Monetary Policy Rules in an Interdependent World

Robert Kollmann(*)

Department of Economics, University of Bonn
24-42 Adenauerallee, D-53113 Bonn, Germany

Centre for Economic Policy Research, UK

January 28, 2003

Abstract

This paper analyzes 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. The model explains the empirical finding that more open economies are more likely to adopt a peg.

JEL classification: E4, F3, F4
Keywords: Exchange rate regime; Business cycles; Interest rate parity.

(*) Tel.: 49 228 734073; Fax: 49 228 739100; E-mail: kollmann@wiwi.uni-bonn.de
http://www.wiwi.uni-bonn.de/kollmann

I thank Roel Beetsma, Matt Canzoneri, Menzie Chinn, Giancarlo Corsetti, Michael Devereux, Chris Erceg, Ken Judd, Jinill Kim, Michael Kumhof, Andy Levin, Paolo Pesenti, Chris Sims, Philippe Weil and seminar participants at the University of Amsterdam, at ECARES (Free University of Brussels), and at the North American Winter Meetings of the Econometric Society (Washington, D.C.) for useful discussions/suggestions.
1. Introduction

What policy rule is best suited for maximizing welfare in open economies—especially: should central banks seek to 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). 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; this may cast doubts on the relevance of these models for assessing the welfare consequences of floating exchange rates.

A first step towards studying welfare effects of monetary policy using richer, more realistic quantitative (calibrated) models was made by Kollmann (2002a) who considered a small open economy with staggered price setting. 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.

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 biased exchange rate forecasts by households. 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 (due to the assumption that international financial transactions are restricted to trade in bonds) and physical capital.

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 (low trade), and on optimal arrangements among European economies (strong trade links).

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 unconditional expected values of Home and Foreign household utility). An exchange rate peg is also considered, 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.

---

1 See Lane (2001), Sarno (2001) and Ganelli and Lane (2002) for surveys.
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 Eude (2001), Duarte and Stockman (2001), Erceg and Levin (2001), Faia (2001), Ghironi and Rebucci (2001), Hairault et al. (2001), Kollmann (2001a,b), McCallum and Nelson (1999, 2000), Monacelli (1999), Schmitt-Grohé and Uribe (2001a), and Smets and Wouters (2000, 2001). With the exception of the models by Batini et al. and by McCallum and Nelson—who like the paper here assume interest 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 papers by, Bergin and Tchakarov (2002) and by Tchakarov (2002) that likewise conduct welfare analyses of quantitative two-country NOEM models based on the same numerical technique as the paper here.
UIP shocks raise the volatility of consumption, of the real exchange rate, and of inflation, and they reduce world welfare. When the world economy is subjected to exogenous UIP shocks, then optimized policy entails exchange rate floating—the welfare gain from optimized policy compared to a peg corresponds to a permanent 0.46% [0.22%] consumption increase, 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). (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.) In the model here, a peg is optimal if a 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 an optimized floating rate regime); within Europe, the predicted welfare gain from such a peg corresponds to a permanent 0.29% consumption increase. In the model, UIP shocks are more harmful 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/computer code 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 effect turns out to be crucial for welfare. 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 the 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 \( s \in [0,1] \). In each country there are competitive firms that bundle domestic and imported intermediate goods into a non-tradable final goods 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

\[
Z_t = \left( (\alpha^d)^{1/\eta} (Q^d_0)^{(\eta-1)/\eta} + (\alpha^m)^{1/\eta} (Q^m_0)^{(\eta-1)/\eta} \right)^{1/(\eta-1)},
\]

(1)
with $\alpha^d, \alpha^m > 0, \quad \alpha^d + \alpha^m = 1, \quad \tilde{\vartheta} > 0$. $Z_t$ is final good output at date $t$; $Q^d_t, Q^m_t$ are quantity indices of domestic and imported intermediate goods, respectively: $Q^i_t = \{\int_0^1 q^i_t(s)^{\nu-i} ds\}^{\nu/(\nu-i)}$ with $\nu > 1$, for $i=d,m$, where $q^d_t(s)$ and $q^m_t(s)$ are quantities of the domestic and imported type $s$ intermediate goods. Let $p^d_t(s)$ and $p^m_t(s)$ be the prices of these goods in Home currency. Cost minimization in final good production implies:

$$q^i_{t}(s) = (p^i_{t}(s)/P^i_t)^{\nu} Q^i_t, \quad Q^i_t = \alpha^i (P^d_t/P^i_t)^{\alpha \tilde{\vartheta}} Z_t \quad \text{for } i=d,m,$$

with $P^i_t = \{\int_0^1 p^i_t(s)^{1-\nu} ds\}^{1/(1-\nu)}$, $P_t = (\alpha^d (P^d_t)^{1-\alpha} + \alpha^m (P^m_t)^{1-\alpha})^{1/(1-\alpha)}$. $P^d_t$ [$P^m_t$] 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 $(\alpha^d (P^d_t)^{1-\alpha} + \alpha^m (P^m_t)^{1-\alpha})^{1/(1-\alpha)}$).

### 2.2. Intermediate goods firms

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

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

$y_{t}(s)$ is the firm’s output at date $t$; $\theta_t$ 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 rental rate of capital and the wage rate. Cost minimization implies:

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

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

$$y_{t}(s) = q^d_{t}(s) + q^m_{t}(s), \quad (6)$$

where $q^d_{t}(s)$ [$q^m_{t}(s)$] is domestic [export] demand. The firm faces the following export demand function: $q^m_{t}(s) = (p^m_{t}(s)/P^m_t)^{-\nu} Q^m_t$, where $p^m_{t}(s)$ is the firm’s export price, in Foreign currency.

The firm’s profit, $\pi_t$, is:

$$\pi_t(p^d_{t}(s), p^m_{t}(s)) = (p^d_{t}(s) - MC_t)(p^d_{t}(s)/P^d_t)^{-\nu} Q^d_t + (e_t p^m_{t}(s) - MC_t)(p^m_{t}(s)/P^m_t)^{-\nu} Q^m_t,$$

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 ($p^d_{t}(s) \neq e_t p^m_{t}(s)$ is possible), and that they set prices in the currencies 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 $1-\tilde{d}$, a constant. Thus, the mean price-change-interval is $1/(1-\tilde{d})$. 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, \( p^d_t \). If no "price-change signal" is received between \( t \) and \( t + \tau \), the price is \( p^d_t \Pi^\tau \) at \( t + \tau \), where \( \Pi \) is the steady state growth factor of the Home price level.

The firm sets \( p^d_t = \text{Arg Max}_P \sum_{\tau=0}^{\infty} d^\tau E_t \{ \rho_{t,\tau+\tau} \pi_{t+\tau} (\Pi^\tau, p^d_{t+\tau}) / P^d_{t+\tau} \} \), where \( \rho_{t,\tau+\tau} \) 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 \( \Xi^d_{t,\tau+\tau} = \rho_{t,\tau+\tau} (P_t / P^d_{t+\tau}) Q^d_{t+\tau} (p^d_{t+\tau})^\nu \). The solution of the maximization problem regarding \( p^d_{t,\tau} \) is:

\[
p^d_{t,\tau} = (\nu / (\nu - 1)) \left\{ \sum_{\tau=0}^{\infty} (d \Pi^\nu)^\tau E_t \Xi^d_{t,\tau+\tau} MC_{t+\tau} \right\} / \left\{ \sum_{\tau=0}^{\infty} (d \Pi^\nu)^\tau E_t \Xi^d_{t,\tau+\tau} \right\}.
\]

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

\[
p^mv_{t,\tau} = \nu (\nu - 1) \left\{ \sum_{\tau=0}^{\infty} (d \Pi^\nu)^\tau E_t \Xi^{mv}_{t,\tau+\tau} MC_{t+\tau} e_{t+\tau} \right\} / \left\{ \sum_{\tau=0}^{\infty} (d \Pi^\nu)^\tau E_t \Xi^{mv}_{t,\tau+\tau} \right\},
\]

where \( \Xi^{mv}_{t,\tau+\tau} = \rho_{t,\tau+\tau} (P_t / P^m_{t+\tau}) (e_{t+\tau} / e_t) Q^{mv}_{t+\tau} (P^m_{t+\tau})^\nu \), while \( \Pi^\nu \) is the steady state growth factor of the Foreign price level.

The price indices \( P^d_t \), \( P^m_{t,\tau} \) (see (3)) evolve according to:

\[
(P^d_t)^{\nu-1} = d(P^d_{t+\tau} \Pi)^{\nu-1} + (1 - d)(p^d_{t,\tau})^{\nu-1}; \quad (P^m_{t,\tau})^{\nu-1} = d(P^m_{t+\tau} \Pi^\nu)^{\nu-1} + (1 - d)(p^m_{t,\tau})^{\nu-1}.
\]

2.3. The representative household

The preferences of the Home household are described by:

\[
E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, L_t).
\]

\( \beta \) 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:

\[
U(C_t, L_t) = \ln(C_t) - L_t.
\]

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

\[
K_{t+1} + \phi(K_{t+1}, K_t) = K_t (1 - \delta) + I_t,
\]

where \( I_t \) is gross investment, \( 0 < \delta < 1 \) is the depreciation rate of capital, and \( \phi \) 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 also holds nominal one-period bonds denominated in Home currency and in Foreign currency. The period \( t \) budget constraint of the Home household is:

\[
A_{t+1} + e_t B_{t+1} + P_t (C_t + I_t + F_t) = A_t (1 + i_{t-1}) + e_t B_t (1 + i'_{t-1}) + R_t K_t + \int_0^t \pi_t(s) ds + W_t L_t.
\]

\( A_t \) 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. \( F_t \) is a real cost (in units of the Home final good) of holding/issuing bonds: \( F_t = \frac{1}{2} \phi^A (A_{t+1} / P_t)^2 + \frac{1}{2} \phi^B (e_t B_{t+1} / P_t)^2 \), with \( \phi^A, \phi^B \geq 0 \), \( \phi^A + \phi^B > 0 \). Without this cost, stocks of bond and consumption would be non-
stationary; the cost $F_t$ ensures stationarity, which allows to analyze properties of the model using a local approximation around a (unique) deterministic steady state.

The household chooses a strategy $\{A_{t+1}, B_{t+1}, K_{t+1}, C_t, L_t\}_{t=0}^{\infty}$ 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:

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

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

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

$$W_t / P_t = C_t, \quad (14)$$

where $\rho_{t,t+1} = \beta C_t / C_{t+1}$. $\phi_{t,t+1} = \partial \phi(K_{t+1}, K_t)/\partial K_{t+1}$. $\phi_{2,t+1} = \partial \phi(K_{t+2}, K_{t+1})/\partial K_{t+1}$. (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:

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

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 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, $\phi_t$ ("UIP shock," henceforth):

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

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

$$E_t \ln(e_{t+1}/e_t) \approx i_t - i_t^* - \phi^A(A_{t+1}/P_t) + \phi^B(e_{t+1}/e_t) - \ln(\varphi_t). \quad (16)$$

$\varphi_t$ 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.

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

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

$^4$ Assume that household beliefs at $t$ about $e_{t+1}$ are given by a probability density function, $f_t$, that differs from the true pdf, $f_t$, by a factor $1/\varphi_t$: $f_t^*(e_{t+1}, \Omega) = f_t(e_{t+1} / \varphi_t, \Omega) / \varphi_t$, where $\Omega$ 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; Taylor, 1993b.)
\[
\frac{1}{1 + \phi^* \cdot (e_t^* / (e_t^* P_t^*))} E_t \left\{ \rho_{t+1} \left( P_{t+1}^* / P_{t+1}^* (e_{t+1}/e_{t+1}) \right) \right\} \left\{ 1 + i_t - \ln(e_{t+1}/e_t) \right\},
\]
(18)

\[ E_t \left\{ \ln(e_{t+1}/e_t) \right\} \approx i_t - i_t^* - \phi^* A_t^* (e_t^* / (e_t^* P_t^*)) + \phi^{**} (B_t^* / P_t^*)^2 - \ln(\phi_t). \]
(19)

(The Foreign household bears the following bond-holding cost, in units of the Foreign final good: \( F_t^* = \frac{1}{2} \phi^* \cdot (A_t^* / (e_t^* P_t^*))^2 + \frac{1}{2} \phi^{**} \cdot (B_t^* / P_t^*)^2 \).)

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:

\[ A_t + A_t^* = 0, \quad B_t + B_t^* = 0, \]
(20)

where \( A_t^*, B_t^* \) are the Foreign household's stocks of Home currency bonds and of Foreign currency bonds, respectively.

2.6. Monetary policy rules

Much recent research on monetary policy regimes has focused on rules that stipulate a response of the interest rate to inflation and to 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:

\[
i_t = i_t + \Gamma_\pi \dot{\pi}_t^d + \Gamma_\gamma \dot{\gamma}_t + \Gamma_\epsilon \ln(e/e_{t-1}),
\]
(21a)

\[
i_t^* = i_t^* + \Gamma_\pi \dot{\pi}_t^{d*} + \Gamma_\gamma \dot{\gamma}_t^* + \Gamma_\epsilon \ln(e/e_{t-1}),
\]
(21b)

with \( \dot{\pi}_t^d = (\Pi_t^d - \Pi_t)/\Pi_t, \dot{\gamma}_t = (Y_t - Y_t)/Y_t, \) 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. \( i_t \) and \( Y_t \) are the steady state Home nominal interest rate and steady state Home GDP, respectively. Throughout the paper, variables without time subscripts denote steady state values, and \( \dot{x} = (x_t - x_t) / x_t \) is the relative deviation of a variable \( x_t \) from its steady state value, \( x_t \). \( \Gamma_\pi, \Gamma_\gamma, \Gamma_\epsilon \) and \( \Gamma_\pi^*, \Gamma_\gamma^*, \Gamma_\epsilon^* \) 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 households' utility, \( E(U(C_t, L_t)) + E(U(C_t^*, L_t^*)) \); I refer to this regime as an (optimized) exchange rate float (as the nominal exchange rate is allowed to fluctuate in that arrangement).

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.

Note that optimizing central banks would, in general, adopt feedback rules that stipulates a response of the interest rate to all current and lagged state variables (e.g., Clarida et al., 1999, and Rotemberg and Woodford, 1997). I focus on "simple" policy rules (such as
those shown in (21a,b)) because (see discussion in Kollmann (2002a)) simple rules appear to capture well actual central bank behavior (e.g., Taylor, 1993a, 1999); the use of simple rules facilitates commitment as the public can easily monitor whether central banks stick to such rules; computationally, it does not seem feasible to determine fully optimal rules for the complex model considered here.

2.7. Welfare measures
A second-order Taylor expansion of the Home utility function around the steady state gives:
\[ E(U(C_t, L_t)) \approx U(C, L) + E(\hat{C}_t) - LE(\hat{L}_t) - \text{Var}(\hat{C}_t), \]
where \( \text{Var}(\hat{C}_t) \) is the variance of \( \hat{C}_t \). (For the parameter values used below, \( L = 0.74 \).)

In what follows, welfare is expressed as the permanent relative change in consumption (compared to the steady state), \( \zeta \), that yields expected utility \( E(U(C_t, L_t)) \):

\[ U((1 + \zeta)C, L) = U(C, L) + E(\hat{C}_t) - LE(\hat{L}_t) - \text{Var}(\hat{C}_t). \]
\( \zeta \) can be decomposed into components, denoted \( \zeta^m \) and \( \zeta^\var \), that reflect the means of consumption and hours worked, and the variance of consumption, respectively:

\[ U((1 + \zeta^m)C, L) = U(C, L) + E(\hat{C}_t) - LE(\hat{L}_t), \quad U((1 + \zeta^\var)C, L) = U(C, L) - \text{Var}(\hat{C}_t). \]

(8) implies
\[ \ln(1 + \zeta) = E(\hat{C}_t) - LE(\hat{L}_t) - \text{Var}(\hat{C}_t), \quad \ln(1 + \zeta^m) = E(\hat{C}_t) - LE(\hat{L}_t), \quad \ln(1 + \zeta^\var) = -\text{Var}(\hat{C}_t) \]
and thus
\[ (1 + \zeta) = (1 + \zeta^m)(1 + \zeta^\var). \]
2.8. The resource cost of price variability

Under staggered price setting, time-varying Home inflation lowers welfare as it induces inefficient dispersion of prices across Home intermediate goods producers that raises the aggregate inputs of labor ($L_t$) and capital ($K_t$) that are required to produce given quantities of the aggregate Home intermediate goods $Q_t^d$ and $Q_t^{m*}$. I now derive a measure of that resource cost of price dispersion that is useful for interpreting (some of) the welfare results below (Smets and Wouters (2002) present a closely related measure). Note that (2), (4), (5) and (6) imply:

$$\theta_t K_t L_t^{1-v} = \delta_t^d Q_t^d + \delta_t^{m*} Q_t^{m*},$$

(22)

with $\delta^d_t = (P_t^-/P_t^t)^-v$, $\delta^m_t = [\int_0^t (P_t^i(s)^-v - 1)^{-1/v} ds]$ for $i = d, m*$. The left-hand side of (22) equals $\int_0^t y_t(s) ds$ and corresponds to Home real GDP, denoted $Y_t$ in what follows. $[\delta_t^d, \delta_t^{m*}] \geq [1, 1]$ is an index of the cross-firm dispersion of the domestic prices (export prices) charged by Home intermediate goods producers at date $t$; $\delta_t^d = 1$, $\delta_t^{m*} = 1$ 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 $\Pi_t^d = \Pi_t^e$, $\Pi_t^{m*} = \Pi_t^e$, where $\Pi_t^d = P_t^d/P_t^t$, $\Pi_t^{m*} = P_t^{m*}/P_t^t$ for $i = d, m*$ (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 $\Pi_t^d$ and $\Pi_t^{m*}$, respectively: $E\delta_t^d = 1 + 0.5v(d/(1-d)^2)Var(\Pi_t^d)$, for $i = d, m*$.

A second-order expansion of (22) yields $\hat{Y}_t \equiv (1-\alpha^m)\hat{Q}_t^d + \alpha^m \hat{Q}_t^{m*} + \delta_t^d$, where $\delta_t^d = (1-\alpha^m)\delta_t^d + \alpha^m \delta_t^{m*}$ is a measure of the total resource cost of price dispersion across Home intermediate goods firms. In the model here, $E\delta_t^d$ is highly negatively correlated with the welfare difference between sticky-price and flex-prices equilibria (correlation: $-0.89$ across the model variants considered in Tables 1 and 2 below).

A policy that perfectly stabilizes $\Pi_t^d$ (at $\Pi^d$) minimizes $\delta_t^d$ (at $\delta_t^d = 1$), while a policy that perfectly stabilizes $\Pi_t^{m*}$ (at $\Pi^{m*}$) minimizes $\delta_t^{m*}$ (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: $\delta_t^d = \delta_t^{m*} = \delta_t^{ds} = \delta_t^{cs} = 1$).

---

5 Home nominal GDP equals the revenue of Home intermediate goods producers:

$$Y_t^{m*} = \int_0^t q_t^d(s)q_t^{m*}(s) + e_i p_t^{m*}(s)q_t^{m*}(s) ds.$$

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 $Y_t = \int_0^t q_t^d(s) + q_t^{m*}(s) ds = \int_0^t y_t(s) ds$ (see (6)).

6 A second-order expansion shows that $\hat{\delta}_t^i \equiv \frac{1}{2}Var_i(\ln p_t^i(s))$ for $i = d, m*$, where $Var_i$ denotes the variance across firms.

7 This formula too is based on a second order expansions (see Rotemberg and Woodford (1997) and Erceg et al. (2001) for derivations).
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. I numerically maximize the central banks' objective functions (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 $\alpha^m=0.01$ (see (1)), "low-trade-variant" henceforth, as well as a variant with $\alpha^m=0.2$ ("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 ratios of US imports from the EU3 divided by US GDP and the ratios 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 $\varphi=1$ (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.

$\varphi$, the elasticity of substitution between aggregate domestic and imported intermediate goods, in final good production, equals the price elasticity of aggregate exports and imports (see (1), (2)). $\varphi$ is set at $\varphi=1$, a value in the range of available estimates of prices elasticities of aggregate exports/imports for the US and for European countries (e.g., Hooper and Marquez (1995)).

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 $\psi$ (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, $\delta=0.025$ is used. The capital adjustment cost parameter $\Phi$ is set at $\Phi=8$ 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 Europe.

---


9 In the simulations, the final good technology is thus of the Cobb-Douglas type:

$$Z_t = (Q^d_t)^{1-\alpha^m} (Q^m_t)^{-\alpha^m}$$

and the final good price is:

$$P_t = (P^d_t)^{1-\alpha^m} (P^m_t)^{\alpha^m}$$

(these expressions correspond to the limits of (1) and (3) as $\varphi \to 1$).
Symmetry of bond-holding-cost parameters across countries requires: $\phi^H = \phi^A$, $\phi^B = \phi^A$. Given this assumption, (16), (19) and (20) imply that, up to a (log-) linear approximation, the stocks of Home and Foreign currency bonds held by a given country each account for half its net asset position:

$$\frac{1}{11} \left( \frac{A_{t+1}}{P_t} + \frac{e_t e_t^*}{P_t} \right) + \frac{1}{11} \left( \frac{F_{t+1}}{P_t} \right) = \frac{1}{11} \left( A_{t+1} + e_t B_t \right)$$

where $A_{t+1} + e_t B_t$ is the Home net foreign asset position (expressed in Home currency). Substituting these expression into (16) shows that, up to a (log-)linear approximation, the cross-country interest rate differential is linked to the net foreign asset position:

$$\frac{1}{11} \left( \frac{A_{t+1}}{P_t} + \frac{e_t e_t^*}{P_t} \right) + \frac{1}{11} \left( \frac{F_{t+1}}{P_t} \right) = \frac{1}{11} \left( A_{t+1} + e_t B_t \right)$$

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). 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 $\frac{1}{11} (\phi^A - \phi^B) = -0.0019/Q^{m*}$, where $Q^{m*}$ is steady state Home exports (see Appendix). Unfortunately, the LMF study does not allow to separately identify $\phi^A$ and $\phi^B$. I set $\phi^A$ and $\phi^B$ at the lowest possible (non-negative) values that are consistent with the LMF estimate for $(\phi^A - \phi^B)$:

$$\phi^A = 0, \quad \phi^B = 0.0038/Q^{m*}.$$  

Estimates of Calvo-style price setting equations for the US and for European countries suggest that the average price-change interval is about 4 quarters (e.g., Lopez-Salido (2000)). Hence, $d$ is set at $d=0.75$. The steady state growth factors of the Home and Foreign price levels are set at $\Pi = \Pi^* = 1$ ($\Pi$ and $\Pi^*$ have no effect on real variables, because of indexing).

Home and Foreign productivity are assumed to follow this process:

$$
\begin{bmatrix}
\ln(\theta_t) \\
\ln(\theta_t^*)
\end{bmatrix} = \begin{bmatrix}
0.81 & 0.03 \\
0.03 & 0.81
\end{bmatrix} \begin{bmatrix}
\ln(\theta_{t-1}) \\
\ln(\theta_{t-1}^*)
\end{bmatrix} + \begin{bmatrix}
\epsilon_t^o \\
\epsilon_t^{o*}
\end{bmatrix},
$$

where $\epsilon_t^o$ and $\epsilon_t^{o*}$ are white noises with standard deviation 0.0059; the correlation between $\epsilon_t^o$ and $\epsilon_t^{o*}$ is 0.18. (24) 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)). (24) 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 departures from UIP between the US and the EU3, for the period 1973-94.

$$10$$ Let $\nu_{t+1} \equiv i_t - i_t^* - \ln(e_{t+1}/e_t)$. (16) and $\phi^A=0$ (as assumed in the simulations) imply:

$$\ln(\phi_{t+1}) \equiv E_t \nu_{t+1} + \phi^B (B_{t+1} e_t/P_t).$$

$$\ln(\phi_{t+1}) \equiv E_t \nu_{t+1}$$

holds when $\phi^B$ is small. Kollmann (2002b) constructs an estimated $\ln(\phi_{t+1})$ series by regressing $\nu_{t+1}$ on $\{v_{t-4}, i_{t-1}, i_{t-1}^*, Y_{t-4}, Y_{t-4}^*\}$. 

---

$10$ Let $\nu_{t+1} \equiv i_t - i_t^* - \ln(e_{t+1}/e_t)$. (16) and $\phi^A=0$ (as assumed in the simulations) imply:

$$\ln(\phi_{t+1}) \equiv E_t \nu_{t+1} + \phi^B (B_{t+1} e_t/P_t).$$

$$\ln(\phi_{t+1}) \equiv E_t \nu_{t+1}$$

holds when $\phi^B$ is small. Kollmann (2002b) constructs an estimated $\ln(\phi_{t+1})$ series by regressing $\nu_{t+1}$ on $\{v_{t-4}, i_{t-1}, i_{t-1}^*, Y_{t-4}, Y_{t-4}^*\}$. 


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 the serial correlation of the historical UIP shocks. The following two-factor structure suits that purpose; it expresses \( \ln(\psi_t) \) as the sum of a serially correlated random variable and of an i.i.d. random variable:

\[
\ln(\psi_t) = a_t + \omega_t, \quad a_t = \lambda a_{t-1} + \eta_t, \quad 0 < \lambda < 1
\]

where \( \omega_t \) and \( \eta_t \) are independent white noises with standard deviations \( \sigma_\omega \) and \( \sigma_\eta \), respectively. (25) 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 above yields these estimates: \( \lambda = 0.88 \), \( \Upsilon = 0.52 \). Under (25), \( Var(\ln(\psi_t)) = \sigma_\omega^2 + \sigma_\eta^2/(1-\lambda^2) \). Setting \( Var(\ln(\psi_t)) \) at its historical value \( 0.0318^2 \), then pins down \( \sigma_\omega \) and \( \sigma_\eta \); \( \sigma_\omega = 0.0220 \), \( \sigma_\eta = 0.0109 \). 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 also used in the "high-trade" variant).

### 3. Results

Tables 1-2 report the results. Because of the symmetric structure of the two countries, results are only shown for the Home country. (The optimized policy coefficients and welfare are identical across countries.) In the Tables, \( \Delta e = e_t/e_{t-1} \) is the depreciation factor of the nominal exchange rate. \( RER = e_t/P_t/P_t^* \) is the (final good based) real exchange rate. \( A_{t+1} \) and \( B_{t+1} \) are the Home household’s stocks of Home-currency bonds and of Foreign-currency bonds, respectively, expressed in final good units, and normalized by steady state (quarterly) GDP.
Predicted standard deviations and/or mean values of these (and other) variables are shown. All variables are quarterly. The statistics for the domestic interest rate ($i_t$) and for bond holdings ($A_{t-1}, B_{t-1}$) refer to differences of these variables from steady state values ($i_t$ is a quarterly rate expressed in fractional units), while statistics for the remaining variables refer to relative deviations from steady state values. All statistics are expressed in percentage terms.

Results are presented for simulations in which the economy is simultaneously subjected to (Home and Foreign) productivity shocks and to UIP shocks (Cols. labeled "θθ∗", as well as for simulations with just productivity shocks (see Cols. labeled "θθ"), and with just UIP shocks (see Cols. labeled "φ").

3.1. Results for the "low-trade" variant ($α"=0.01$)
Table 1 reports results for the "low-trade" world. Cols. 1-3 pertain to the optimized floating exchange rate regime, and Cols. 5-6 consider the 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
With simultaneous productivity shocks and UIP shocks, the policy coefficients and welfare in the optimized floating rate regime (with sticky prices) are: $Γ_π = 7.93$, $Γ_y = 0.12$, $Γ_ε = 0.00$, $ζ = -0.006\%$. Welfare is thus slightly lower in the stochastic economy than in the deterministic steady state. Optimized policy has an aggressive stance against PPI inflation—notice the high positive value of $Γ_π$—and as a result, the standard deviation of PPI inflation ($dΠ$) is close to zero (0.01%), and there is very little cross-firm dispersion of domestic price charged by Home producers ($d tE δ = 0.00\%$). By contrast, the optimized response coefficients on output and the nominal exchange rate ($yτΓ$) are close to zero.

If the two economies here were closed (i.e. under autarky), optimal monetary policy would (essentially) stabilize PPI inflation; that policy would fully eliminate price dispersion across firms—and it would imply that the behavior of real variables (essentially) replicates the behavior under flexible prices. This helps to understand why optimized policy in the "low-trade" variant likewise has a strong stance against PPI inflation, and why in that variant most predicted statistics (including welfare) are virtually identical across the sticky-prices version and the flex-prices version, as can be seen by comparing Cols. 1-3 and Cols. 6-8.

Optimized monetary policy (under price stickiness) entails that the standard deviations of GDP, consumption and investment are 1.39%, 1.06% and 3.64%, respectively (with simultaneous two types of shock); nominal and real exchange rates are markedly more volatile than these variables (standard deviations of $∆ε$, RER: 7.44%, 12.44%). The real exchange rate is furthermore predicted to have a sizable 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 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, 13 See Rotemberg and Woodford's (1997) analysis of optimal monetary policy in closed economies with staggered price setting.

14 Under flexible prices, the monetary policy rule does not affect real variables; the flex-prices model considered in Tables 1 and 2 uses the policy parameters from the optimized float, under sticky-prices (with simultaneous productivity shocks and UIP shocks; see Col. 1).
1973-1994: 4.89% and 12.89%, respectively; autocorrelation of linearly detrended log real exchange rate: 0.95.)

Cols. 2-3 of Table 1 (where model versions 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 variance of nominal and real exchange rates.15

The sizable volatility of the nominal exchange rate (when there are UIP shocks) implies that exports price inflation fluctuates much more than domestic PPI inflation (standard deviation: 1.45%); however, the ensuing cross-firm price dispersion in exports markets has only a very small effect on the aggregate resource cost of the intermediate goods sector (\(E\delta^y=0.01\%\)), due to the small trade share assumed in Table 1.

Mean consumption, hours, GDP and the mean stock of physical capital differ only very slightly from steady state values (e.g. \(E\tilde{C}=0.01\%\)). Mean asset stocks are more strongly affected by stochastic shocks—especially by UIP shocks; the mean stock of Home-currency bonds held by the Home household is negative, while its mean stock of Foreign-currency bonds is positive (\(EA_{t+1}=-0.48\%, EB_{t+1}=0.48\%\)). As discussed in the Appendix, the real exchange rate volatility triggered by UIP shocks raises the Home household's expected marginal rate of substitution between units of foreign currency available at \(t\) and \(t+1\), which increases Home demand for Foreign currency bonds (analogously, real exchange rate volatility raises Foreign demand for Home currency bonds); thus \(EA_{t+1}<0, EB_{t+1}>0\).

3.1.2. Exchange rate peg

A peg can be achieved by picking "large" values of the policy parameters \(\Gamma_e\) and/or \(\Gamma_e^\ast\) (see (21a,b)). In the limit, as \(\Gamma_e\) and/or \(\Gamma_e^\ast\) tend to infinity, the exchange rate is constant:

\[e_t = e_{t-1},\]

and the following interest rate rule holds:

\[(1-\lambda)\gamma_t + \lambda \gamma_t^\ast = i_t + (1-\lambda) \left( \Gamma_e \tilde{\Pi}^e_t + \Gamma_\gamma \tilde{\gamma}_t^e \right) + \lambda \left( \Gamma_e^\ast \tilde{\Pi}^e_t + \Gamma_\gamma \tilde{\gamma}_t^e \right),\]

where \(\lambda\) is the limiting value of the ratio \(\Gamma_e/\Gamma_e^\ast\) (see Appendix). The peg discussed here is a model variant in which (21a), (21b) are replaced by equations (26), (27), and in which \(\lambda,\gamma_t,\tilde{\gamma}_t^e,\Gamma_e,\Gamma_\gamma^\ast\) are set at the values that maximize world welfare (due to symmetry, optimization yields \(\lambda=0.5\)).

When the world economy is simultaneously subjected to productivity shocks and to UIP shocks, then welfare is noticeably lower welfare under the peg (\(\zeta=-0.460\%) than under the optimized float (see Col. 4).16 The low welfare under the peg is due to the UIP shocks (welfare under peg when there are just productivity shocks: \(\zeta=-0.002\%\); see Col. 6).

---

15 In Cols. 2 and 3, the policy parameters are set at the values that maximize world welfare under simultaneous productivity shocks and UIP shocks (see Col. 1). Reoptimizing the policy coefficients when are just productivity shocks (or just UIP shocks) hardly affects welfare (and other predicted statistics).

16 The optimized inflation response coefficient under the peg is very large (the output response coefficient too is sizable, but much smaller than the inflation coefficient): \(\Gamma_e=453066.99, \Gamma_\gamma=21.51\). World welfare is a very "flat" function of the policy parameters. Imposing "moderate" upper bounds on the absolute values of \(\Gamma_e,\Gamma_\gamma\) (such as \(|\Gamma_e|,|\Gamma_\gamma|\leq 50\) ) leaves the model predictions basically unaffected. The same remark also applies to "high-trade" variant of the model (Table 2).
Under the peg, UIP shocks have a much stronger effect on Home and Foreign interest rates (than under the optimized float)--basically because under the peg the cross-country interest rate differential adjusts roughly one-to-one to UIP shocks. With UIP shocks, consumption and domestic PPI inflation are thus markedly more volatile under the peg (standard deviations: 3.63%, 0.82%), and the resource cost of cross-firm price dispersion is higher than under the optimized float ($E\delta_t = 0.24\%$); mean consumption under the peg ($E\tilde{C}_t = -0.36\%$), is noticeably lower than under the float ($E\tilde{C}_t = 0.01\%$). The welfare loss brought about by the peg (with 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 under the peg is negligible, by comparison ($\zeta^v = -0.066\%$).

Choice of exchange rate regime when peg eliminates UIP shocks
As discussed by Kollmann (2002a), a key question in modeling an exchange rate 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). This finding can easily be rationalized if UIP shocks reflect irrational exchange rate forecasts: under a (credible) peg there is obviously less scope for biased 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 source of disturbances). 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 predicted welfare gain from the peg is very small (it corresponds to a permanent 0.004% rise in consumption).

17 Under the peg $i_t - i^*_t \equiv \frac{3}{4}(\phi^a - \phi^b)NFA_t / P_t + \ln(\phi_t)$ holds, up to a (log-)linear approximation (see (23)), and the behavior of $i_t - i^*_t$ closely mimics that of $\ln(\phi_t)$.

18 The policy coefficients in Col. 6 have re-optimized (with just productivity shocks), and differ thus from those used in Col. 5.
3.2. Results for the "high-trade" variant ($\alpha^m=0.20$)

Table 2 shows results for the "high-trade" variant. With simultaneous productivity shocks and UIP shocks, the policy coefficients under the optimized float are: $\Gamma_x=34.59$, $\Gamma_y=0.27$, $\Gamma_e=0.27$ (see Col. 1). As in the "low-trade" variant, optimized policy has a clear stance against PPI inflation, and nominal and real exchange rates fluctuate widely (standard deviations of $\Pi_t^I, \Delta e, RER_t$: 0.07%, 5.62%, 8.98%). However, welfare ($\zeta=0.188\%$) is lower than in the "low-trade" world (there $\zeta=-0.006\%$). This lower welfare level is almost entirely caused by UIP shocks ($\zeta=0.188\%$ when there are just UIP shocks) in the "high-trade" world, UIP shocks are thus markedly more harmful than in the "low-trade" variant.

In the "high-trade" world, welfare under flexible prices (with simultaneous productivity and UIP shocks) is $\zeta=-0.144\%$; see Col. 6 (again, welfare is mainly driven by UIP shocks); optimized policy under sticky prices comes thus slightly less close to replicating the flex-prices equilibrium (in welfare terms), than in the "low-trade" world; note that, in the "high-trade" world with sticky prices, the inefficient cross-firm dispersion of export prices has a stronger effect on the mean resource cost of aggregate intermediate goods production ($E\hat{\delta}_t^q=0.13\%$).

For understanding why under flexible prices UIP shocks reduce welfare, it is helpful to note that the exchange rate fluctuations induced by UIP shocks lead to sizable fluctuations in the relative price between domestically produced and imported intermediate goods, i.e. in $P_t^m/P_t^d$ (and $P_t^{m^*}/P_t^{d^*}$); see Appendix. Because of the concavity of the final good production function, higher aggregate domestic and imported inputs $Q_t^d$ and $Q_t^m$ are, on average, used to produce a given quantity of the Home final good, the higher the variance of the relative price $P_t^m/P_t^d$. This effect on the resource cost of the final good is stronger, the higher the trade share $\alpha^m$ (see Appendix). The effect of $P_t^m/P_t^d$ fluctuations (largely driven by UIP shocks) on this resource cost shows itself in that fact that (under sticky and flexible prices) UIP shocks induce a rise in mean hours worked (as well as in mean GDP) of about 0.25% (relative to steady state); mean consumption changes much less. The negative welfare effect of UIP shocks mainly reflects the rise in mean hours.

In the "high-trade" world with sticky prices, the exchange rate peg markedly reduces welfare ($\zeta=-0.408\%$), when there are UIP shocks (Col. 4). 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 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.

---

19 $P_t^m/P_t^d$ is more volatile under flexible prices (than under sticky prices). Regarding welfare, this partly offsets the fact that the resource cost due to price dispersion across firms located in the Home country ($\delta^*$) is lower (namely zero), under flexible prices.

20 $E\hat{C}_t=0.01\%$ under sticky prices, and $E\hat{C}_t=0.07\%$ under flexible prices.
3.3. Sensitivity analysis

3.3.1. 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 (results available upon request).\(^{21}\)

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 therefore 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 the 'initial' period \(t=0\): \(E_0 \{\sum_{t=0}^\infty \beta^t U(C_t, L_t) + \sum_{t=0}^\infty \beta^t U(C^*_t, L^*_t)\}\). I assume that the economy is in its (deterministic) steady state at \(t=0\), and that the date 0 innovations to exogenous variables \((\epsilon_t, \epsilon^*_t, \omega_t, \eta_t)\) equal zero.

It appears that 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 unconditional welfare is \(\xi = 0.189\%\) (conditional welfare is: \(\xi = -0.060\%\)); under the float (with just productivity shocks), unconditional (conditional) welfare is \(\xi = -0.002\%\) (\(\xi = -0.001\%\)).

3.3.1. Persistence of UIP shocks

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 empirical evidence in Section 2.9 suggest that UIP shocks are highly persistent. Persistent shocks are needed to capture the high empirical autocorrelation of real exchange rates. This is shown in the Table below where variants of the model with two alternative specifications for UIP shocks are considered:

(i) An estimated AR(1) process (Cols. 1-2). Previous structural models with UIP shocks have mostly assumed that these shocks follow AR(1) processes.\(^{24}\) Fitting an AR(1) process to the historical US-EU3 UIP series described in Sect. 2.9 yields an autoregressive parameter of 0.53 (standard deviation of the regression residuals: 2.69%). Note that the autocorrelation function of the estimated AR(1) process decays faster than the empirical

---

\(^{21}\) 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 objective function is widely assumed in the literature: see, e.g., Rotemberg and Woodford (1997), Benigno (1999), 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.

autocorrelation function of UIP shocks reported in Sect. 2.9.\footnote{25} When these AR(1) parameters are used, the predicted standard deviation and autocorrelation of real exchange rate (about 5% and 0.5) are smaller than in the baseline model; the welfare cost of UIP shocks is noticeably smaller than in the baseline model, and the welfare gain from adopting a peg (that eliminates the UIP shocks) accordingly is likewise noticeably smaller—note that now the peg lowers welfare (very slightly) in the "low-trade" world (the welfare gain from the peg remains positive in the "high-trade" world; there $\zeta = -0.002\%$ (see Col. 5 in Table 1), compared to $\zeta = -0.014\%$ under float).

(ii) A two-factor UIP process (see (25)) is considered 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\%); see Cols. 3-4 in Table below. In this variant, the welfare cost of UIP shocks (and the welfare gains of a peg that eliminates the UIP shocks) is roughly 5 to 7 times higher than in the baseline model (that gain represents a permanent 0.728\% consumption increase when $\alpha^m=0.20$).

\footnote{25} The autocorrelations of order 2, 3, and 4 implied by the fitted AR(1) process are 0.28, 0.14 and 0.08, while the corresponding historical autocorrelations 0.31, 0.29 and 0.34.

\footnote{26} The parameters that achieve this are: $\lambda = 0.998$, $\sigma_\iota = 0.11\%$, $\sigma_\omega = 2.66\%$. These parameter values are used in the "low-trade" variant, as well as in the "high-trade" variant in the Table below.
The following Table considers a variant of the model in which only bonds denominated in the currency of one of the countries ("Foreign") can be traded internationally:  

---

### Notes: See Table 1.
World in which only Foreign currency bonds can be traded internationally

<table>
<thead>
<tr>
<th></th>
<th>Float</th>
<th>Peg</th>
<th>Float</th>
<th>Peg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\theta, \theta^*$</td>
<td>$\theta^*$</td>
<td>$\theta, \theta^*$</td>
<td>$\theta^*$</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>$EB_{i,t+1}$</td>
<td>0.95%</td>
<td>0.00%</td>
<td>18.32%</td>
<td>0.00%</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>0.002%</td>
<td>-0.001%</td>
<td>-0.079%</td>
<td>-0.002%</td>
</tr>
<tr>
<td>$\zeta^*$</td>
<td>-0.015%</td>
<td>-0.001%</td>
<td>-0.307%</td>
<td>-0.002%</td>
</tr>
<tr>
<td>$(\zeta + \zeta^*) / 2$</td>
<td>-0.006%</td>
<td>-0.001%</td>
<td>-0.193%</td>
<td>-0.002%</td>
</tr>
</tbody>
</table>

Notes: $EB$: Mean stock of Foreign currency bonds held by Home country (normalized by steady state GDP); $\zeta$ [\$\zeta^*$]: Home [Foreign] welfare (equivalent permanent variation in consumption). See Notes in Table 1 for further informations.

The restriction to Foreign currency bonds has little effect on world welfare, $\zeta + \zeta^*$ (compared to the baseline model). It remains true that a peg (that eliminates UIP shocks) raises world welfare (compared to the optimized float), and that the gain in world welfare generated by the peg is positively linked to the degree of openness.

However, the restriction to Foreign currency bonds affects the distribution of financial wealth and of welfare across countries. Under the float, Home holds (on average) a positive stock of external claims denominated in Foreign currency ($EB_{i,t+1} > 0$, as in the baseline model); when just Foreign currency bonds are traded internationally, Home is thus (on average) a net creditor vis-à-vis Foreign (under float)—and as a result Home enjoys higher welfare than Foreign. (In the symmetric baseline model, by contrast, Home's mean net asset position is zero, as its external assets denominated in Foreign currency are counterbalanced by external liabilities denominated in Home currency—and Home and Foreign enjoy equal welfare.)

The restriction to Foreign currency bonds has virtually no effect on the cross-country distribution of wealth and of welfare, under the peg (without UIP shocks), as productivity shocks have little effect on asset positions—both countries thus enjoy (basically) the same welfare under the peg; both in "low-trade" world and in the "high-trade" world, the peg raises Foreign welfare (by 0.014% and 0.305%, respectively); the peg very slightly lowers Home welfare in the "low-trade" world (by 0.003%), but it raises Home welfare in the "high-trade" world (by 0.077%).

3.3.3. 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 discussed above confirm point (i). Regarding point (ii), it can be noted that, in the model here, productivity shocks have a 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 baseline model, 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. For example in a version of the "high-trade" world in which productivity shocks are perfectly negatively correlated across countries ($\text{Corr}(\xi^i, \xi^*^i) = -1$), welfare is $\zeta = -0.197\%$ under the optimized float, compared to $\zeta = -0.010\%$ under a 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 (23))

(23) implies that

$$\tilde{r}_t - \tilde{r}_t^* \approx \frac{1}{2}(\phi^A - \phi^B)NFA/P_t + E\ln(RER_{re_t}/RER_t) + \ln(\varphi_t)$$

where

$$\tilde{r}_t = \tilde{r}_t - E\ln(P_{re_t}/P_t)$$

and

$$\tilde{r}_t^* = \tilde{r}_t^* - E\ln(P_{re_t}^*/P_t^*)$$

are Home and Foreign real interest rates, and

$$RER = e_tP_t^*/P_t$$

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 exports, this implies a coefficient $\frac{1}{2}(\phi^A - \phi^B) = -3/1600 = -0.0019$ (the value used in the simulations).

2. Explaining average asset stocks of external assets/liabilities

Following Kollmann (2002a, p.1012), note that (15) implies:

$$1 + \phi^A E(e_tB_t^*/P_t) = E(1^* \xi_{t+1})$$

with $1^* = \ln e_t^*$ and $\xi_{t+1} = \beta(C_t/C_{t+1})(RER_{re_t}/RER_t)(\Pi_{t+1}^*)^{-1}\varphi_t$; $\xi_{t+1}$ is the Home household's marginal rate of substitution between units of foreign currency available at t and t+1. Second order approximations give:

$$\phi^B E(e_tB_t^*/P_t) \approx E(\xi_{t+1}^*) + \Gamma_1 = E(\xi_{t+1}^*) + Cov(\xi_{t+1}, \xi_{t+1})$$

and

$$E(\xi_{t+1}^*) = \frac{1}{2} [\text{Var}(\xi_{t+1}) + \text{Var}(\Pi_{t+1}^*)] + \Gamma_2$$

with $\Gamma_1 = Cov(\phi_t, \Pi_{t+1}^*) - E(\Pi_{t+1}^*)$. $\Gamma_1$ and $\Gamma_2$ are small, as the variances of final good inflation and of nominal interest rates are small (the mean values of these variables are likewise small: $E(\Pi_{t+1}^*) = 0.00\%$, $E(\xi_{t+1}) = 0.00\%$; not shown in Tables).

Note that $E(B_t^*/e_t/P_t)$ is increasing in $E(\xi_{t+1}^*)$, and that the latter is increasing in $\text{Var}(\xi_{t+1})$.

When there are UIP shocks, real exchange rates and $\xi_{t+1}$ are highly volatile—and $\text{Var}(\xi_{t+1})$ dominates the terms $\Gamma_1$ and $\Gamma_2$, which implies $E(\xi_{t+1}^*) > 0$, $E(B_t^*/e_t/P_t) > 0$ (and thus $EB_t^*/e_t/P_t > 0$).

The same logic explains why $E(A_{t+1}/(e_t/P_t)) < 0$ (and thus $EA_{t+1}/e_t/P_t > 0$).

3. Exchange rate peg

Substituting (21a) and (21b) into (23) yields:

$$\ln(e_t/e_{t-1}) = (1/(\Gamma_{t} + \Gamma_{t}^*)) \left[ E_t \ln(e_{t+1}/e_t) - (\Gamma_{t}^* \Pi_{t}^* - \Gamma_{t}^* \Pi_{t}^*) - (\Gamma_{t}^* \tilde{Y}_t - \Gamma_{t}^* \tilde{Y}_t^*) + \Psi_t \right]$$

where $\Psi_t = \ln(\varphi_t) + \frac{1}{2}(\phi^A - \phi^B)NFA/P_t + (2nd \text{ and higher order terms})$. An exchange rate peg obtains asymptotically when $|\Gamma_{t} + \Gamma_{t}^*| \to \infty$; $\Gamma_{t}^*/(\Gamma_{t} + \Gamma_{t}^*)$, $\Gamma_{t}/(\Gamma_{t} + \Gamma_{t}^*)$, $\Gamma_{t}^*/(\Gamma_{t} + \Gamma_{t}^*)$, $\Gamma_{t}/(\Gamma_{t} + \Gamma_{t}^*) \to 0$.

Multiplying (21a) by $\Gamma_{t}^*/(\Gamma_{t} + \Gamma_{t}^*)$, and multiplying (19b) by $\Gamma_t^*/(\Gamma_{t} + \Gamma_{t}^*)$, and then summing the resulting equations gives

$$(1 - \Gamma_{t}/(\Gamma_{t} + \Gamma_{t}^*)) i_t + \Gamma_{t}^*/(\Gamma_{t} + \Gamma_{t}^*) i_t^* = i + (1 - \Gamma_{t}/(\Gamma_{t} + \Gamma_{t}^*)) (\Gamma_{t}^* \Sigma_{t}^* + \Gamma_{t}^* \tilde{Y}_t) + (\Gamma_t^*/(\Gamma_{t} + \Gamma_{t}^*)) (\Gamma_t^* \Sigma_{t}^* + \Gamma_t^* \tilde{Y}_t^*)$$

which yields (27) (when $|\Gamma_{t} + \Gamma_{t}^*| \to \infty$).
3. Volatility of $P_t^n/P_t^d$ and the resource cost of the final good

(22) and (2) imply that $EY_t=E\delta_t^zZ_t$ with $\delta_t^z = \delta_t^z \alpha^d (P_t^d/P_t)^{\alpha^d} + \delta_t^z (1-\alpha^d) (P_t^m/P_t)^{\alpha^d}$, in a symmetric equilibrium, where $Y_t$ and $Z_t$ are Home GDP and final good output, respectively (symmetry implies: $E(\delta_t^m Q_t^*)=E(\delta_t^m Q_t)$). A second-order Taylor expansion gives: $EY_t = (E\delta_t^q + \delta_t^{dm}) E\tilde{Z}_t$, where $\delta_t^{dm} = \alpha^m (1-\alpha^m) \frac{1}{2} \vartheta Var\left(\frac{P_t^m}{P_t^d}\right)$. $\delta_t^{dm}$ reflects the effect of the variance of the relative price $P_t^n/P_t^d$, on the (mean) resource cost of providing the final good; note that $\delta_t^{dm}$ is increasing in $\vartheta Var\left(\frac{P_t^m}{P_t^d}\right)$ and in the trade share $\alpha^m$ (for $\alpha^m<0.5$). $(E\delta_t^q$ is a measure of the resource cost of price dispersion across producers located in the same country—see Sect. 2.8.)

When there are UIP shocks, the standard deviation of $P_t^n/P_t^d$ is approx. 7% when prices are sticky, and approx. 12% when prices are flexible (and that both when $\alpha^m=0.01$ and when $\alpha^m=0.20$). Productivity shocks induce standard deviations (of $P_t^n/P_t^d$) of about 1%.

When $\alpha^m=0.01$, $\delta_t^{dm}$ is smaller than 0.01% (with UIP shocks). When $\alpha^m=0.20$, $\delta_t^{dm}$ is greater (with UIP shocks): $\delta_t^{dm}=0.04\%$ under sticky prices, and $\delta_t^{dm}=0.10\%$ under flexible prices; $E\delta_t^q$ is 0.13% under sticky prices.
REFERENCES


Gaspar, J., Judd, K., 1997. Solving Large-Scale Rational Expectations Models, Macroeconomic Dynamics 1, 45-75.


Table 1. World with low trade shares ($\alpha'' = 0.01$)

<table>
<thead>
<tr>
<th></th>
<th>Sticky prices</th>
<th>Peg prices</th>
<th>Flexible prices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\theta_{\theta}$</td>
<td>$\phi_{\theta}$</td>
<td>$\theta_{\theta}$</td>
</tr>
<tr>
<td>Standard deviations (in %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Y$</td>
<td>1.39</td>
<td>1.39</td>
<td>0.04</td>
</tr>
<tr>
<td>$C$</td>
<td>1.06</td>
<td>1.05</td>
<td>0.08</td>
</tr>
<tr>
<td>$I$</td>
<td>3.64</td>
<td>3.63</td>
<td>0.27</td>
</tr>
<tr>
<td>$\Pi_{d}$</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>$\Pi_{m*}$</td>
<td>1.45</td>
<td>0.15</td>
<td>1.44</td>
</tr>
<tr>
<td>$i$</td>
<td>0.14</td>
<td>0.14</td>
<td>0.00</td>
</tr>
<tr>
<td>$\Delta e$</td>
<td>7.45</td>
<td>0.74</td>
<td>7.41</td>
</tr>
<tr>
<td>$RER$</td>
<td>12.44</td>
<td>1.30</td>
<td>12.37</td>
</tr>
<tr>
<td>$A$</td>
<td>0.68</td>
<td>0.01</td>
<td>0.68</td>
</tr>
<tr>
<td>$B$</td>
<td>0.68</td>
<td>0.01</td>
<td>0.68</td>
</tr>
<tr>
<td>Means (in %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Y$</td>
<td>0.03</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>$C$</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>$L$</td>
<td>0.02</td>
<td>-0.00</td>
<td>0.02</td>
</tr>
<tr>
<td>$K$</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>$RER$</td>
<td>0.77</td>
<td>0.01</td>
<td>0.76</td>
</tr>
<tr>
<td>$A$</td>
<td>-0.48</td>
<td>-0.00</td>
<td>-0.48</td>
</tr>
<tr>
<td>$B$</td>
<td>0.48</td>
<td>0.00</td>
<td>0.48</td>
</tr>
<tr>
<td>$\delta_{d}$</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>$\delta_{m*}$</td>
<td>0.86</td>
<td>0.01</td>
<td>0.85</td>
</tr>
<tr>
<td>First-order autocorrelations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$RER$</td>
<td>0.82</td>
<td>0.83</td>
<td>0.82</td>
</tr>
<tr>
<td>Welfare (% equivalent permanent variation in consumption)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\zeta$</td>
<td>-0.006</td>
<td>0.003</td>
<td>-0.009</td>
</tr>
<tr>
<td>$\zeta^m$</td>
<td>-0.001</td>
<td>0.009</td>
<td>-0.009</td>
</tr>
<tr>
<td>$\zeta^v$</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.000</td>
</tr>
<tr>
<td>Policy parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Gamma_0$</td>
<td>7.93</td>
<td>7.93</td>
<td>7.93</td>
</tr>
<tr>
<td>$\Gamma_1$</td>
<td>-0.12</td>
<td>-0.12</td>
<td>-0.12</td>
</tr>
<tr>
<td>$\Gamma_\infty$</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Notes: $\theta$ ($\theta^+$): Home [Foreign] productivity. $\phi$: UIP shock. $Y$: Home GDP. $C$: Home consumption. $I$: Home physical investment. $\Pi$: Home gross CPI (final good) inflation. $\Pi^*$: Home gross domestic PPI inflation. $\Pi^m$: Home gross export price inflation (in Foreign currency). $i$: Home nominal interest rate. $\Delta e$: depreciation factor of nominal exchange rate. $RER$: real exchange rate. A [B]: stock of Home [Foreign] currency bonds held by Home (normalized by steady state GDP). $L$: Home hours worked. $K$: Home capital stock. $\delta^d$: total resource cost of price dispersion across Home intermediate good producers; $\delta^d/\delta^m$: resource cost of price dispersion (across Home firms) in domestic/export market ($\delta^m = \alpha \delta^m + (1-\alpha) \delta^m$); $\zeta$, $\zeta^m$, $\zeta^v$: measures of Home welfare. Standard deviations and means of $i$, A, 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.

Cols. labeled "θ,θ,φ" report model simulations with simultaneous (Home and Foreign) productivity shocks and UIP shocks; Cols. "θ,θ," ["φ"] assume just (Home and Foreign) productivity shocks [just UIP shocks].
Table 2. World with high trade shares \((\alpha'' = 0.2)\)

<table>
<thead>
<tr>
<th></th>
<th>Float (\theta, \phi)</th>
<th>Peg (\theta, \phi)</th>
<th>Flexible prices (\theta, \phi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\theta), (\phi)</td>
<td>(\theta), (\phi)</td>
<td>(\theta), (\phi)</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
</tbody>
</table>

**Standard deviations (in %)**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1.67</td>
<td>1.24</td>
<td>1.11</td>
<td>3.19</td>
<td>1.18</td>
<td>1.99</td>
<td>1.32</td>
<td>1.49</td>
</tr>
<tr>
<td>C</td>
<td>2.08</td>
<td>0.96</td>
<td>1.84</td>
<td>4.51</td>
<td>0.88</td>
<td>2.89</td>
<td>0.93</td>
<td>2.73</td>
</tr>
<tr>
<td>I</td>
<td>7.16</td>
<td>3.35</td>
<td>6.33</td>
<td>18.55</td>
<td>2.95</td>
<td>10.75</td>
<td>3.18</td>
<td>10.27</td>
</tr>
<tr>
<td>(\Pi)</td>
<td>0.07</td>
<td>0.04</td>
<td>0.07</td>
<td>0.72</td>
<td>0.08</td>
<td>0.11</td>
<td>0.02</td>
<td>0.11</td>
</tr>
<tr>
<td>(\Pi^m)</td>
<td>1.32</td>
<td>0.15</td>
<td>1.31</td>
<td>0.72</td>
<td>0.08</td>
<td>6.72</td>
<td>0.76</td>
<td>6.68</td>
</tr>
<tr>
<td>(\delta)</td>
<td>0.67</td>
<td>0.14</td>
<td>0.65</td>
<td>1.53</td>
<td>0.09</td>
<td>0.20</td>
<td>0.16</td>
<td>0.11</td>
</tr>
<tr>
<td>(\Delta)</td>
<td>5.62</td>
<td>0.63</td>
<td>5.59</td>
<td>0.00</td>
<td>0.00</td>
<td>6.61</td>
<td>0.75</td>
<td>6.57</td>
</tr>
<tr>
<td>RER</td>
<td>8.98</td>
<td>1.01</td>
<td>8.92</td>
<td>4.20</td>
<td>0.39</td>
<td>6.83</td>
<td>0.76</td>
<td>6.79</td>
</tr>
<tr>
<td>A</td>
<td>14.48</td>
<td>0.20</td>
<td>14.47</td>
<td>15.39</td>
<td>0.08</td>
<td>14.87</td>
<td>0.16</td>
<td>14.87</td>
</tr>
<tr>
<td>B</td>
<td>14.48</td>
<td>0.20</td>
<td>14.47</td>
<td>15.39</td>
<td>0.08</td>
<td>14.87</td>
<td>0.16</td>
<td>14.87</td>
</tr>
</tbody>
</table>

**Means (in %)**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>0.25</td>
<td>0.01</td>
<td>0.24</td>
<td>0.27</td>
<td>0.01</td>
<td>0.27</td>
<td>0.01</td>
<td>0.26</td>
</tr>
<tr>
<td>C</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>-0.10</td>
<td>0.00</td>
<td>0.07</td>
<td>0.01</td>
<td>0.07</td>
</tr>
<tr>
<td>L</td>
<td>0.24</td>
<td>-0.00</td>
<td>0.24</td>
<td>0.27</td>
<td>0.00</td>
<td>0.23</td>
<td>-0.00</td>
<td>0.23</td>
</tr>
<tr>
<td>K</td>
<td>0.28</td>
<td>0.01</td>
<td>0.27</td>
<td>0.35</td>
<td>0.01</td>
<td>0.38</td>
<td>0.01</td>
<td>0.37</td>
</tr>
<tr>
<td>RER</td>
<td>0.40</td>
<td>0.01</td>
<td>0.40</td>
<td>0.09</td>
<td>0.00</td>
<td>0.23</td>
<td>0.00</td>
<td>0.23</td>
</tr>
<tr>
<td>A</td>
<td>-7.18</td>
<td>-0.00</td>
<td>-7.18</td>
<td>-0.33</td>
<td>-0.00</td>
<td>-8.54</td>
<td>-0.00</td>
<td>-8.54</td>
</tr>
<tr>
<td>B</td>
<td>7.18</td>
<td>0.00</td>
<td>7.18</td>
<td>0.33</td>
<td>0.00</td>
<td>8.54</td>
<td>0.00</td>
<td>8.54</td>
</tr>
<tr>
<td>(\delta^p)</td>
<td>0.13</td>
<td>0.00</td>
<td>0.13</td>
<td>0.19</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>(\delta^m)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.19</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>(\delta^m^*)</td>
<td>0.63</td>
<td>0.01</td>
<td>0.62</td>
<td>0.19</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**First-order autocorrelations**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RER</td>
<td>0.82</td>
<td>0.82</td>
<td>0.82</td>
<td>0.97</td>
<td>0.96</td>
<td>0.82</td>
<td>0.81</td>
<td>0.82</td>
</tr>
</tbody>
</table>

**Welfare (% equivalent permanent variation in consumption)**

<table>
<thead>
<tr>
<th></th>
<th>(\zeta)</th>
<th>(\zeta^m)</th>
<th>(\zeta^v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>-0.188</td>
<td>-0.166</td>
<td>-0.022</td>
</tr>
<tr>
<td>(2)</td>
<td>-0.001</td>
<td>-0.004</td>
<td>-0.005</td>
</tr>
<tr>
<td>(3)</td>
<td>-0.188</td>
<td>-0.171</td>
<td>-0.017</td>
</tr>
</tbody>
</table>

**Policy parameters**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Gamma)</td>
<td>34.59</td>
<td>34.59</td>
<td>34.59</td>
<td>34.59</td>
<td>34.59</td>
<td>34.59</td>
<td>34.59</td>
<td>34.59</td>
</tr>
<tr>
<td>(\Gamma_p)</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>-0.01</td>
<td>-1.3e3</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>(\Gamma_m)</td>
<td>0.56</td>
<td>0.56</td>
<td>0.59</td>
<td>\infty</td>
<td>\infty</td>
<td>0.56</td>
<td>0.56</td>
<td>0.56</td>
</tr>
</tbody>
</table>

**Notes:** See Table 1.