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ABSTRACT

Monetary Policy Rules in an Interdependent World*

This Paper analyses the welfare effects of monetary policy rules in a quantitative business cycle model of a two-country world. The model features staggered price setting, and shocks to productivity and to the uncovered interest-rate parity (UIP) condition. UIP shocks have a sizable negative effect on welfare, when trade links are strong. An exchange rate peg may raise world welfare, if the peg eliminates the UIP shocks. The model explains the empirical finding that more open economies are more likely to adopt a peg.

JEL Classification: E40, F30 and F40
Keywords: business cycles, exchange rate regime and interest rate parity

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1. Introduction

What policy rule is best suited for maximizing welfare in open economies--especially: should central banks stabilize the exchange rate? Recent work has addressed this normative question, using general equilibrium models of open economies in which monetary policy affects real variables because of sticky prices—a literature often referred to as "New Open Economy Macroeconomics" (NOEM).[1] Because of its rigorous microeconomic foundations, that approach is better suited for normative issues than the traditional Keynesian models. However, existing *normative* NOEM studies use highly stylized (often static) models (that permit to derive closed form solutions) which underpredict sharply the high volatility of exchange rates observed during the post-Bretton Woods period;[2] this may cast doubts on the relevance of these models for assessing the welfare consequences of floating exchange rates.

A first step towards determining welfare maximizing monetary policy rules, using richer, more realistic quantitative (calibrated) models was made by Kollmann (2002a) who considered a small open economy with staggered price setting.[3] The present paper extends that analysis by studying a two-country world. A two-country model allows to examine the effect of monetary policy on *world* welfare. Model variants with weak trade links between the two countries (1% imports/GDP ratio) and with strong trade links (20% trade share) are considered. These variants shed, inter alia, light on optimal monetary arrangements between the US and Europe (weak trade links), and on optimal arrangements *among* European economies (strong trade).

A key feature of the model here is that (besides the standard productivity shocks) there are shocks to the uncovered interest parity (UIP) condition; these "UIP shocks" can be interpreted as reflecting biases in households' exchange rate forecasts. (I use empirical estimates of the time-series process of UIP shocks to calibrate the model.) These disturbances enable the model to generate highly volatile nominal and real exchange rates. Other features that enhance the realism of the present model—and that distinguish the model here from those typically used in previous normative NOEM studies—are incomplete international risk sharing (international financial transactions are restricted to trade in bonds) and physical capital.

Monetary policy is described by 'simple' rules under which a country's interest rate is set as a function of inflation, of GDP, and of the rate of depreciation of the nominal exchange rate. The parameters of both central banks' policy rules are set at the values that maximize world welfare (defined as the sum of the expected values of Home and Foreign household utility). An exchange rate peg is also considered, in which the policy parameters are set at the

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[1] See Lane (2001), Sarno (2001) and Ganelli and Lane (2002) for surveys.

[2] See, for example, Bacchetta and van Wincoop (2000), Benigno (2000, 2001), Canzoneri, Cumby and Diba (2002), Clarida et al. (2001), Corsetti and Pesenti (2001), Corsetti and Dedola (2002), Devereux and Engel (2000), Galí and Monacelli (2000), Lombardo (2002), Obstfeld and Rogoff (2000, 2002), Parrado and Velasco (2001), Sutherland (2001), Tille (2002).

[3] Several recent papers have studied quantitative NOEM business cycle models; however, these papers do not compute welfare (and thus do not determine welfare maximizing policy rules). See, for example, Batini et al. (2000,2001), Benigno (1999), Bergin (2001), Betts and Devereux (2001), Chari et al. (2000), Collard and Dellas (2002), Dedola and Leduc (2001), Duarte and Stockman (2001), Erceg and Levin (2001), Faia (2001), Ghironi and Rebucci (2001), Hairault et al. (2001), Kollmann (2001a,b), Laxton and Pesenti (2002), Lubik (2000), McCallum and Nelson (1999, 2000), Monacelli (1999), Pappa (2002), Schmitt-Grohé and Uribe (2001a), and Smets and Wouters (2000, 2002). With the exception of the models by Batini et al. and by McCallum and Nelson--who like the paper here assume interest rate parity shocks (see discussion below)--these models do not capture the strong exchange rate volatility observed in the post-Bretton Woods period. After the research here was completed, I received a paper by Bergin and Tchakarov (2002) that uses quantitative NOEM models to conduct welfare analyses, based on the same numerical technique as the paper here (these authors do not assume interest rate parity shocks, and they do not determine welfare maximizing monetary policy rules).

values that maximize world welfare, subject to the constraint that the exchange rate has to be kept constant.

Under staggered price setting, inflation induces inefficient dispersion of prices across producer located in the same country (e.g., Rotemberg and Woodford, 1997); this helps to understand why, in the model here, optimized *unconstrained* (no-peg) policy rules essentially stabilize the inflation rate of the domestic producer price index.

UIP shocks raise the volatility of consumption and of the real exchange rate, and they reduce world welfare. When the world economy (with sticky prices) is subjected to *exogenous* UIP shocks, then optimized policy entails exchange rate floating. This is so, because pegging the exchange rate requires strong adjustments of (Home and Foreign) interest rates, in response to UIP shocks--under a peg, UIP shocks induce thus markedly wider fluctuations of inflation and consumption, and lower welfare, than under optimized policy. When there are UIP shocks, the welfare loss from the peg, compared to optimized policy corresponds to a permanent 0.46% [0.22%] consumption reduction, in the variant of the baseline model with weak [strong] trade links.

However, the key issue for welfare is whether a peg affects the UIP shocks. Departures from interest rate parity were markedly smaller in the Bretton Woods [BW] era than in the post-BW period (e.g., Kollmann, 2002b). (This finding can easily be rationalized when UIP shocks reflect biases in exchange rate forecasts--under a (credible) peg there is much less scope for irrational exchange rate forecasts than under a float.) In the model here, a peg is optimal *if* that peg eliminates the UIP shocks. The baseline model predicts that the welfare gain from an exchange rate peg that eliminates UIP shocks would be very slightly positive between the US and Europe--the equivalent of a permanent 0.004% consumption increase (compared to the optimized floating rate regime); *within* Europe, the predicted welfare gain from such a peg corresponds to a permanent 0.18% consumption increase. The results here suggest that UIP shocks are more destabilizing for real economic activity, and more harmful for welfare, in more open economies—the welfare gain from a peg that eliminates the UIP shocks is thus predicted to be higher the greater the degree of external openness. Empirically, the likelihood that a country pegs its exchange rate is positively linked to openness; see e.g. Edwards (1996). The model here can rationalize this finding.

The model is solved using Sims' (2000) algorithm that is based on second-order Taylor expansions of the equilibrium conditions. In contrast to the linear, certainty-equivalent approximations that are widely used in macroeconomics, this approach allows to capture the effect of risk on *mean* values of endogenous variables--that level effect turns out to be crucial for welfare. For example, the welfare cost of UIP shocks can mainly be accounted for by a reduction in mean consumption and/or a rise in mean hours worked; this level effect can be linked to the fact that UIP shocks induce sizable changes in relative prices between productive inputs, and thus in producers' input mix--given concave production functions, larger mean inputs are thus used to produce a given quantity of final consumption.

Compared to other non-linear methods (see Judd, 1998, for an overview), a key advantage of the method used here is the much greater ease and speed with which it allows to solve models with a large number of state variables. This allows me to numerically determine welfare maximizing monetary policy parameters, in the rich business cycle model considered here.

Section 2 of this paper describes the model. Section 3 presents the results and Section 4 concludes.

2. The model

I consider a world with two countries, referred to as "Home" and "Foreign" . In each country there are firms, a representative household and a central bank (the structure of preferences and technologies follows Kollmann, 2002a, 2001a). Each country produces a continuum of tradable intermediate goods indexed by s∈ [0,1]. In each country there are competitive firms that bundle domestic and imported intermediate goods into a non-tradable final good that is consumed and used for investment. There is monopolistic competition in intermediate goods markets. Intermediate goods producers use domestic capital and labor as inputs (capital and labor are immobile internationally). In each country, the household owns all domestic producers and the capital stock, which it rents to producers. It also supplies labor. The markets for rental capital and for labor are competitive.

Preferences and technologies are symmetric across the countries. An asterisk denotes Foreign variables. The following description focuses on the Home country.

2.1. Final good production

The Home final good is produced using the aggregate technology

$$Z_t = (Q_t^d/\alpha^d)^{\alpha^d} (Q_t^m/\alpha^m)^{\alpha^m} , \tag{1}$$

with $\alpha^d, \alpha^m > 0$, $\alpha^d + \alpha^m = 1$. Z_t is final good output at date *t*; Q_t^d, Q_t^m are quantity indices of domestic and imported intermediate goods, respectively: $Q_t^{\mathbf{i}} = \{\int_0^1 q_t^{\mathbf{i}}(s)^{(\nu-1)/\nu} ds\}^{\nu/(\nu-1)}$ with $\nu > 1$, for **i**=d,m, where $q_t^d(s)$ and $q_t^m(s)$ are quantities of the domestic and imported 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 final good production implies:

$$q_t^{\mathbf{i}}(s) = (p_t^{\mathbf{i}}(s)/P_t^{\mathbf{i}})^{-\nu} Q_t^{\mathbf{i}}, \quad Q_t^{\mathbf{i}} = \alpha^{\mathbf{i}} P_t Z_t / P_t^{\mathbf{i}} \quad \text{for } \mathbf{i}=\text{d,m}, \tag{2}$$

$$\text{with } P_t^{\mathbf{i}} = \{\int_0^1 p_t^{\mathbf{i}}(s)^{1-\nu} ds\}^{1/(1-\nu)}, \quad P_t = (P_t^d)^{\alpha^d} (P_t^m)^{\alpha^m} . \tag{3}$$

P_t^d [P_t^m] is a price index for domestic [imported] intermediate goods that are sold in the Home market. Perfect competition implies that the price of the Home final good is P_t (its marginal cost is $P_t = (P_t^d)^{\alpha^d} (P_t^m)^{\alpha^m}$).

2.2. Intermediate goods firms

The technology of the firm that produces intermediate good s, in the Home country, is:

$$y_t(s) = \theta_t (K_t(s))^{\psi} (L_t(s))^{1-\psi} , \quad 0 < \psi < 1. \tag{4}$$

$y_t(s)$ is the firm's output at date *t*; θ_t is an exogenous productivity parameter that is identical for all Home intermediate goods producers; $K_t(s)$ and $L_t(s)$ 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 the Home wage rate. Cost minimization implies:

$$L_t(s)/K_t(s) = \psi^{-1}(1-\psi) R_t/W_t . \tag{5}$$

The firm's marginal cost is: $MC_t = (1/\theta_t) R_t^{\psi} W_t^{1-\psi} \psi^{-\psi} (1-\psi)^{\psi-1}$. The firm’s good is sold in the domestic market and exported:

$$y_t(s) = q_t^d(s) + q_t^{m*}(s) , \tag{6}$$

where $q_t^d(s)$ $[q_t^{m*}(s)]$ is domestic [export] demand. The firm faces the following export demand function: $q_t^{m*}(s)=(p_t^{m*}(s)/P_t^{m*})^{-\nu}Q_t^{m*}$, where $p_t^{m*}(s)$ is the firm's export price, in Foreign currency.

The firm's profit, π_t, is:

$$\pi_t(p_t^d(s), p_t^{m*}(s))=(p_t^d(s)-MC_t)(p_t^d(s)/P_t^d)^{-\nu}Q_t^d+(e_t p_t^{m*}(s)-MC_t)(p_t^{m*}(s)/P_t^{m*})^{-\nu}Q_t^{m*},$$

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

Motivated by the empirical failure of the Law of One Price, and in particular by widespread pricing to market behavior (e.g., Knetter, 1993), it is assumed that intermediate goods producers can price discriminate between the domestic market and the export market ($p_t^d(s)\neq e_t p_t^{m*}(s)$ is possible), and that they set prices in the currency of their customers.

There is staggered price setting, à la Calvo (1983): intermediate goods firms cannot change prices (in buyer currency) unless they receive a random "price-change signal." The probability of receiving this signal in any particular period is 1-*d*, a constant. Thus, the mean price-change-interval is 1/(1-*d*). Following Yun (1996) and Erceg et al. (2000) it is assumed that when a firm does not receive a "price-change signal," its price is automatically increased at the steady state growth factor of the price level (in the buyer's country). (Throughout this paper, the term "steady state" refers to the deterministic steady state.) Firms are assumed to meet all demand at posted prices.

Consider a Home country intermediate good producer that, at time *t*, sets a new price in the domestic market, $p_{t,t}^d$. If no "price-change signal" is received between t and $t+\tau$, the price is $p_{t,t}^d\Pi^\tau$ at $t+\tau$, where Π is the steady state growth factor of the Home price level. The firm sets $p_{t,t}^d = Arg\ \underset{\mathrm{p}}{Max}\ \sum_{\tau=0}^{\tau=\infty} d^\tau E_t\{\rho_{t,t+\tau}\,\pi_{t+\tau}(\mathrm{p}\Pi^\tau, p_{t+\tau}^x(s))/P_{t+\tau}\}$, where $\rho_{t,t+\tau}$ is a pricing kernel for valuing date $t+\tau$ pay-offs (expressed in units of the Home final good) that equals the Home household's marginal rate of substitution between consumption at *t* and at $t+\tau$ (see discussion below).

Let $\Xi_{t,t+\tau}^d=\rho_{t,t+\tau}(P_t/P_{t+\tau})Q_{t+\tau}^d(P_{t+\tau}^d)^\nu$. The solution of the maximization problem regarding $p_{t,t}^d$ is:

$$p_{t,t}^d=(\nu/(\nu-1))\left\{\sum_{\tau=0}^{\infty}(d\Pi^{-\nu})^\tau E_t\Xi_{t,t+\tau}^d MC_{t+\tau}\right\}\Big/\left\{\sum_{\tau=0}^{\infty}(d\Pi^{1-\nu})^\tau E_t\Xi_{t,t+\tau}^d\right\}.$$

Analogously, a Home intermediate good producer that gets to choose a new export price at date *t* sets that price at:

$$p_{t,t}^{m*}=(\nu/(\nu-1))\left\{\sum_{\tau=0}^{\infty}(d(\Pi^*)^{-\nu})^\tau E_t\Xi_{t,t+\tau}^{m*}MC_{t+\tau}/e_{t+\tau}\right\}\Big/\left\{\sum_{\tau=0}^{\infty}(d(\Pi^*)^{1-\nu})^\tau E_t\Xi_{t,t+\tau}^{m*}\right\},$$

where $\Xi_{t,t+\tau}^{m*}=\rho_{t,t+\tau}(P_t/P_{t+\tau})(e_{t+\tau}/e_t)Q_{t+\tau}^{m*}(P_{t+\tau}^{m*})^\nu$, while Π^* is the steady state growth factor of the Foreign price level.

The price indices P_t^d, P_t^{m*} (see (3)) evolve according to:

$$(P_t^d)^{1-\nu}=d(P_{t-1}^d\Pi)^{1-\nu}+(1-d)(p_{t,t}^d)^{1-\nu}; \quad (P_t^{m*})^{1-\nu}=d(P_{t-1}^{m*}\Pi^*)^{1-\nu}+(1-d)(p_{t,t}^{m*})^{1-\nu}.$$

2.3. The representative household

The preferences of the Home household are described by:

$$E_0\sum_{t=0}^{\infty}\beta^t U(C_t, L_t). \tag{7}$$

E_t denotes the mathematical expectation conditional upon complete information pertaining to period t and earlier. C_t and L_t are period t consumption and labor effort. $0<\beta<1$ is the subjective discount factor. U is a utility function given by:

$$U(C_t, L_t) = \ln(C_t) - L_t\,. \tag{8}$$

As indicated earlier, the Home household owns all domestic producers and the Home physical capital stock. The law of motion of the capital stock is:

$$K_{t+1} + \phi(K_{t+1}, K_t) = K_t(1-\delta) + I_t\,, \tag{9}$$

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

The Home household holds nominal one-period bonds denominated in Home currency and in Foreign currency. Its period t budget constraint is:

$$A_{t+1} + e_t B_{t+1} + P_t(C_t + I_t + F_t) = A_t(1+i_{t-1}) + e_t B_t(1+i^*_{t-1}) + \int_0^1 \pi_t(s)\,ds + R_t K_t + W_t L_t\,. \tag{10}$$

A_t and B_t are stocks of Home and Foreign currency bonds that mature in period t, while i_{t-1} and i^*_{t-1} are the interest rates on these bonds. The household bears a real cost (in Home final good units) of holding/issuing bonds, denoted F_t; F_t is a quadratic function of A_{t+1} and B_{t+1}: $F_t = \frac{1}{2}\phi^A \cdot (A_{t+1}/P_t)^2 + \frac{1}{2}\phi^B \cdot (e_t B_{t+1}/P_t)^2$, with $\phi^A, \phi^B \geq 0$, $\phi^A + \phi^B > 0$. This cost ensures the existence of a stationary equilibrium, which allows to solve the model using the Sims (2000) method. [4]

The household chooses a strategy $\{A_{t+1}, B_{t+1}, K_{t+1}, C_t, L_t\}_{t=0}^{t=\infty}$ to maximize its expected lifetime utility (7), subject to constraints (9) and (10) and to initial values A_0, B_0, K_0. Ruling out Ponzi schemes, the following equations are first-order conditions of this decision problem:

$$1 = \frac{1+i_t}{1+\phi^A \cdot (A_{t+1}/P_t)} E_t\{\rho_{t,t+1}(P_t/P_{t+1})\}\,, \tag{11}$$

$$1 = \frac{1+i^*_t}{1+\phi^B \cdot (e_t B_{t+1}/P_t)} E_t\{\rho_{t,t+1}(P_t/P_{t+1})(e_{t+1}/e_t)\}\,, \tag{12}$$

$$1 = E_t\{\rho_{t,t+1}(R_{t+1}/P_{t+1} + 1 - \delta - \phi_{2,t+1})/(1+\phi_{1,t})\}\,, \tag{13}$$

$$W_t / P_t = C_t\,, \tag{14}$$

where $\rho_{t,t+1} = \beta C_t / C_{t+1}$, $\phi_{1,t} = \partial\phi(K_{t+1}, K_t)/\partial K_{t+1}$, $\phi_{2,t+1} = \partial\phi(K_{t+2}, K_{t+1})/\partial K_{t+1}$. (11)-(13) are Euler conditions, and (14) says that the household equates its marginal rate of substitution between consumption and leisure to the real wage rate.

2.4. Uncovered interest parity

Taking a (log-)linear approximation of (11) and (12) (around $A_{t+1} = B_{t+1} = 0$) yields:

$$E_t \ln(e_{t+1}/e_t) \cong i_t - i^*_t - \phi^A(A_{t+1}/P_t) + \phi^B(B_{t+1}e_t/P_t)\,.$$

Because of bond-holding costs (and because of the second order terms that have been suppressed in this approximation), uncovered interest parity (UIP) (i.e. the condition $E_t \ln(e_{t+1}/e_t) = i_t - i^*_t$) does *not* hold in the model here. However, departures from UIP that are caused by bond-holding costs (and by second order terms) turn out to be very small, in the present model. Given the well-documented strong and persistent empirical departures from

[4] When the cost F_t is zero (i.e. when $\phi^A = \phi^B = 0$), the decision problem of the household is a version of the permanent income theory of consumption, and asset positions and consumption are non-stationary.

UIP during the post-Bretton Woods era (e.g., Lewis, 1995), variants of the model are explored in which the Home Euler condition for Foreign currency bonds (12) is disturbed by a stationary exogenous stochastic random variable, φ_t ("UIP shock," henceforth):

$$1=\frac{1+i_t^*}{1+\phi^B\cdot(e_t B_{t+1}/P_t)}\,\varphi_t\;E_t\{\rho_{t,t+1}\,(P_t\,/\,P_{t+1})\,(e_{t+1}\,/\,e_t)\}\,. \tag{15}$$

Up to a (log-)linear approximation (around $A_{t+1}=B_{t+1}=0$, $\varphi_t=1$) (11) and (15) imply

$$E_t\,\ln(e_{t+1}/e_t)\cong i_t-i_t^*-\phi^A\cdot(A_{t+1}/P_t)+\phi^B\cdot(e_t B_{t+1}/P_t)-\ln(\varphi_t)\,. \tag{16}$$

φ_t can be interpreted as reflecting a bias in the households' date *t* forecast of the date *t*+1 exchange rate, e_{t+1}. It is assumed that Home and Foreign households make identical exchange rate forecasts—and, thus that these forecasts exhibit the same bias. [5]

The counterparts to (11), (15) and (16), for the Foreign household are:

$$1=\frac{1+i_t^*}{1+\phi^{B*}\cdot(B_{t+1}^*/P_t^*)}E_t\{\rho_{t,t+1}^*\,(P_t^*/P_{t+1}^*)\}\,, \tag{17}$$

$$1=\frac{1+i_t}{1+\phi^{A*}\cdot A_{t+1}^*/(e_t P_t^*)}\,\frac{1}{\varphi_t}\;E_t\{\rho_{t,t+1}^*\,(P_t^*/P_{t+1}^*)(e_t/e_{t+1})\}\,, \tag{18}$$

$$E_t\ln(e_{t+1}/e_t)\cong i_t-i_t^*-\phi^{A*}\cdot A_{t+1}^*/(e_t P_t^*)+\phi^{B*}\cdot(B_{t+1}^*/P_t^*)-\ln(\varphi_t)\,, \tag{19}$$

where A_t^*, B_t^* are the Foreign household's stocks of Home currency bonds and of Foreign currency bonds, respectively. (The Foreign household bears the following bond-holding cost, in units of the Foreign final good: $F_t^*=\frac{1}{2}\,\phi^{A*}\cdot(A_{t+1}^*/(e_t P_t^*))^2+\frac{1}{2}\,\phi^{B*}\cdot(B_{t+1}^*/P_t^*)^2$.)

2.5. Market clearing conditions

Supply equals demand in intermediate goods markets because intermediate goods firms meet all demand at posted prices. In the Home country, market clearing for the final good, labor, and rental capital requires:

$$Z_t=C_t+I_t+F_t\,,\quad L_t=\int_0^1 L_t(s)ds\,,\quad K_t=\int_0^1 K_t(s)ds\,,$$

where Z_t, L_t and K_t are supplies of the final good, labor, and rental capital, respectively, while $\int_0^1 L_t(s)ds$ and $\int_0^1 K_t(s)ds$ represent total demand for labor and capital (by intermediate goods producers). Market clearing for bonds requires:

$$A_t+A_t^*=0\,,\;\;B_t+B_t^*=0\,. \tag{20}$$

2.6. Monetary policy rules

Much recent research has been devoted to policy rules under which the nominal interest rate is set as a function of inflation and of real GDP (e.g., Taylor, 1993a, 1999). In the present study, I also include the exchange rate (e_t) as an argument in the policy rule, as this allows to study whether monetary authorities should respond (directly) to that variable. The following rules for Home and Foreign monetary policy are considered:

[5] Assume that household *beliefs* at *t* about e_{t+1} are given by a probability density function, f_t^s, that differs from the true pdf, f_t, by a factor $1/\varphi_t$: $f_t^s(e_{t+1},\Omega)=f_t(e_{t+1}/\varphi_t,\Omega)/\varphi_t$, where Ω is any other random variable. The Home [Foreign] Euler equation for foreign currency bonds is then given by (15) [(18)]. Frankel and Froot, 1989, document biases in exchange rate forecasts; structural models with UIP shocks have, i.a., been studied by Mark and Wu (1998), Jeanne and Rose (2002), McCallum and Nelson (1999, 2000), and Taylor (1993b).

$$i_t = i + \Gamma_\pi \widehat{\Pi}_t^d + \Gamma_y \widehat{Y}_t + \Gamma_e \ln(e_t/e_{t-1}) \qquad (21a)$$

$$\text{and } i_t^* = i^* + \Gamma_\pi^* \widehat{\Pi}_t^{d*} + \Gamma_y^* \widehat{Y_t^*} - \Gamma_e^* \ln(e_t/e_{t-1}), \qquad (21b)$$

with $\widehat{\Pi}_t^d = (\Pi_t^d - \Pi)/\Pi$, $\widehat{Y}_t = (Y_t - Y)/Y$, where $\Pi_t^d = P_t^d/P_{t-1}^d$ is the growth factor of the price index of Home-produced domestic intermediate goods that are sold in the Home market (i.e. gross Home domestic PPI inflation), and Y_t is Home real GDP.[6] i and Y are the steady state Home nominal interest rate and steady state Home GDP, respectively. Throughout the paper, steady state values are denoted by variables without time subscripts, and $\hat{x}_t = (x_t - x)/x$ is the relative deviation of a variable x_t from its steady state value, x. Γ_π, Γ_y, Γ_e, Γ_π^*, Γ_y^* and Γ_e^* are parameters.

The central banks make a commitment to set the parameters of their policy rules at time-invariant values that maximize world welfare, defined as the sum of the unconditional expected values of Home and Foreign household utility, $E(U(C_t, L_t)) + E(U(C_t^*, L_t^*))$. I also consider an (optimized) exchange rate **peg**, in which the policy parameters are set at the values that maximize world welfare, subject to the constraint that the exchange rate has to be kept constant through time.

As discussed in Kollmann (2002a), a fully optimal policy rule would allow for a response of the interest rate to all current and lagged state variables; I focus on "simple" rules (such as (21a,b)) because: (i) simple rules capture well actual central bank behavior (Taylor, 1999); (ii) the use of simple rules facilitates policy commitment; (iii) computationally, it does not seem feasible to determine fully optimal rules for the complex model considered here.[7]

2.7. Welfare measures

A second-order Taylor expansion of the Home utility function around the steady state gives: $E(U(C_t, L_t)) \cong U(C, L) + E(\widehat{C}_t) - LE(\widehat{L}_t) - \frac{1}{2}Var(\widehat{C}_t)$, where $Var(\widehat{C}_t)$ is the variance of $\widehat{C}_t$. (For the parameter values used below, L =0.74.) I express welfare as the permanent relative change in consumption (compared to the steady state), ζ, that yields expected utility $E(U(C_t, L_t))$: $U((1+\zeta)C, L) = U(C, L) + E(\widehat{C}_t) - LE(\widehat{L}_t) - \frac{1}{2}Var(\widehat{C}_t)$. ζ can be decomposed into components, denoted ζ^m and ζ^v, that reflect the means of consumption and hours worked, and the variance of consumption, respectively: $U((1+\zeta^m)C, L) = U(C, L) + E(\widehat{C}_t) - LE(\widehat{L}_t)$, $U((1+\zeta^v)C, L) = U(C, L) - \frac{1}{2}Var(\widehat{C}_t)$. (8) implies $\ln(1+\zeta) = E(\widehat{C}_t) - LE(\widehat{L}_t) - \frac{1}{2}Var(\widehat{C}_t)$, $\ln(1+\zeta^m) = E(\widehat{C}_t) - LE(\widehat{L}_t)$, $\ln(1+\zeta^v) = -\frac{1}{2}Var(\widehat{C}_t)$ and thus $(1+\zeta) = (1+\zeta^m)(1+\zeta^v)$.

2.8. The resource cost of price dispersion across Home firms

Under staggered price setting, time-varying inflation of the Home domestic PPI, P_t^d [of the index of Home export prices, P_t^{m*}] lowers welfare as that inflation induces inefficient dispersion of across the prices that Home intermediate goods producers charge in their domestic market [export market]; that dispersion raises the inputs of Home labor (L_t) and

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[6] Home *nominal* GDP equals the aggregate revenue of Home intermediate goods producers: $Y_t^{nom} = \int_0^1 [p_t^d(s) q_t^d(s) + e_t p_t^{m*}(s) q_t^{m*}(s)]\, ds$. Evaluating the quantities $q_t^d(s)$, $q_t^{m*}(s)$ at the prices of some baseline period gives *real* GDP. Here, I normalize all baseline prices at unity. Thus $Y_t = \int_0^1 q_t^d(s) + q_t^{m*}(s)\, ds = \int_0^1 y_t(s)\, ds$ (see (6)).

[7] See Kollmann's (2002a , p.998) discussion of the computational difficulties pertaining to fully optimal rules (in a related model).

capital (K_t) used to produce given quantities of the *aggregate* intermediate goods Q_t^d and Q_t^{m*} (that are inputs into Home and Foreign final good production, respectively). I now derive a measure of that resource cost of cross-firm price dispersion.

Note that (2), (4), (5) and (6) imply that the following relation holds between aggregate Home factor inputs and Q_t^d, Q_t^{m*}:

$$Y_t = \theta_t K_t^{\psi} L_t^{1-\psi} = \delta_t^d Q_t^d + \delta_t^{m*} Q_t^{m*}, \tag{22}$$

with $\delta_t^{\mathbf{i}} = (\overline{P}_t^{\mathbf{i}}/P_t^{\mathbf{i}})^{-\nu}$, $\overline{P}_t^{\mathbf{i}} = \{\int_0^1 p_t^{\mathbf{i}}(s)^{-\nu} ds\}^{-1/\nu}$ for $\mathbf{i}=d,m*$. (NB Y_t : Home real GDP.) $\delta_t^d \geq 1$ $[\delta_t^{m*} \geq 1]$ is an index of the cross-firm dispersion of the domestic prices [export prices] charged by Home intermediate goods producers. $\delta_t^d, \delta_t^{m*}$--and thus aggregate Home factor inputs--are increasing functions of the variance of prices *across* Home firms.[8] $\delta_t^d = \delta_t^{m*} = 1$ holds when there is no cross-firm price dispersion--as is the case under price flexibility or when domestic and export price inflation are constant at $\Pi_t^d = \Pi$ and $\Pi_t^{m*} = \Pi^*$, respectively, where $\Pi_t^{m*} = P_t^{m*}/P_{t-1}^{m*}$. (In steady state: $\delta^d = \delta^{m*} = 1$.) $E\delta_t^d$ and $E\delta_t^{m*}$ are increasing functions of the degree of price stickiness (d) and of the variances of Π_t^d and Π_t^{m*}, respectively: $E\delta_t^{\mathbf{i}} \cong 1 + 0.5\nu(d/(1-d)^2)Var(\Pi_t^{\mathbf{i}})$, for $\mathbf{i}=d, m*$.[9]

Under *sticky prices*, a policy that perfectly stabilizes Π_t^d (at Π) minimizes δ_t^d (at $\delta_t^d = 1$), while a policy that perfectly stabilizes Π_t^{m*} (at Π^*) minimizes δ_t^{m*} (at $\delta_t^{m*} = 1$). Under pricing to market (as assumed here), firms generally charge domestic prices that differ from their export prices, and control over the *two* policy instruments i_t and i_t^* does not permit to fully eliminate all price dispersion across Home firms and across Foreign firms (as this would require attaining these *four* targets: $\delta_t^d = \delta_t^{m*} = \delta_t^{d*} = \delta_t^m = 1$).

A second-order expansion of (22) yields

$$\widehat{Y}_t \cong (1-\alpha^m)\widehat{Q}_t^d + \alpha^m \widehat{Q}_t^{m*} + \widehat{\delta}_t^q, \text{ with } \delta_t^q = (1-\alpha^m)\delta_t^d + \alpha^m \delta_t^{m*} \geq 1. \tag{23}$$

δ_t^q is a measure of the total resource cost of price dispersion across Home intermediate goods firms. (Smets and Wouters (2002) present a closely related measure.) This measure proves to be useful for explaining the welfare loss that results from price stickiness, compared to the flex-prices equilibrium (of course, $\delta_t^q = 1$ under flexible prices). Across the model variants considered in Tables 1 and 2 below, $E\delta_t^q$ is highly negatively correlated with the welfare *difference* between sticky-price and flex-prices equilibria; correlation: –0.89.

2.9. Solution method and parameters (non-policy)

The model is solved using Sims' (2000) algorithm/computer code that is based on second-order Taylor expansions of the equilibrium conditions.[10] I numerically maximize the central

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[8] A second-order expansion shows that $\delta_t^{\mathbf{i}} \cong 1 + \frac{1}{2}\nu Var_s(\ln p_t^{\mathbf{i}}(s))$ for $\mathbf{i} = d, m^*$, where Var_s denotes the variance *across* firms $0 \leq s \leq 1$.

[9] This formula too is based on a second order expansion (see Rotemberg and Woodford (1997) and Erceg et al. (2001) for derivations).

[10] See Kim et al. (2002) and Kollmann (2002a) for more detailed discussions of the Sims algorithm. Judd and Guu (1993), Judd and Gaspar (1996), Kim and Kim (1999), Collard and Juillard (2001), Schmitt-Grohé and Uribe (2001b), Sutherland (2002) and Anderson and Levin (2002) also develop solutions of dynamic models based on second-order expansions.

banks' objective function (world welfare) with respect to the policy parameters (attention is restricted to parameter values for which a unique stationary equilibrium exists).

Preference and technology parameters are assumed to be symmetric across countries.

The effects of the exchange rate regime depend on the countries' openness to trade (imports/GDP ratio). A variant of the model is considered in which the (steady state) imports/GDP ratio is set at α^m=0.01 (see (1)), "low-trade-variant" henceforth, as well as a variant with α^m=0.2 ("high-trade-variant").

The *"low-trade-variant"* is (for example) suitable for analyzing monetary arrangements between the US and the European Union (EU); I calibrate that variant to data for the US and an aggregate of three large EU economies: France, Germany and Italy, 'EU3' henceforth (the ratio of US imports from the EU3 divided by US GDP and the ratio of EU3 imports from the US divided by EU3 GDP both averaged about 0.01 during the post-Bretton Woods era).

The *"high-trade"* variant allows to analyze the optimal exchange regime *among* EU countries (the ratio of total trade among EU members, divided by aggregate EU GDP is roughly 0.2).

The remaining *technology* parameters as well as *preference* parameters are set at identical values across these two variants.

The steady state value of the UIP shock is set at φ=1 (in steady state, exchange rate expectations are thus unbiased). This implies that steady state stocks of bonds are zero (A=B=A^*=B^*=0), and that the steady state real interest rate $r=(1+i)/\Pi-1=(1+i^*)/\Pi^*-1$ is given by: $\beta(1+r)=1$; the subjective discount factor is set at $\beta=(1.01)^{-1}$ which implies $r=0.01$, a real interest rate that corresponds roughly to the long-run historical average quarterly return on capital.

The steady state price-marginal cost markup factor for intermediate goods is set at $\nu/(\nu-1)=1.2$, consistent with the findings of Martins et al. (1996) for the US and for European countries. The technology parameter ψ (see (4)) is set at $\psi=0.24$, which entails a 60% steady state labor income/GDP ratio, consistent with US and European data. Aggregate data suggest a quarterly capital depreciation rate of about 2.5%; thus, δ=0.025 is used. The capital adjustment cost parameter Φ is set at Φ=8 in order to match the fact that the standard deviation of Hodrick-Prescott filtered log investment is three to four times larger than that of GDP in the US and in EU3 economies.

Symmetry of bond-holding cost parameters across countries requires: $\phi^A=\phi^{B*}$, $\phi^B=\phi^{A*}$. Given this assumption, (16), (19) and (20) imply that, up to a (log-) linear approximation (around A_{t+1}=B_{t+1}=0, φ_t=1), Home and Foreign currency bonds each account for half of the Home net asset position: $A_{t+1}/P_t \cong \frac{1}{2}NFA_{t+1}/P_t$, $e_tB_{t+1}/P_t \cong \frac{1}{2}NFA_{t+1}/P_t$, where $NFA_{t+1}=A_{t+1}+e_tB_{t+1}$ is the Home net foreign asset position (expressed in Home currency). Substituting these expressions into (16) shows that, up to a (log-)linear approximation, the cross-country interest rate differential is linked to NFA_{t+1}:

$$i_t-i_t^* \cong E_t\ln(e_{t+1}/e_t)+\tfrac{1}{2}(\phi^A-\phi^B)NFA_{t+1}/P_t+\ln(\varphi_t)\,. \tag{24}$$

Panel regressions (for 21 OECD countries) presented by Lane and Milesi-Ferretti (2001) [LMF] show that cross-country interest rate differentials are *negatively* related to net foreign assets (normalized by exports). In terms of the model here, this suggests that $\phi^A<\phi^B$, i.e. that (for a given country) holding a given stock of own-currency bonds is less costly than holding a stock of foreign-currency bonds of equal value. The LMF estimates imply that $\frac{1}{2}(\phi^A-\phi^B)=-0.0019/\chi$, where χ is the steady state value of Home exports, expressed in units of the Home final good $(P_t^{m*}Q_t^{m*}/P_t)$; see Appendix. The LMF study does not allow to separately identify ϕ^A and ϕ^B. I set ϕ^A and ϕ^B at the lowest possible (non-negative) values that are consistent with the LMF estimate for $(\phi^A-\phi^B)$: ϕ^A=0, $\phi^B=0.0038/Q^{m*}$.

The average price-change interval is assumed to be 4 quarters (and *d* is thus set at *d*=0.75), a value consistent with microeconomic evidence on the frequency of price adjustment (Romer, 2001, p.315), as well as with recent estimates of Calvo-style price setting equations for the US and for Europe (e.g., Sbordone (2002), Galí et al. (2001)). The steady state growth factors of the Home and Foreign price levels are set at $\Pi=\Pi^*=1$ (Π and Π^* have no effect on real variables, because of indexing).

Home and Foreign productivity are assumed to follow this process:

$$\begin{bmatrix}\ln(\theta_t)\\ \ln(\theta_t^*)\end{bmatrix}=\begin{bmatrix}0.81 & 0.03\\ 0.03 & 0.81\end{bmatrix}\begin{bmatrix}\ln(\theta_{t-1})\\ \ln(\theta_{t-1}^*)\end{bmatrix}+\begin{bmatrix}\varepsilon_t^{\theta}\\ \varepsilon_t^{\theta*}\end{bmatrix}, \qquad (25)$$

where ε_t^{θ} and $\varepsilon_t^{\theta*}$ are white noises with standard deviation 0.0059; the correlation between ε_t^{θ} and $\varepsilon_t^{\theta*}$ is 0.18. (25) is a "symmetrized" version of a VAR model that Kollmann (2002b) fitted to quarterly US and EU3 total factor productivity (1973-1994). Similar autoregressive processes for productivity have also been used in International Real Business Cycle models, as these processes fit well the behavior of productivity in industrialized countries (see, e.g., Backus et al. (1995), Kollmann (1996)). (25) is thus assumed in the "low-trade" variant as well as in the "high-trade" variant of the model.

Kollmann (2002b) constructs quarterly estimates of UIP shocks between the US and the EU3, for the period 1973-94. [11] The standard deviation of the estimated $\ln(\varphi_t)$ series is 3.18%, and its autocorrelations $\rho(\tau)$ of order $\tau=1,..,16$ are (standard errors in parentheses):

τ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\rho(\tau)$	0.53	0.31	0.39	0.34	0.28	0.23	0.16	0.19	0.28	0.08	0.08	0.10	0.10	0.15	0.11	0.04
	(0.10)	*(0.09)*	*(0.05)*	*(0.09)*	*(0.12)*	*(0.10)*	*(0.11)*	*(0.13)*	*(0.16)*	*(0.17)*	*(0.13)*	*(0.15)*	*(0.15)*	*(0.13)*	*(0.14)*	*(0.13)*

The first-order autocorrelation is 0.53; the autocorrelation function decays gradually towards zero. As discussed below, the welfare effect of UIP shocks is sensitive to the persistence of these shocks—it is thus important to ensure that the simulation model captures adequately the serial correlation of the historical UIP shocks. The following two-factor structure suits that purpose;[12] it expresses $\ln(\varphi_t)$ as the sum of a serially correlated random variable and of a white noise disturbance:

$$\ln(\varphi_t)=a_t+\omega_t, \quad a_t=\lambda a_{t-1}+\eta_t, \quad 0<\lambda<1 \qquad (26)$$

[11] Let $\upsilon_{t+1}\equiv i_t-i_t^*-\ln(e_{t+1}/e_t)$. (16) implies $\ln(\varphi_t)\cong E_t\upsilon_{t+1}$ when $\phi^A=0$ and ϕ^B is small. Kollmann (2002b) constructs estimated $\ln(\varphi_t)$ series by regressing υ_{t+1} on $\{\upsilon_{t-s}, i_{t-s}, i_{t-s}^*, \widetilde{Y}_{t-s}, \widetilde{Y}_{t-s}^*\}_{s=0,..,4}$, where $\widetilde{Y}_{t-s}$ is linearly detrended log GDP.

[12] An AR(1) process is not suitable for that purpose: fitting an AR(1) to the historical US-EU3 UIP series yields an autoregressive parameter of 0.53; the implied autocorrelation function decays faster than the empirical autocorrelation function. An AR process of order 3 (or higher) is needed to capture the shape of that function. Model simulations based on fitted high-order AR processes yield results that are roughly similar to those obtained using (26). As (26) is a more parsimonious specification, (26) is used, in what follows.

where ω_t and η_t are independent white noises with standard deviations σ_ω and σ_η, respectively. (26) implies $\rho(\tau) = \lambda^\tau \Upsilon$, for $\tau \geq 1$, where $\Upsilon = \{\sigma_\eta^2/(1-\lambda^2)\}/\{\sigma_\omega^2 + \sigma_\eta^2/(1-\lambda^2)\}$. Using Non-Linear Least Squares to fit the equation $\rho(\tau) = \lambda^\tau \Upsilon$ to the autocorrelations reported in the above Table yields these estimates: $\lambda = 0.88$, $\Upsilon = 0.52$. Under (26), $Var(\ln(\varphi_t)) = \sigma_\omega^2 + \sigma_\eta^2/(1-\lambda^2)$. Setting $Var(\ln(\varphi_t))$ at its historical value $(0.0318)^2$, then pins down σ_ω and σ_η: $\sigma_\omega = 0.0220$, $\sigma_\eta = 0.0109$. The "low-trade" (US-EU3) variant of the model uses these parameter values.

During the post-Bretton Woods era, EU countries have used a system of fixed-but-adjustable exchange rates (EMS), followed in 1999 by a currency union (EMU), to achieve bilateral exchange rate volatility that has been markedly lower than US-EU3 exchange rate volatility. The analysis here only considers irrevocable floats and pegs. I assume that, under a float, UIP shocks in the "high-trade" (EU) variant of the model would have the same stochastic properties as the post-Bretton Woods US-EU3 UIP shocks--the above estimates of $\lambda, \sigma_\omega, \sigma_\eta$ are thus also used in the "high-trade" variant.

3. Results

Tables 1-3 report results. Because of the symmetric structures of the two countries, model predictions are only shown for the Home country. (The optimized policy parameters and welfare are identical across countries.) In the Tables, $\Delta e_t = e_t/e_{t-1}$ is the depreciation factor of the nominal exchange rate. $RER_t = e_t P_t^*/P_t$ is the (final good based) real exchange rate. $\mathsf{A}_{t+1} = (A_{t+1}/P_t)/Y$ and $\mathsf{B}_{t+1} = (B_{t+1}/P_t^*)/Y$ are the Home household's stocks of Home currency bonds and of Foreign currency bonds, respectively, expressed in (Home/Foreign) final good units, and normalized by steady state (quarterly) GDP.

Tables 1-2 show standard deviations and/or mean values of these (and other) variables, while Table 3 reports impulse responses. All variables are quarterly. The moments/responses for the interest rate (i_t) and for bond holdings refer to differences of these variables from steady state values (i_t is a quarterly rate expressed in fractional units), while moments/statistics for the remaining variables refer to relative deviations from steady state values. All statistics are expressed in percentage terms. In Tables 1-2, results are presented for simulations in which the world economy is simultaneously subjected to (Home and Foreign) productivity shocks and to UIP shocks, as well as for simulations with just productivity shocks, and for simulations with just UIP shocks (see Cols. labeled "$\theta, \theta^*, \varphi$", "$\theta, \theta^*$" and "$\varphi$", respectively).

3.1. Results for the "low-trade" world (α^m=0.01)

Table 1 reports results for the "low-trade" world. Cols. 1-3 pertain to the optimized regime in which the exchange rate is *not* constrained to be constant; henceforth that regime is referred to as the "float". Cols. 4-5 consider the optimized exchange rate peg. These variants assume sticky prices. A flex-prices version of the model is considered in Cols. 6-8.

3.1.1. Floating exchange rate regime

In the "low-trade" world with sticky prices, welfare and the optimized policy parameters under the float are: $\zeta = -0.006\%$, $\Gamma_\pi = 7.93$, $\Gamma_y = -0.12$, $\Gamma_e = 0.00$, when there are simultaneous productivity shocks and UIP shocks (see Col. 1). Welfare is thus slightly lower in the stochastic economy than in the deterministic steady state. In this variant of the model, welfare is mainly driven by the volatility of consumption--the "variance-component" of the welfare measure is $\zeta^{v}=-0.005\%$; mean consumption and mean hours differ only very slightly from steady state values (e.g. $E\widehat{C}_t=0.01\%$)--and the "mean-component" of the welfare is accordingly very small $(\zeta^{m}=-0.001\%)$.

Optimized policy has an aggressive stance against PPI inflation--notice the high positive value of Γ_π. As a result, the standard deviation of PPI inflation (Π^d) is close to zero (0.01%), and the resource cost of cross-firm dispersion of domestic prices charged by Home intermediate goods producers is very low ($E\hat{\delta}_t^d=0.01\%$). The optimized policy response parameters on output and the nominal exchange rate (Γ_y, Γ_e) are smaller than Γ_π; note especially that Γ_e is very close to zero. (Setting $\Gamma_y=\Gamma_e=0$ has virtually no effect on welfare and on other model predictions.)

If the two economies were *closed*, optimal monetary policy would (essentially) stabilize PPI inflation (see, e.g., Rotemberg and Woodford's (1997) analysis of optimal monetary policy in closed economies with staggered price setting); that policy would fully eliminate price dispersion across intermediate goods producers located in the same country--and it would imply that the behavior of real variables replicates the flex-prices equilibrium. This helps to understand why optimized policy in the "low-trade" world (where the steady state imports/GDP ratio is merely 1%) likewise has a strict stance against PPI inflation, and why in that world most predicted statistics (including welfare) are virtually identical across the sticky-prices version and the flex-prices version (welfare under flex-prices: $\zeta=-0.006\%$; see Col. 6). (Under *flexible* prices, the monetary policy rule does not affect real variables; in the flex-prices variant, I set the policy parameters at the values obtained for the optimized float, under *sticky* prices, with simultaneous productivity shocks and UIP shocks--i.e. at the values used in Col. 1.)

In the "low-trade" world (with sticky prices), optimized policy entails that the standard deviations of GDP, consumption and investment are 1.39%, 1.06% and 3.64%, respectively (with simultaneous productivity shocks and UIP shocks); nominal and real exchange rates are markedly more volatile than these variables (standard deviations of Δe_t, RER_t: 7.44%, 12.44%). The real exchange rate is furthermore predicted to have a positive autocorrelation (0.82). The model captures thus the fact that, during the post-Bretton Woods era, nominal and real US-EU3 exchange rates have been highly volatile--although it underpredicts the persistence of post-Bretton Woods exchange rate fluctuations. (Standard deviations of the growth factor of the nominal exchange rate and of the linearly detrended log real exchange rate between US and EU3, 1973-1994: 4.89% and 12.89%, respectively; autocorrelation of linearly detrended log real exchange rate: 0.95.)

The sizable volatility of the nominal exchange rate implies that exports price inflation (Π_t^{m*}) fluctuates much more than domestic PPI inflation (standard deviation of Π_t^{m*}: 1.45%). The cross-firm dispersion of exports prices that results from the volatility of Π_t^{m*} (under price stickiness) has a noticeable effect on the resource cost of the aggregate export good: $E\hat{\delta}_t^{m*}=0.86\%$; however, due to the small trade share in the "low-trade" world, the effect of the volatility of Π_t^{m*} on the *aggregate* resource cost of price dispersion is very small: $E\hat{\delta}_t^{q}=0.01\%$ (see (23)). This (further) helps to understand why welfare in the sticky-prices economy is so close to that in the flex-prices economy.

Cols. 2-3 of Table 1 (where versions of the stick-prices model with just productivity shocks, and with just UIP shocks are considered) show that, in the "low-trade" world, productivity shocks account for about 99% of the variances of output, consumption and investment (that are generated under simultaneous productivity and UIP shocks), while UIP shocks explain 99% of the variances of Δe_t and RER_t.[13] UIP shocks have a (small) negative effect on welfare $(\zeta = -0.009\%)$.

The strong effect of UIP shocks $(\ln\varphi_t)$ on the real exchange rate is mainly driven by the serially component a_t of $\ln\varphi_t$ (see (26)). a_t accounts for 52% of the variance of $\ln\varphi_t$ -- but a_t explains roughly 97% of the variances of the real exchange rate, GDP, consumption and bonds holdings induced by $\ln\varphi_t$.[14] The negative welfare effect of the UIP shocks is almost entirely due to a_t ($\zeta = -0.009\%$ when there are just a_t shocks). To explain the dominant role of a_t for real exchange rate behavior, note that (24) implies: $\ln(RER_t) = \ln(\varphi_t) + x_t + E_t \ln(RER_{t+1})$, with $x_t = r_t^* - r_t + \frac{1}{2}(\phi^A - \phi^B) NFA_{t+1}/P_t + (\textit{higher order terms})$, where $r_t = i_t - E_t \ln(P_{t+1}/P_t)$ and $r_t^* = i_t^* - E_t \ln(P_{t+1}^*/P_t^*)$ are Home and Foreign real interest rates. This difference equation in $\ln(RER_t)$ entails that $\ln(RER_t)$ depends on the sum of future expected UIP shocks: $\ln(RER_t) = E_t \sum_{\tau=0}^{\infty} [\ln(\varphi_{t+\tau}) + x_{t+\tau}]$. a_t has a stronger and more persistent effect than ω_t on $E_t \sum_{\tau=0}^{\infty} \ln(\varphi_{t+\tau})$, and thus on the real exchange rate (which also helps to understand the stronger effect of a_t on other macro variables). (Note that $E_t \sum_{\tau=0}^{\infty} \ln(\varphi_{t+\tau}) = \frac{1}{1-\lambda} a_t + \omega_t$, i.e. the effect of a_t is magnified by the factor $\frac{1}{1-\lambda} = 8.33$.)

3.1.2. Exchange rate peg

A peg can be achieved by picking "large" values of the policy parameters Γ_e and/or Γ_e^*. In the limit, as Γ_e and/or Γ_e^* tend to infinity, the exchange rate is constant:

$$e_t = e_{t-1}, \tag{27}$$

and the following interest rate rule holds:

$$(1-\lambda) i_t + \lambda i_t^* = i + (1-\lambda)(\Gamma_\pi \widehat{\Pi}_t^d + \Gamma_y \widehat{Y}_t) + \lambda (\Gamma_\pi^* \widehat{\Pi}_t^{d*} + \Gamma_y^* \widehat{Y_t^*}), \tag{28}$$

where λ is the limiting value of the ratio $\Gamma_e/(\Gamma_e + \Gamma_e^*)$ (see Appendix). The peg discussed here is a model variant in which equations (21a), (21b) are replaced by (27), (28), and in which $\lambda, \Gamma_\pi, \Gamma_y, \Gamma_\pi^*, \Gamma_y^*$ are set at the values that maximize world welfare (due to symmetry, optimization yields $\lambda = 0.5$).

When the "low-trade" world (with sticky prices) is simultaneously subjected to productivity shocks and to UIP shocks, then welfare is noticeably lower under the peg $(\zeta = -0.460\%)$ than under the (optimized) float (see Table 1, Col. 4).[15] The low welfare under

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[13] In Cols. 2 and 3, the policy parameters are set at the values that maximize world welfare under *simultaneous* productivity shocks and UIP shocks (i.e. at the values used in Col. 1). Reoptimizing the policy coefficients when there are just productivity shocks (or just UIP shocks) hardly affects predicted behavior.

[14] Table 1 does not provide predictions for a model variant with just a_t shocks--those predictions are very similar to the predictions shown in Col. 3 (simultaneous a_t and ω_t shocks); Table 3 (impulse responses) separately reports effects of a_t and ω_t shocks.

[15] The optimized Γ_π, Γ_y parameters under the peg are very large: $\Gamma_\pi = 453066.99$, $\Gamma_y = 121.51$. World welfare is a very "flat" function of these parameters. Imposing "moderate" upper bounds on the absolute values of Γ_π, Γ_π

the peg is almost entirely due to UIP shocks (welfare with just UIP shocks: $\zeta = -0.458\%$). UIP shocks are thus markedly more detrimental for welfare under the peg than under the float.

Under the peg, UIP shocks have a much stronger effect on (Home and Foreign) nominal interest rates than under the float (when prices are sticky)--basically because the peg requires that the cross-country interest rate *differential* adjusts roughly one-to-one to UIP shocks.[16] (Standard deviation of i_t under peg [float]: 1.54% [0.14%].) Under the peg, UIP shocks induce thus markedly higher standard deviations of domestic PPI inflation (and of consumption); as a result, the (aggregate) resource cost of (inefficient) cross-firm price dispersion ($E\hat{\delta}_t^q = 0.24\%$) is higher under the peg than under the float (recall that $E\hat{\delta}_t^q = 0.01\%$). This efficiency loss is accompanied by a fall in mean consumption ($E\hat{C}_t = -0.36\%$ [$E\hat{C}_t = 0.01\%$] under the peg [float]). The welfare loss brought about by the peg (when there are UIP shocks) mainly reflects this reduction in mean consumption--and thus that loss mainly reflects a reduction in the "mean-component" of the welfare measure: $\zeta^m = -0.394\%$ under the peg (compared to $\zeta^m = -0.001\%$ under the float). The welfare cost of consumption variability is much smaller ($\zeta^v = -0.066\%$).

Choice of exchange rate regime when the peg eliminates UIP shocks

As discussed by Kollmann (2002a), a key question in modeling a peg is whether it affects the variance of the UIP shocks. Departures from interest parity were markedly smaller in the Bretton Woods [BW] era than in the post-BW era (see, e.g., Kollmann, 2002b). (Under the interpretation that UIP shocks reflect biased exchange rate forecasts, this finding can easily be rationalized--under a (credible) peg there is much less scope for irrational exchange rate forecasts than under a float.) Col. 5 in Table 1 considers a version of the "low-trade" model, in which the peg eliminates the UIP shocks (in that variant, productivity shocks are the only disturbance).[17] That peg generates higher welfare ($\zeta = -0.002\%$) than the optimized float with UIP shocks (there $\zeta = -0.006\%$).

According to the model here, it would thus be desirable to peg the exchange rate between the US and Europe--if that peg fully eliminated the UIP shocks. But note that the welfare gain from such a peg is predicted to be very small (it corresponds to a permanent 0.004% rise in consumption).

3.2. Results for the "high-trade" world ($\alpha^m = 0.20$)

Table 2 shows results for the "high-trade" world. With sticky prices and simultaneous productivity shocks and UIP shocks, the optimized policy parameters under the float are $\Gamma_\pi = 34.59$, $\Gamma_y = 0.27$, $\Gamma_e = 0.56$ (see Col. 1), and policy has a clear stance against PPI inflation (standard deviation of Π_t^d: 0.07%). As in the "low-trade" variant, UIP shocks induce wide real exchange rate fluctuations--and that under both sticky and flexible prices (Col. 6). (Standard deviation of RER_t under sticky [flexible] prices: 8.98% [6.83%].)

(such as $|\Gamma_\pi|, |\Gamma_y| \leq 50$) leaves the model predictions basically unaffected. The same remark also applies to the "high-trade" variant of the model discussed below (Table 2).

[16] Under the peg $i_t - i_t^* \cong \frac{1}{2}(\phi^A - \phi^B) NFA_t / P_t + \ln(\varphi_t)$ holds, up to a (log-)linear approximation (see (24)), and the behavior of $i_t - i_t^*$ closely mimics that of $\ln(\varphi_t)$ (see the impulse responses shown in Table 3).

[17] The policy coefficients in Col. 5 have been re-optimized (with just productivity shocks), and differ thus from those used in Col. 4.

However, UIP shocks have a markedly more destabilizing effect on macro aggregates, in the "high-trade" world (compared to the "low-trade" world), both under sticky and flexible prices. (The standard deviation of consumption induced by UIP shocks is roughly 20 times greater in the "high-trade" world than in the "low-trade" world.) Welfare is noticeably lower in the "high-trade" world: $\zeta = -0.188$ [$\zeta = -0.144$] under sticky [flexible] prices, with simultaneous productivity and UIP shocks (compared to $\zeta = -0.006\%$, in the "low-trade" world). The lower welfare is almost entirely caused by UIP shocks--in particular by the serially correlated component of these shocks, a_t (e.g., under sticky prices, $\zeta = -0.187\%$, when there are just a_t shocks.)

The welfare loss induced by UIP shocks is mainly accounted for by a reduction in the "mean-component" of the welfare measure, ζ^m : mean hours worked (as well as the mean capital stock and mean GDP) rise by about 0.3% relative to steady state (mean consumption changes much less). Intuitively, this level effect can be linked to the fact that UIP shocks raise the volatility of productive inputs--larger mean inputs are thus used to produce a given average quantity of the final good, as production functions are concave; this effect operates in the "low-trade" world too, but it is stronger in the "high-trade" world. [18]

In the "high-trade" world, the optimized float under *sticky* prices comes less close to replicating the *flex-prices* equilibrium (in welfare terms), than in the "low-trade" world. This reflects the fact that, in the "high-trade" world, the inefficient cross-firm dispersion of export prices (under sticky prices) has a greater effect on the *total* resource cost of the intermediate goods sector ($E\hat{\delta}_t^q = 0.13\%$, compared to $E\hat{\delta}_t^q = 0.01\%$ in the "low-trade" world).

In the "high-trade" world with sticky prices, the exchange rate *peg* again (as in the "low-trade" world), markedly reduces welfare when there are UIP shocks ($\zeta = -0.408\%$)--see Col. 4. (That welfare loss again mainly reflects a reduction in the "mean-component" of the welfare measure.)

However, under the plausible assumption that a peg *eliminates* the UIP shocks (see discussion in Sect. 3.1.2.), welfare under the peg is $\zeta = -0.002\%$ (see Col. 5)—which represents a noticeable welfare improvement, compared to the optimized float *with* UIP shocks (recall that there $\zeta = -0.188\%$). Thus, the welfare gain from adopting a peg that eliminates UIP shocks is noticeably greater in the "high-trade" world than in the "low-trade" world.

The intuition for this is simple: as UIP shocks are more harmful the higher the degree of openness, the benefit from eliminating these shocks (by adopting a peg) are greater, the

[18] For example, UIP shocks induce sizable changes in the relative price between imported and domestic intermediate goods (P_t^m / P_t^d), and thus in the final good producers' mix between these goods (standard deviation of $\widehat{P_t^m / P_t^d} = \widehat{Q_t^d / Q_t^m}$: about 7% with just UIP shocks, compared to 0.7% when there are just productivity shocks, both for $\alpha^m = 0.01$ and for $\alpha^m = 0.2$). Greater average quantities of aggregate domestic and imported inputs, Q_t^d, Q_t^m (and thus of Home and Foreign labor and capital) are used to produce a given average quantity of the Home final good, the greater the volatility of the relative price, P_t^m / P_t^d. (2) and a second order expansion of (1) show that the following relation holds between mean levels of Q_t^d, Q_t^m and Home final good output, Z_t: $(1-\alpha^m) E\hat{Q}_t^d + \alpha^m E\hat{Q}_t^m = E\hat{Z}_t + \delta^{md}$, where $\delta^{md} = \frac{1}{2}(1-\alpha^m)\alpha^m Var\left(\widehat{P_t^m / P_t^d}\right)$ represents the effect of volatility of the relative price P_t^m / P_t^d on the mean intermediate goods input. δ^{md} is increasing in the trade share, α^m. When $\alpha^m = 0.01$, then δ^{md} is 0.002%. When $\alpha^m = 0.20$: $\delta^{md} = 0.04\%$ under sticky prices, and $\delta^{md} = 0.10\%$ under flexible prices (with UIP shocks).

higher is openness. Empirically, the likelihood that a country pegs its exchange rate is positively linked to openness (e.g., Edwards, 1996). The model here can rationalize this fact.

3.3. Impulse response functions

Responses of *Home* variables to exogenous shocks are shown in Table 3, for the following variants of the "low-trade" world: (optimized) float under sticky prices; peg under sticky prices; float under flexible prices--see Panels (a),(b) and (c) respectively. [19] (Foreign responses to Home productivity shocks are identical to the Home responses to Foreign productivity shocks that are shown in Table 3; Foreign responses to UIP shocks are symmetric, with changed sign, to Home responses.)

In all three variants, a positive *Home productivity shock* triggers a rise in Home GDP, consumption, investment and hours worked, a fall in the Home interest rate, and a depreciation of the Home real exchange rate. Responses of real variables in the floating rate (sticky-prices) model version mimic the responses in the flex-prices version; in these two versions, country-specific productivity shocks trigger Home and Foreign interest rates responses that are *negatively* correlated, and Foreign productivity shocks have little effect on Home output. Under the peg (with sticky prices), by contrast, country-specific productivity shocks trigger (almost) perfectly synchronized Home and Foreign interest rate changes, and Home and Foreign output *both* rise in response to a country-specific productivity increase.

In all three model variants, increases in the persistent and white noise components of *UIP shocks* (a_t and ω_t, respectively) trigger, on impact, a real exchange rate depreciation (followed by a return of the real exchange rate to its pre-shock value), a rise in the Home interest rate, a reduction in the price of Home exports (P_t^{m*}), a rise in Home exports (Q_t^{m*}), a fall in Home consumption and investment, and a rise in the Home bond holdings (A_{t+1} and B_{t+1} increase by roughly the same amount); these responses are stronger under flexible prices than under sticky prices (with optimized float). Serially correlated UIP disturbances (a_t) have stronger effects than white noise disturbances (ω_t). The peg greatly magnifies the responses of interest rates, GDP, consumption and goods prices to UIP shocks.

3.4. Sensitivity analysis [20]

3.4.1. Nash equilibria

The baseline model assumes international cooperation in the setting of policy parameters. I also computed Nash equilibria under a floating exchange rate regime, in which each central bank selects the policy parameters that maximize the welfare of 'its' household, taking as given the parameters of the other central bank. Under Nash too (as under cooperation), monetary policy has a strict anti-inflation stance, and UIP shocks induce sizable exchange rate fluctuations. In the "low-trade" world, welfare and the moments of most variables are (virtually) identical across cooperation and Nash--the welfare gain from international cooperation (compared to the Nash outcome), is equivalent to a permanent consumption increase of 0.003%. In the "high-trade" world, the gain from cooperation is greater (the equivalent of a permanent 0.105% consumption increase).

[19]In terms of model parameters, Panels (a), (b) and (c) correspond to Cols. 1, 4 and 6, respectively, in Table 1.
[20] A more detailed presentation of the results summarized in this section is available from the author.

3.4.2. Alternative policy rules; maximizing conditional welfare

Experiments with interest rate rules that respond to additional state variables (beyond those included in (27a,b)) only generated small welfare gains. [21]

The analysis here assumes that central banks maximize *unconditional* world welfare. Rotemberg and Woodford (1999, p.70) justify using unconditional welfare as a policy objective by pointing out that this objective is "not subject to any problem of time consistency". [22] However, as discussed by, i.a., Levin (2002) and Kim et al. (2002), this policy objective is not optimal if households discount future period utility $(\beta < 1)$. [23]

I thus considered a version of the model in which monetary authorities maximize the sum of the conditional expectation of Home and Foreign life-time utility, in some 'initial' period t=0: $E_0\left\{\sum_{t=0}^{\infty}\beta^t U(C_t, L_t) + \sum_{t=0}^{\infty}\beta^t U(C_t^*, L_t^*)\right\}$. (I assumed that the economy is in its (deterministic) steady state at t=0, and that the t=0 innovations to exogenous variables equal zero: $\varepsilon_0^{\theta} = \varepsilon_0^{\theta*} = \omega_0 = \eta_0 = 0$.)

The policy implications of this alternative objective function are the same as those of the baseline objective: optimized policy still has a strict stance against PPI inflation, and it remains true that an exchange rate peg that eliminates UIP shocks yields higher welfare than the optimized float. Also, implied (unconditional) moments of macro variables are very similar to those predicted in the baseline model--the only difference is that conditional welfare is lower than unconditional welfare.

For example, in the "high-trade" variant with simultaneous productivity shocks and UIP shocks, maximization of conditional welfare yields these results: the standard deviations of domestic PPI inflation and of the real exchange rate are 0.06% and 9.12%, respectively, and conditional welfare is: $\zeta = -0.060\%$ (*un*conditional welfare: $\zeta = -0.189\%$).

3.4.3. More persistent UIP shocks

As discussed above, the welfare cost of UIP shocks, and the welfare gain from a peg (that eliminates the UIP shocks), are both positively linked to the *persistence* of these shocks. The baseline model underpredicts the historical autocorrelation of the US-EU3 real exchange rate. More persistent UIP shocks are needed to replicate that historical autocorrelation. I considered a two-factor UIP process whose parameters are selected in such a manner that the "low-trade" variant of the model (under float) replicates exactly the historical standard deviation (12.89%) and first-order autocorrelation (0.95) of the (linearly detrended and logged) post-Bretton Woods US-EU3 real exchange rate, as well as the historical standard deviation of the US-EU3 UIP shock (3.18%). These more persistent UIP shocks are more destabilizing for real activity; their welfare cost (both in the "low-" and "high-trade" world) is roughly 5 times higher than in the baseline model--and the welfare gain induced by a peg is higher (by the same factor) than in the baseline model.

3.4.4. Cross-country correlation of productivity

The literature on 'optimal currency areas' argues that two countries benefit more from a peg (i) the closer these countries are integrated in goods markets and (ii) the higher the cross-country correlation of productivity shocks (see Obstfeld and Rogoff (1996)). The simulations

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[21] These experiments included rules under which the interest rate is a function of exports inflation, imports inflation, CPI inflation and employment, as well as rules under which each countries' interest rate is a function of domestic *and* foreign variables.

[22] This policy objective is widely assumed in the literature: see, e.g., Rotemberg and Woodford (1997), Benigno (2000), Clarida et al. (2001) and Smets and Wouters (2002).

[23] Levin (2002) points out that the logic for this is the same as that of the suboptimality of the Golden-Rule of capital accumulation relative to the Modified-Golden-Rule.

discussed above confirm point (i). Regarding point (ii), it can be noted that, in the "high-trade" variant of the model here, productivity shocks have a markedly smaller effect on welfare than (persistent) UIP shocks. The ability of a peg to raise welfare hinges on its ability to eliminate the UIP shocks. In the "high-trade" world, the adoption of a peg (that eliminates the UIP shocks) raises welfare, even in the extreme case where productivity shocks are perfectly negatively correlated across countries, $Corr(\varepsilon_t^{\theta}, \varepsilon_t^{\theta *}) = -1$ (in that case, welfare is $\zeta = -0.193\%$ under the optimized float, compared to $\zeta = -0.010\%$ under the peg without UIP shocks).

4. Conclusions

This paper has analyzed welfare effects of monetary policy rules, in a quantitative business cycle model of a two-country world. The model assumes staggered price setting, and shocks to productivity and to the uncovered interest rate parity (UIP) condition. UIP shocks have a sizable *negative* effect on welfare, when trade links are strong. An exchange rate peg raises world welfare, if the peg eliminates (or sufficiently reduces) the UIP shocks. The model explains the empirical finding that more open economies are more likely to adopt a peg.

APPENDIX

1. Estimation of $\frac{1}{2}(\phi^A - \phi^B)$ (see (24))

(24) implies $r_t - r_t^* \cong \frac{1}{2}(\phi^A - \phi^B) NFA_t/P_t + E_t \ln(RER_{t+1}/RER_t) + \ln(\varphi_t)$ where $r_t = i_t - E_t \ln(P_{t+1}/P_t)$ and $r_t^* = i_t^* - E_t \ln(P_{t+1}^*/P_t^*)$ are Home and Foreign real interest rates, and $RER_t = e_t P_t^*/P_t$ is the real exchange rate. Lane and Milesi-Ferretti (2001) fit this equation to a panel of 21 OECD economies, using annualized % interest rates and net foreign assets (NFA) normalized by annual exports. Based on instrumental variables (allowing for country fixed-effects), estimates of about -3 are obtained for the coefficient of the normalized NFA (Table 7, Cols. 5-8). In terms of the relation between quarterly fractional interest rate differentials and NFA normalized by quarterly Home exports (χ), this implies a coefficient $\frac{1}{2}(\phi^A - \phi^B)\chi = -3/1600 = -0.0019$ (the value used in the simulations).

2. Exchange rate peg

Substituting (21a) and (21b) into (24) yields:

$$\ln(e_t/e_{t-1}) = (1/(\Gamma_e + \Gamma_e^*)) \Big[E_t \ln(e_{t+1}/e_t) - (\Gamma_\pi \widehat{\Pi_t^d} - \Gamma_\pi^* \widehat{\Pi_t^{d*}}) - (\Gamma_y \widehat{Y}_t - \Gamma_y^* \widehat{Y_t^*}) + \Psi_t \Big],$$

where $\Psi_t = \ln(\varphi_t) + \frac{1}{2}(\phi^A - \phi^B) NFA_t/P_t + (2nd\ and\ higher\ order\ terms)$. An exchange rate peg ($e_t = e_{t-1}$) obtains asymptotically when these four conditions are met: $|\Gamma_e + \Gamma_e^*| \to \infty$, $\Gamma_\pi/(\Gamma_e + \Gamma_e^*) \to 0$, $\Gamma_y/(\Gamma_e + \Gamma_e^*) \to 0$, $\Gamma_\pi^*/(\Gamma_e + \Gamma_e^*) \to 0$, $\Gamma_y^*/(\Gamma_e + \Gamma_e^*) \to 0$. Multiplying (21a) by $\Gamma_e^*/(\Gamma_e + \Gamma_e^*)$, and multiplying (21b) by $\Gamma_e/(\Gamma_e + \Gamma_e^*)$, and then summing the resulting equations gives:

$$(1 - \Gamma_e/(\Gamma_e + \Gamma_e^*))\, i_t + (\Gamma_e/(\Gamma_e + \Gamma_e^*))\, i_t^* = i + (1 - \Gamma_e/(\Gamma_e + \Gamma_e^*))\,(\Gamma_\pi \widehat{\Pi_t^d} + \Gamma_y \widehat{Y}_t) + (\Gamma_e/(\Gamma_e + \Gamma_e^*))\,(\Gamma_\pi^* \widehat{\Pi_t^{d*}} + \Gamma_y^* \widehat{Y_t^*}),$$

which yields (28) (when $|\Gamma_e + \Gamma_e^*| \to \infty$).

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Table 1. "Low-trade" world ($\alpha^m = 0.01$)

	Sticky prices					Flexible prices		
	Float			Peg				
	θ,θ^*,φ	θ,θ^*	φ	θ,θ^*,φ	θ,θ^*	θ,θ^*,φ	θ,θ^*	φ
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Standard deviations (in %)								
Y	1.39	1.39	0.05	5.19	1.20	1.39	1.39	0.06
C	1.06	1.05	0.08	3.63	0.92	1.05	1.05	0.14
I	3.64	3.63	0.27	16.07	3.05	3.63	3.59	0.54
Q^{m*}	7.22	1.27	7.11	10.85	1.17	12.60	1.25	12.54
Π^d	0.01	0.01	0.00	0.82	0.08	0.01	0.01	0.00
Π^{m*}	1.45	0.15	1.44	0.82	0.08	7.43	0.74	7.39
i	0.14	0.14	0.00	1.54	0.10	0.14	0.14	0.00
Δe	7.45	0.74	7.41	0.00	0.00	7.43	0.74	7.39
RER	12.44	1.30	12.37	7.40	0.67	12.28	1.29	12.22
A	0.68	0.01	0.68	0.73	0.01	0.68	0.01	0.68
B	0.68	0.01	0.68	0.73	0.01	0.68	0.01	0.68
Means (in %)								
Y	0.03	0.01	0.02	-0.06	0.01	0.02	0.01	0.01
C	0.01	0.01	0.00	-0.36	0.00	0.01	0.01	0.00
L	0.02	-0.00	0.02	0.04	0.00	0.01	-0.00	0.01
K	0.04	0.02	0.02	-0.21	0.01	0.03	0.02	0.01
δ^q	0.01	0.00	0.01	0.24	0.00	0.00	0.00	0.00
δ^d	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00
δ^{m*}	0.86	0.01	0.85	0.35	0.00	0.00	0.00	0.00
First-order autocorrelations								
RER	0.82	0.83	0.82	0.97	0.97	0.82	0.83	0.82
Welfare (% equivalent permanent variation in consumption)								
ζ	-0.006	0.003	-0.009	-0.460	-0.002	-0.006	0.003	-0.010
ζ^m	-0.001	0.009	-0.009	-0.394	0.002	-0.001	0.009	-0.010
ζ^v	-0.005	-0.005	-0.000	-0.066	-0.004	-0.005	-0.006	-0.000
Policy parameters								
Γ_π	7.93	7.93	7.93	4.5e5	5.5e5	7.93	7.93	7.93
Γ_y	-0.12	-0.12	-0.12	1.2e2	-1.4e3	-0.12	-0.12	-0.12
Γ_e	0.00	0.00	0.00	∞	∞	0.00	0.00	0.00

Notes: Cols. labeled "θ,θ^*,φ" report model simulations with simultaneous (Home and Foreign) productivity shocks and UIP shocks; Cols. "θ,θ^*" ["φ"] assume just productivity shocks [just UIP shocks].

θ [θ^*]: Home [Foreign] productivity. φ: UIP shock. ***Y***: Home GDP. ***C***: Home consumption. ***I***: Home physical investment. Q^{m*}: Home exports. Π^d: Home gross domestic PPI inflation. Π^{m*}: Home gross export price inflation (in Foreign currency). ***i***: Home nominal interest rate. Δe: depreciation factor of nominal exchange rate. ***RER***: real exchange rate. **A** [**B**]: stock of Home [Foreign] currency bonds held by Home (expressed in final good units and normalized by steady state GDP). ***L***: Home hours worked. ***K***: Home capital stock. δ^q: total resource cost of price dispersion across Home intermediate good producers; δ^d /δ^{m*}: resource cost of price dispersion across Home firms in their domestic/export market ($\delta^q = (1-\alpha^m)\delta^d + \alpha^m \delta^{m*}$); ζ, ζ^m, ζ^v: measures of Home welfare. **Standard deviations and means of i, A and B refer to differences from steady state values. Statistics for the remaining variables refer to relative deviations from steady state values**. All statistics have been multiplied by 100, i.e. expressed in percentage terms.

Table 2. "High-trade" world ($\alpha^m = 0.2$)

	Sticky prices							
	Float			Peg		Flexible prices		
	θ,θ^*,φ	θ,θ^*	φ	θ,θ^*,φ	θ,θ^*	θ,θ^*,φ	θ,θ^*	φ
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Standard deviations (in %)								
Y	1.67	1.24	1.11	3.19	1.18	1.99	1.32	1.49
C	2.08	0.96	1.84	4.51	0.88	2.89	0.93	2.73
I	7.16	3.35	6.33	18.55	2.95	10.75	3.18	10.27
Q^{m*}	7.68	1.21	7.58	10.88	1.17	12.84	1.25	12.78
Π^d	0.07	0.02	0.07	0.72	0.08	0.11	0.02	0.11
Π^{m*}	1.32	0.15	1.31	0.72	0.08	6.72	0.76	6.68
i	0.67	0.14	0.65	1.53	0.09	0.20	0.16	0.11
Δe	5.62	0.63	5.59	0.00	0.00	6.61	0.75	6.57
RER	8.98	1.01	8.92	4.20	0.39	6.83	0.76	6.79
A	14.48	0.20	14.47	15.39	0.08	14.87	0.16	14.87
B	14.48	0.20	14.47	15.39	0.08	14.87	0.16	14.87
Means (in %)								
Y	0.25	0.01	0.24	0.27	0.01	0.27	0.01	0.26
C	0.01	0.00	0.01	-0.10	0.00	0.07	0.01	0.07
L	0.24	-0.00	0.24	0.27	0.00	0.23	-0.00	0.23
K	0.28	0.01	0.27	0.35	0.01	0.38	0.01	0.37
δ^q	0.13	0.00	0.13	0.19	0.00	0.00	0.00	0.00
δ^d	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00
δ^{m*}	0.63	0.01	0.62	0.19	0.00	0.00	0.00	0.00
First-order autocorrelations								
RER	0.82	0.82	0.82	0.97	0.96	0.82	0.81	0.82
Welfare (% equivalent permanent variation in consumption)								
ζ	-0.188	-0.000	-0.188	-0.408	-0.002	-0.144	0.003	-0.146
ζ^m	-0.166	0.004	-0.171	-0.307	0.002	-0.102	0.007	-0.109
ζ^v	-0.022	-0.005	-0.017	-0.101	-0.004	-0.041	-0.004	-0.037
Policy parameters								
Γ_π	34.59	34.59	34.59	5.2e5	5.4e5	34.59	34.59	34.59
Γ_y	0.27	0.27	0.27	-0.01	-1.3e3	0.27	0.27	0.27
Γ_e	0.56	0.56	0.59	∞	∞	0.56	0.56	0.56

Notes: See Table 1.

Table 3. "Low-trade" world *(α^m=0.01)*: responses to 1 standard deviation innovations

	Y	C	I	L	Q^{m*}	P^d	P^{m*}	i	A	B	e	RER	Exogenous variables
(a) Sticky prices, float													
(i) Home productivity shock													θ
τ=0	0.76	0.53	2.20	0.23	0.09	0.00	-0.09	-0.08	-0.00	-0.00	0.55	0.55	0.59
τ=4	0.35	0.27	0.84	0.08	0.23	0.01	-0.17	-0.04	-0.00	-0.00	0.26	0.26	0.25
(ii) Foreign productivity shock													θ^*
τ=0	0.01	0.00	-0.01	0.01	0.67	0.00	0.09	0.02	0.00	0.00	-0.55	-0.55	0.59
τ=4	0.05	0.04	0.13	0.02	0.16	0.01	0.19	0.00	0.00	0.00	-0.26	-0.26	0.25
(iii) UIP shock--serially correlated component													a
τ=0	-0.02	-0.03	-0.11	-0.02	1.07	-0.00	-1.04	0.02	0.03	0.03	6.38	6.36	1.08
τ=4	0.01	-0.02	-0.10	0.01	1.90	0.00	-1.89	0.00	0.12	0.11	2.73	2.86	0.65
(iv) UIP shock--white noise component													ω
τ=0	-0.01	-0.00	-0.03	-0.01	0.12	0.00	-0.11	0.01	0.01	0.01	2.08	2.08	2.20
τ=4	-0.00	0.00	-0.00	-0.00	-0.02	0.00	0.02	0.00	0.01	0.01	-0.13	-0.08	0.00
(b) Sticky prices, peg													
(i) Home productivity shock													θ
τ=0	0.43	0.31	1.16	-0.20	0.43	-0.05	-0.05	-0.03	0.00	0.00	0.00	0.10	0.59
τ=4	0.31	0.23	0.78	0.04	0.26	-0.09	-0.09	-0.02	-0.00	-0.00	0.00	0.18	0.25
(ii) Foreign productivity shock													θ^*
τ=0	0.32	0.21	0.99	0.43	0.32	0.05	0.05	-0.03	-0.00	-0.00	0.00	-0.10	0.59
τ=4	0.09	0.07	0.18	0.05	0.13	0.09	0.09	-0.02	0.00	0.00	0.00	-0.18	0.25
(iii) UIP shock--serially correlated component													a
τ=0	-3.75	-2.52	-11.9	-4.94	5.08	-0.62	-0.62	0.54	0.04	0.04	0.00	1.21	1.08
τ=4	-0.51	-0.48	-1.02	-0.48	2.38	-0.93	-0.92	0.30	0.14	0.14	0.00	1.80	0.65
(iv) UIP shock--white noise component													ω
τ=0	-1.42	-0.96	-4.43	-1.87	1.60	-0.08	-0.08	1.10	0.01	0.01	0.00	0.15	2.20
τ=4	0.05	0.02	0.23	0.09	-0.11	0.03	0.03	0.00	0.01	0.01	0.00	-0.06	0.00
(c) Flexible prices, float													
(i) Home productivity shock													θ
τ=0	0.76	0.52	2.17	0.23	0.56	0.00	-0.55	-0.08	-0.00	-0.00	0.56	0.55	0.59
τ=4	0.35	0.27	0.84	0.08	0.31	0.01	-0.25	-0.04	-0.00	-0.00	0.26	0.26	0.25
(ii) Foreign productivity shock													θ^*
τ=0	-0.00	0.01	-0.02	-0.00	0.20	0.00	0.56	0.02	0.00	0.00	-0.56	-0.55	0.59
τ=4	0.05	0.04	0.13	0.01	0.09	0.01	0.26	0.00	0.00	0.00	-0.26	-0.26	0.25
(iii) UIP shock--serially correlated component													a
τ=0	0.03	-0.07	-0.29	0.03	6.44	-0.00	-6.39	0.00	0.03	0.03	6.39	6.27	1.08
τ=4	0.01	-0.04	-0.14	0.01	2.91	0.00	-2.89	0.00	0.12	0.11	2.71	2.83	0.65
(iv) UIP shock--white noise component													ω
τ=0	0.01	-0.02	-0.11	0.01	2.10	-0.00	-2.09	0.00	0.01	0.01	2.09	2.05	2.20
τ=4	-0.00	0.00	0.00	-0.00	-0.09	0.00	0.09	0.00	0.01	0.00	-0.14	-0.09	0.00

Table 3.--continued

Notes:
Panels (a), (b) and (c) pertain to the following model variants, respectively: (optimized) float under sticky prices; peg under sticky prices; float under flexible prices.

Dynamic effects of innovations to Home productivity (θ), Foreign productivity (θ^*), the serially component of the UIP shock (a), and to the white noise component of the UIP shock (ω) are shown (see Panels (i), (ii), (iii) (iv), respectively).

τ : periods after shock. Columns labeled *Y*, *C* etc. show responses of the corresponding variables. P^d : Home domestic PPI; P^{m*} : index of Home export prices (in Foreign currency); e : nominal exchange rate (Home currency price of Foreign currency). The remaining variables are defined in Table 1. (Responses of stocks of bonds reported for a period t pertain to end-of-period stocks: $\mathsf{A}_{t+1}, \mathsf{B}_{t+1}$.)

The impulse responses are generated as follows. At a given date, say *T*, all variables are set at steady state values. A "baseline" path for the endogenous variables is computed by setting all exogenous innovations to zero in periods $t \geq T$. Then responses to one-time 1 standard deviation exogenous innovation at *T* are computed; the Table reports differences/relative deviations (that have been multiplied by 100, i.e. expressed in percentage terms) of these responses from the "baseline" path. Response of interest rate (*i*) and stocks of bonds (*A*, *B*): differences from baseline path; responses of remaining variables: relative deviations from baseline path.