level	0.16 (.22)		0.56 (.08)	
Nominal interest rate	0.54 (.10)		0.45 (.13)	
Corr. between nom. & real $ exchange rate	0.43 (.22)		0.99 (.00)	

Notes: The figures in parentheses are standard errors (obtained using GMM, assuming tenth-order serial correlation in residuals). All series were logged (with exception of interest rates) and HP filtered.

In Cols. (1),(2), doubly underlined statistics (═══): difference compared to Bretton Woods statistics (Cols. (3), (4)) significant at 1% level (two-sided test); once underlined statistics (───): difference significant at 10% level.

Table 3. Predictions of baseline floating exchange rate model

	Flexible-prices model				Sticky-prices model				Data, 73-94	
	Schocks to			M, θ,	Schocks to			M, θ,	U.S.	EU3
	M	θ	UIP	UIP	M	θ	UIP	UIP		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Standard deviations (in %)										
GDP	0.00	0.96	0.02	0.96	1.95	0.39	0.01	1.99	1.82	1.16
C	0.00	0.63	0.13	0.64	1.21	0.27	0.02	1.24	1.46	0.88
I	0.00	3.32	0.78	3.41	7.57	1.28	0.13	7.68	7.20	5.05
NX	0.00	0.15	10.33	10.33	2.96	0.07	1.78	3.46	7.93	3.07
M	1.85	0.00	0.00	1.85	1.85	0.00	0.00	1.85	2.36	1.49
P	1.99	0.63	0.13	2.09	1.27	0.27	0.02	1.30	1.67	1.21
r	0.07	0.00	0.00	0.07	0.07	0.00	0.00	0.07	0.48	0.35
e	2.73	0.06	6.73	7.26	2.78	0.04	6.70	7.26	8.75	
RER	0.00	0.83	6.47	6.52	1.71	0.33	6.67	6.90	8.11	
Cross-country correlations										
GDP	u	0.23	-1.00	0.23	0.08	0.36	-1.00	0.09	0.48	
C	u	0.25	-1.00	0.20	0.04	0.38	-1.00	0.05	0.30	
I	u	0.20	-1.00	0.14	0.04	0.35	-1.00	0.05	0.27	
M	0.04	u	u	0.04	0.04	u	u	0.04	0.04	
P	0.06	0.19	-1.00	0.07	0.06	0.38	-1.00	0.08	0.56	
r	0.25	u	u	0.25	0.25	u	u	0.25	0.45	
Corr between e & RER										
	u	0.88	1.00	0.92	0.80	0.93	1.00	0.97	0.99	

Notes: **C**: Consumption; **I**: investment; **M**: money supply; **P**: price level; **r**: nominal interest rate; **e/RER**: nominal/real exchange rate; **NX**: net exports (defined as Q_t^{m*}/Q_t^m, where Q_t^{m*} [Q_t^m] is an index of Foreign [Home] imports).

Cols. labelled "Shocks to M", "Shocks to θ", "Shocks to UIP" pertain to cases in which shock just to Home and Foreign money, just to Home and Foreign productivity, and just to the UIP equation are assumed. Cols. labelled "All Shocks": all shocks used simultaneously. All series were logged (with exception of interest rates) and HP filtered.

Table 4. Predictions: pegged exchange rate model (Bretton Woods)

	Schocks to:						All Shocks		Data, 59-70	
	M		θ,θ^*		UIP					
	H	F	H	F	H	F	H	F	U.S.	EU3
	(1)	(2)	(3)	(4)	(5)	(6)	(9)	(10)	(11)	(12)
(a) Flexible prices										
Standard deviations (in %)										
GDP	0.00	0.00	1.13	1.19	0.01	0.01	1.13	1.18	1.22	1.05
C	0.00	0.00	0.78	0.72	0.01	0.01	0.78	0.72	1.04	1.18
I	0.00	0.00	3.45	4.48	0.08	0.08	3.45	4.48	3.97	4.83
NX	0.00		0.36		1.12		1.18		6.10	4.09
M	1.24	1.24	0.00	0.16	0.00	3.57	1.24	3.78	0.87	1.31
P	1.36	1.36	0.78	0.77	0.01	0.72	1.57	1.72	0.62	0.74
r	0.06	0.06	0.00	0.00	0.00	0.56	0.06	0.57	0.20	0.16
e	0.00		0.00		0.00		0.00		0.46	
RER	0.00		1.23		0.70		1.42		0.98	
Cross-country correlations										
GDP	u		-0.06		-1.00		-0.06		-0.18	
C	u		-0.07		-1.00		-0.07		-0.34	
I	u		-0.05		-1.00		-0.05		-0.25	
M	1.00		u		u		0.32		0.12	
P	1.00		-0.27		0.99		0.63		0.16	
r	1.00		u		u		0.11		0.54	
Correlation between nominal & real exchange rate										
	u		u		u		u		0.43	
(b) Sticky prices										
Standard deviations (in %)										
GDP	1.33	1.33	0.61	0.15	0.02	1.05	1.46	1.71	1.22	1.05
C	0.81	0.81	0.44	0.09	0.00	0.65	0.92	1.04	1.04	1.18
I	5.09	5.09	1.86	0.56	0.01	4.08	5.42	6.55	3.97	4.83
NX	0.00		0.29		1.18		1.22		6.10	4.09
M	1.24	1.24	0.00	0.12	0.00	3.56	1.24	3.77	0.87	1.31
P	0.88	0.88	0.44	0.11	0.01	0.10	0.98	0.89	0.62	0.74
r	0.06	0.06	0.00	0.00	0.00	0.56	0.06	0.57	0.20	0.16
e	0.00		0.00		0.00		0.00		0.46	
RER	0.00		0.50		0.09		0.51		0.98	
Cross-country correlations										
GDP	1.00		0.28		0.99		0.73		-0.18	
C	1.00		0.40		-0.73		0.69		-0.34	
I	1.00		0.13		-0.66		0.73		-0.25	
M	1.00		u		u		0.32		0.12	
P	1.00		-0.39		0.99		0.85		0.16	
r	1.00		u		u		0.11		0.54	
Correlation between nominal & real exchange rate										
	u		u		u		u		0.43	

Notes: **Columns labelled H [F]: statistics for Home [Foreign] economy.**
C: Consumption; **I**: investment; **M**: money supply; **P**: price level; **r**: nominal interest rate; **e/RER**: nominal/real exchange rate; **NX**: net exports (defined as

Q_t^{m*}/Q_t^m, where Q_t^{m*} [Q_t^m] is an index of Foreign [Home] imports). Cols. labelled "Shocks to M,M^*", "Shocks to θ,θ^*", "Shocks to UIP", "Shocks to $\bar{e}$" pertain to cases in which shock to just *one* of the exogenous variables are assumed (θ,θ^*: productivity; UIP: shock to UIP equation; $\bar{e}$: official parity). Cols. labelled "All Shocks": all shocks used simultaneously.
All series were logged (with exception of interest rates) and HP filtered.

Table 5. Sensitivity of floating rate model to steady state imports/GDP ratio; just UIP shocks.

	Flex. prices	Sticky prices		
		PTM	PCP	
	α=.25	α=.25	α=.01	α=.25
	(1)	(2)	(3)	(4)
Standard deviations (in %)				
GDP	0.43	0.09	0.02	0.53
C	1.71	0.29	0.13	1.67
I	10.25	1.57	0.79	9.96
NX	12.80	2.17	10.41	12.91
P	1.71	0.29	0.13	1.67
r	0.00	0.00	0.00	0.00
e	6.65	6.67	6.78	6.69
RER	3.23	6.29	6.51	3.34
Corr between e & RER				
	0.99	0.99	0.99	0.99

Notes: **C**: Consumption; **I**: investment; **M**: money supply; **P**: price level; **r**: nominal interest rate; **e/RER**: nominal/real exchange rate; **NX**: net exports. **PTM: pricing to market (stickiness of prices in buyer currency); PCP: producer currency pricing (stickiness of prices in producer currency).**

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