Monetary Policy Rules in the Open Economy: Effects on Welfare and Business Cycles

Robert Kollmann(*)
University of Bonn
October 25, 2001

This paper computes welfare maximizing Taylor-style interest rate rules, in a business cycle model of a small open economy with staggered price setting, and shocks to domestic productivity, to the world interest rate, to world inflation and to the uncovered interest rate parity condition. Optimized policy rules have a pronounced anti-inflation stance and imply significant nominal and real exchange rate volatility. The country responds to an increase in external volatility by holding more foreign assets. The policy regime affects the means and the variances of consumption and hours worked. The change in means matters more for welfare than the effect on variances.

Fields: International Macroeconomics, Monetary Economics
JEL Code: E4, F3, F4

(*) Department of Economics; University of Bonn; 24-42 Adenauerallee
D-53113 Bonn; Germany; Tel: 49 228 734073; Fax: 49 228 739100
e-mail: kollmann@wiwi.uni-bonn.de; http://www.wiwi.uni-bonn.de/kollmann

Thanks for discussions/advice are due to Pierpaolo Benigno, Paul Bergin, Luca Dedola, Chris Erceg, Mark Gertler, Jinill Kim, Sylvain Leduc, Andy Levin, Tommaso Monacelli, Ed Nelson, Paolo Pesenti, Stephanie Schmitt-Grohé, Chris Sims, Frank Smets, Pedro Teles, Harald Uhlig, Michael Woodford and Raf Wouters, as well as to seminar participants at the Bank of Portugal, the ECB, the Bank of Spain, the North American Summer Meeting of the Econometric Society, and at the Annual Meeting of the Society for Economic Dynamics.
1. Introduction

The effect of the nominal exchange rate regime on welfare and business cycles is a key question in economics. This paper studies that question using a micro-based quantitative (calibrated) business cycle model of a small open economy, in which monetary policy affects real activity due to price stickiness.

Much recent effort has been devoted to developing dynamic general equilibrium models of open economies with monopolistic competition and sluggish prices (or wages)—see Lane (2001) for a survey of that work, often referred to as 'New Open Economy Macroeconomics' (NOEM).1 An important strand of the NOEM literature uses highly stylized models (that permit analytical results) to determine welfare under alternative policy regimes and to derive optimal policy rules; the simplifying assumptions generally made in these studies include, in particular: absence of physical capital and full international risk sharing.2 Another strand of the literature has developed quantitative business cycle models that can be used to study the key features of international macroeconomic data.3

The models studied in the first strand seem too stylized for empirical analysis, whereas computing welfare (and welfare maximizing policy rules) in quantitative business cycle models has, until now, not been practically feasible, given available numerical techniques. The paper here bridges these two approaches by determining welfare maximizing policy rules, using a quantitative business cycle model. This is made possible by recent advances in solving dynamic models (Sims (2000)).

The model here extends the open economy model that Kollmann (2000) calibrated to data for Japan, Germany and the U.K. (G3 henceforth). It

---

1 See also B. Doyle's NOEM web site geocities.com/brian_m_doyle/open.html
assumes physical capital (like standard business cycle models), imperfect international risk sharing due to incomplete international financial markets (transactions restricted to trade in bonds), monopolistic competition, and staggered price setting; there are shocks to domestic productivity, to the world interest rate, to world inflation, and to the uncovered interest parity condition ('UIP shocks'). In the model, monetary policy is described by Taylor-style rules---i.e. rules according to which the nominal interest rate is set as a linear function of GDP and of the inflation rate (Taylor (1993a)).

Imperfect risk sharing is more realistic than the complete risk sharing assumed in previous welfare analyses (the data reject full international risk sharing; see Kollmann (1995)); in the bonds-only structure considered here, macroeconomic variability affects the net asset position---an effect that is shown to have significant welfare consequences (this effect is not present in models with complete risk sharing).

UIP shocks are assumed here because econometric attempts to explain short-run exchange rate movements from changes in monetary policy (and other macro fundamentals) have failed (e.g., Rogoff (2000)); also, calibrated models driven just by 'traditional' fundamentals generate predicted exchange rate variability that is much smaller than that seen in post-Bretton Woods data; thus, such models are not well suited for analyzing a floating-rate regime.\(^4\) (With the exception of McCallum and Nelson (1999) and Batini and Nelson (2000), UIP shocks have not been considered in the NOEM literature.)

The present model is solved using Sims' (2000) new solution method that is based on a quadratic approximation of the equilibrium conditions. In contrast to the solution methods based on linear approximations that are widely used in macroeconomics, the Sims approach allows to compute the (second-order accurate) effect of the policy rule on expected values of

\(^4\)For example, in the baseline model considered here, the standard deviation of the (quarterly rate of change of) the nominal exchange rate is 2.2% when the model is simultaneously subjected to shocks to productivity, to the foreign interest rate and to the foreign inflation rate. When, in addition, UIP shocks are assumed, that standard deviation increases to 6.4%. The historical standard deviation (post-Bretton Woods) of bilateral exchange rates of the G3 countries vis-à-vis the U.S. is about 5.2%.
consumption and hours—an effect that is shown to be crucial for welfare, in the model here. Compared to other non-linear solution methods (see Judd (1998)), two key advantages of the Sims method are the ease with which it can be applied to models with a large number of state variables and its high computational speed—this allows to numerically determine the coefficients of the monetary policy rule that maximize welfare, in the model here.\footnote{Smets and Wouters (2000) also discuss welfare in a calibrated open economy model with incomplete financial markets (but without capital or UIP shocks); these authors do not compute the effect of the policy rule on expected values of macro variables.}

The optimized rule in the present model has an aggressive anti-inflation stance: the optimized response coefficient to (CPI) inflation and output are 4.16 and -0.01, respectively, in the baseline model. The implied standard deviation of inflation is low (about 0.2%, in the baseline model). The optimized rule yields a welfare level that is close to that of the economy under flexible prices. Under the optimized rule, the domestic interest rate falls in response to positive shocks to domestic productivity and to the foreign inflation rate; the domestic interest rate shows little response to world interest rate shocks and to UIP shocks. The optimized rule implies hence significant nominal and real exchange rate volatility. Extending the rule by permitting a direct response of the interest rate to the nominal exchange rate only yields a minuscule welfare gain and does not reduce exchange rate volatility.

Previous research shows that when price stickiness is the only economic distortion and exchange rate changes are fully passed through into import prices, then welfare maximizing monetary policy implies perfect stabilization of the (domestic) Producer Price Index, PPI (Devereux and Engel (2000), Galli and Monacelli (2000)); that policy replicates the flex-price equilibrium of the economy, and it entails a floating exchange rate.\footnote{This result mirrors the widely-discussed result that in a closed economy in which price stickiness is the only distortion, optimal policy entails complete stabilization of the price level (see Ireland (1996), Rotemberg and Woodford (1997), Goodfriend and King (1997), Erceg et al. (2000), Aoki (2001)).} Stabilizing the PPI is not necessarily optimal when, as in the model here, there are additional distortions (besides price stickiness). However,
despite the fact that the economy considered in the present paper differs in several key dimensions from those considered in previous normative policy analyses, the results here lend support to a policy of PPI stabilization. This is the case irrespective of whether full exchange rate pass through is assumed or limited pass through, due to pricing-to-market.

Under the optimized rule, domestic productivity shocks are the main source of fluctuations in output and consumption, followed by UIP shocks; the latter are the dominant source of exchange rate fluctuations. Despite the fact that UIP shocks raise macroeconomic variability, these shocks have a positive effect on welfare, inter alia because they induce the country to hold a bigger stock of foreign bonds: with UIP shocks, the country is, hence, wealthier (on average), and it enjoys higher (mean) consumption and works less.

The model predicts that economies which are more closely integrated into the international financial market (in the sense of facing a more elastic (net) supply schedule of foreign funds) enjoy higher welfare than economies which are less closely integrated, mainly because the former economies hold (on average) a higher stock of foreign bonds.

Pegging the exchange rate reduces welfare. Under a peg, external shocks require strong and immediate adjustments of the domestic interest rate—these shocks thus have a more destabilizing effect on domestic real activity (than under the optimized rule). In addition, a peg reduces mean consumption, as the increased volatility of goods demand under a peg induces firms to set higher price-cost markups. Under the plausible assumption that pegging the exchange rate reduces the variance of UIP shocks (departures from interest rate parity were smaller under the Bretton Woods (BW) system than in the post-BW era), the country holds less foreign bonds under a peg—which also lowers welfare.

An extensive literature assesses the merits of alternative policy rules by using loss functions that depend solely on the variances of key macroeconomic variables (output, inflation etc.): a rule is viewed as more desirable if it generates smaller variances. 7 In the model here, the effect

---

7 Previous research on NOEM business cycle models has often used this metric (given the technical difficulty of computing welfare in these models). The same metric has also widely been used in models without
of the policy regime on the mean values of macroeconomic variables matters generally more for economic welfare than its effect on variances—it would thus be inappropriate to neglect the change in mean values when selecting a monetary policy rule.

Standard flex-prices RBC models driven solely by money and productivity shocks exhibit 'nominal exchange rate neutrality' (Mussa (1990)): in these models an exchange rate peg does not affect real variables. In a flex-prices variant of the model here, by contrast, real variables are affected by a peg, under the assumption (discussed above) that the peg reduces the variance of the UIP shocks. Under that assumption, the flex-prices variant predicts that a peg reduces welfare, and flex- and sticky-prices variants both capture the fact that nominal and real exchange rate volatility between the major currency blocs has risen sharply after the end of the Bretton-Woods (BW) system, whereas output volatility showed little change (e.g., Baxter and Stockman (1989)).

The post-BW rise in real exchange rate volatility has often been viewed as reflecting price stickiness—and used to justify sticky-prices models; see, e.g., Mussa (1986), Dornbusch and Giovannini (1990), Caves et al. (1993), and Obstfeld and Rogoff (1996). The results presented here cast doubts on that view (as flex- and sticky-prices variants of the model here are both consistent with this fact). That view seems to be based on the assumption that monetary policy shocks are the main source of exchange rate fluctuations (in standard models, these shocks have no effect on the real exchange rate under price flexibility, but induce real exchange rate movements that closely track the nominal exchange rate when prices are (sufficiently) sticky). However, that view is inconsistent with the empirical finding (discussed above) that monetary policy has little explanatory power for short-run exchange rate movements. The paper shows that when one allows for UIP shocks, price stickiness is not critical for capturing the above cross-exchange rate regime facts.

Section 2 of this paper presents the model and discusses the solution method, Section 3 presents the results and Section 4 concludes.

explicit micro-foundations (as household welfare is not defined in such models)—see, e.g., Turnovsky (1990), Ball (1999) and Svensson (2000).
2. The model

A small open economy with a representative household, firms, and a central bank is considered (the structure of preferences and technologies follows Kollmann (2000)). The country produces a single non-tradable final good and a continuum of tradable intermediate goods indexed by \( \sigma \in [0,1] \); it imports a continuum of foreign intermediate goods, also indexed by \( \sigma \in [0,1] \). Domestic and foreign intermediate goods are used by perfectly competitive firms to produce the final good; the latter is consumed and used for investment. There is monopolistic competition in intermediate goods markets—each intermediate good is produced or imported by a single firm. Intermediate goods producers use domestic capital and labor as inputs—capital and labor are immobile internationally. The household owns all domestic producers and the capital stock, which it rents to domestic producers; it also supplies labor to firms. The markets for rental capital and for labor are competitive.

2.1. Final good production

The final good is produced using the aggregate technology

\[
Z_t = \left( \alpha_d \right)^{1/\theta} \left( Q_t^d \right)^{(\theta - 1)/\theta} + \left( \alpha_m \right)^{1/\theta} \left( Q_t^m \right)^{(\theta - 1)/\theta} \right) ^{\theta/(\theta - 1)},
\]

with \( \alpha_d, \alpha_m > 0, \alpha_d + \alpha_m = 1, \theta > 0 \). \( Z_t \) is final output at date \( t \); \( Q_t^d, Q_t^m \) are quantity indices of domestic and imported intermediate goods, respectively:

\[
Q_t^i = \int_0^{q_t^i(s)/(\nu - 1)/\nu} ds / (\nu - 1),
\]

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 \( \rho_t^d(s) \) and \( \rho_t^m(s) \) be the prices of these goods, in domestic currency.

Cost minimization in final good production implies:

\[
q_t^i(s) = (\rho_t^i(s)/\rho_t^i) - \nu Q_t^i, \quad Q_t^i = \alpha^i \left( P_t^d/P_t^m \right)^{-\theta} Z_t \quad \text{for } i = d, m,
\]

with \( \rho_t^i = \int_0^1 (\rho_t^i(s))^{1-\nu} ds / (1-\nu) \), \( P_t^d = (P_t^d)^{1-\theta} + \alpha_m (P_t^m)^{1-\theta} \), \( 1/(1-\theta) \).

\( P_t \) is a price index for domestic [imported] intermediate goods. Perfect competition in the final good market implies that the good's price is \( P_t \) (its marginal cost is \( \alpha^d \left( P_t^d \right)^{1-\theta} + \alpha_m \left( P_t^m \right)^{1-\theta} \)).

2.2. Intermediate goods firms

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

\[
\gamma_t(s) = \theta_t \left( K_t(s) \right)^{\psi} \left( Z_t(s) \right)^{1-\psi}, \quad 0 < \psi < 1.
\]
$y_t(s)$ is the firm's output at date $t$. $\theta_t$ is an exogenous productivity parameter that is identical for all domestic 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: $L_t(s)/K_t(s) = \psi^{-1}(1-\psi)R_t/W_t$. The firm's marginal cost is: $\psi^{-1}(1-\psi)R_t/W_t \psi^{-\psi} (1-\psi)^{-1}$.

The firm's good is sold in the domestic market and exported: $y_t(s) = q_t^d(s) + q_t^X(s)$, where $q_t^d(s)$ [$q_t^X(s)$] is domestic [export] demand. The export demand function is assumed to resemble the domestic demand function (2):

$$q_t^X(s) = (\rho_t^X(s)/\varphi_t^X)^{-\eta} Q_t^X,$$

with $Q_t^X = \alpha_t^X (\varphi_t^X)^{-\eta}$, $\eta > 0$,

$$Q_t^X = \int_0^1 (q_t^X(s))^{(\nu-1)}/\nu ds \nu/(\nu-1), \quad \varphi_t^X = \int_0^1 (\rho_t^X(s))^{1-\nu} ds (1-\nu)^{-\nu}$$

are a quantity index and a price index for the country's exports. $P_t^*$ is the foreign price level and also represents the purchase price of foreign intermediate goods paid by domestic importers; $P_t^*$ is exogenous.

The profits of a domestic intermediate good producer, $\pi_t^{dx}$, and of an intermediate good importer, $\pi_t^{m}$, are:

$$\pi_t^{dx}(\rho_t^d(s), \rho_t^X(s)) = (\rho_t^d(s)/\varphi_t^d) - (\rho_t^d(s)/\varphi_t^d)^{-\nu} Q_t^d + (e_t \rho_t^X(s)/\varphi_t^X) - (\rho_t^X(s)/\varphi_t^X)^{-\nu} Q_t^X,$$

where $e_t$ is the nominal exchange rate, expressed as the domestic 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 good producers can price discriminate between the domestic market and the export market ($\rho_t^d(s) \neq e_t \rho_t^X(s)$ is possible), and that they set prices in the currencies of their customers.

There is staggered price setting, à la Calvo (1983), in buyer currency: intermediate goods firms cannot reset their price, in buyer currency, unless they receive a random "price-change signal". The probability of receiving this signal in any particular period is $1-\beta$, a constant. Thus, the mean price-change-interval is $1/(1-\beta)$. Following 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 of the economy.) Firms are assumed to meet all demand at posted prices.

Consider an intermediate good producer that, at \( t \), sets a new price in the domestic market, \( \rho_{t,t}^d \). If no "price-change signal" is received between \( t \) and \( t+\tau \), the price is \( \rho_{t,t}^d \Pi_t \) at \( t+\tau \), where \( \Pi_t \) is the steady state growth factor of the domestic price level. The firm sets

\[
\rho_{t,t}^d = \text{Arg Max}_p \sum_{t=0}^{\tau} \delta_t E_t \{ \rho_{t,t+\tau}^d \Pi_{t+\tau} (\rho_{t+\tau}^x (s))/P_{t+\tau} \},
\]

where \( \rho_{t,t+\tau} \) is a pricing kernel (for valuing real date \( t+\tau \) pay-offs) that is assumed to equal the household's intertemporal marginal rate of substitution in consumption (see discussion below).

Let \( \mathbb{E}_{t,t+\tau}^i \rho_{t,t+\tau} (P/P_{t+\tau}) \mathbb{E}_{t+\tau} (\rho_{t+\tau}^i)^{\nu} \), for \( i=d,x \). The solution of the maximization problem regarding \( \rho_{t,t}^d \) is:

\[
\rho_{t,t}^d = (\nu/(\nu-1))(\sum_{t=0}^{\tau=\infty} \delta (\Pi_t)^{\nu} E_t \mathbb{E}_{t,t+\tau} \mathbb{E}_{t+\tau} \rho_{t,t+\tau}^d) / \{ \sum_{t=0}^{\tau=\infty} (\delta (\Pi_t)^{1-\nu}) E_t \mathbb{E}_{t,t+\tau} \mathbb{E}_{t+\tau} \}. \tag{8}
\]

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

\[
\rho_{t,t}^x = (\nu/(\nu-1))(\sum_{t=0}^{\tau=\infty} (\delta (\Pi_t)^{1-\nu}) E_t \mathbb{E}_{t,t+\tau} \mathbb{E}_{t+\tau} \rho_{t,t+\tau}^x) / \{ \sum_{t=0}^{\tau=\infty} (\delta (\Pi_t)^{1-\nu}) E_t \mathbb{E}_{t,t+\tau} \mathbb{E}_{t+\tau} \}, \tag{9}
\]

where \( \Pi_t \) is the steady state growth factor of the foreign price level.

Firms that import foreign intermediate goods solve an analogous decision problem. These firms are owned by risk-neutral foreigner who discount future payoffs using the world nominal interest rate. An importer that gets to set a new price selects:

\[
\rho_{t,t}^m = \text{Arg Max}_p \sum_{t=0}^{\tau=\infty} \delta_t E_t \{ R_{t,t+\tau} (\rho_{t+\tau}^m (s)^{\nu}) / \mathbb{E}_{t+\tau} \}, \tag{10}
\]

with \( R_{t,t} = 1 \) and \( R_{t,t+\tau} = \prod_{k=1}^{t+t} (1+i_k^{\ast})^{-1} \) for \( \tau > 1 \), where \( i_k^{\ast} \) is the world nominal interest rate between \( t \) and \( t+1 \). The solution of this decision problem is:

\[
\rho_{t,t}^m = (\nu/(\nu-1))(\sum_{t=0}^{\tau=\infty} (\delta (\Pi_t)^{1-\nu}) E_t \mathbb{E}_{t,t+\tau} \mathbb{E}_{t+\tau} \rho_{t,t+\tau}^m) / \{ \sum_{t=0}^{\tau=\infty} (\delta (\Pi_t)^{1-\nu}) E_t \mathbb{E}_{t,t+\tau} \mathbb{E}_{t+\tau} \}, \tag{11}
\]

with \( \mathbb{E}_{t,t+\tau}^m \rho_{t,t+\tau} (P_{t+\tau}) \). The price indices \( \rho_{t,t}^d, \rho_{t,t}^m, \rho_{t,t}^x \) (see (3), (6)) evolve according to:

---

\( ^8 \) For reasons of symmetry, it might seem preferable to assume that importers use a pricing kernel that equals the foreign intertemporal marginal rate of substitution in consumption. This would require to model the consumption behavior of foreign households—which is beyond the scope of the small open economy model here.
\[(p^1_t)^{1-\nu} = \delta (p^1_{t-1})^{1-\nu} + (1-\delta) (\rho^1_{t, t})^{1-\nu}, \quad i=d, m \quad \text{(11)}\]

\[(p^X_t)^{1-\nu} = \delta (p^X_{t-1} \Pi^*)^{1-\nu} + (1-\delta) (\rho^X_{t, t})^{1-\nu}. \quad \]

2.3. The representative household

Household preferences are described by:
\[E_0 \sum_{t=0}^{t=\infty} \beta^t U(C_t, L_t). \quad \text{(12)}\]

\(E_t\) denotes the mathematical expectation conditional on date \(t\) information. \(C_t\) and \(L_t\) are period \(t\) consumption and labor effort. \(0<\beta<1\) is the subjective discount factor. \(U\) is a utility function of the following form:
\[U(C_t, L_t) = \ln(C_t) - L_t. \quad \text{(13)}\]

As indicated earlier, the household owns all domestic producers and accumulates physical capital. The law of motion of the capital stock is:
\[K_{t+1} + \phi(K_{t+1}, K_t) = K_t (1-\delta) + I_t, \quad \text{(14)}\]
where \(I_t\) is gross investment, \(0<\delta<1\) is the depreciation rate of capital, and \(\phi\) is an adjustment cost function: \(\phi(K_{t+1}, K_t) = 0.5 \phi (K_{t+1} - K_t)^2 / K_t, \) \(\phi>0.\)

The household also holds nominal one-period bonds denominated in domestic and foreign currency. Its period \(t\) budget constraint is:
\[A_{t+1} + e_t B_{t+1} + P_t (C_t + I_t) = A_t (1+i_t) + e_t B_t (1+i_{t-1}) + R_t K_t + \int_0^t dx \Pi_t (s) ds + W_t L_t. \quad \text{(15)}\]

The last two terms in (15) are the household’s dividend and labor income, while \(A_t\) and \(B_t\) are net stocks of domestic and foreign currency bonds that mature in period \(t.\) \(i_t\) and \(i_{t-1}\) are the nominal interest rates on these bonds.

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 (12), subject to constraints (14) and (15) 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:
\[1 = (1+i_t) E_t (\rho_{t, t+1}/(P_t/P_{t+1})), \quad \text{(16)}\]
\[1 = (1+i_{t-1}) E_t (\rho_{t, t+1}/(P_t/P_{t+1})), \quad \text{(17)}\]
\[1 = E_t (\rho_{t, t+1} (R_{t+1}/P_{t+1} + 1-\delta - \phi_2, t+1)/(1 + \phi_1, t)), \quad \text{(18)}\]
\[W_t/P_t = C_t, \quad \text{(19)}\]

where \(\rho_{t, t+1} \equiv \beta C_t / C_{t+1}\) is the household’s marginal rate of substitution between consumption in \(t\) and \(t+1.\) Furthermore, \(\phi_1, t \equiv \partial (K_{t+1} / K_t) / \partial K_{t+1}, \)
\(\phi_2, t+1 \equiv \partial (K_{t+2} / K_{t+1}) / \partial K_{t+1}.\) (16)-(18) are Euler conditions, and (19)
expresses the fact that the household equates her marginal rate of substitution between consumption and leisure to the real wage rate.

2.4. Uncovered Interest Parity
Up to a (log-)linear approximation, (16) and (17) imply uncovered interest parity (UIP): $E_t \ln(e_{t+1}/e_t) \equiv_{t} t^f$. 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 Euler condition for foreign currency bonds (17) is disturbed by a stationary exogenous stochastic random variable, $\varphi_t$ ("UIP shock", henceforth) whose unconditional mean is unity ($E\varphi_t = 1$):

$$1 = \varphi_t \left(1+i^f_t\right) E_t \left(p_{t+1}/p_t\right) \left(e_{t+1}/e_t\right).$$

(20)

$\varphi_t$ can be interpreted as reflecting biased exchange rate forecasts or a time-varying "risk premium".9

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

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

(21)

respectively, where $Z_t$, $L_t$ and $K_t$ are the supplies of the final good, of labor and of rental capital, respectively, while $\int_0^t (s) ds$ and $\int_0^t K(s) ds$ represent total demand for labor and for capital (by intermediate good producers).

It is assumed that foreigners do not hold bonds denominated in the currency of the small open economy. Thus market clearing for domestic

---

9Assume that household beliefs at $t$ about $e_{t+1}$ are given by a probability density function, $p_t^S$, that differs from the true pdf, $f_t$, by a factor $1/\varphi_t$: $f_t^S(e_{t+1}, \Omega) = f_t(e_{t+1}/\varphi_t, \Omega)/\varphi_t$ ($\Omega$ is any other random variable). The Euler equation for foreign currency bonds is then given by (20). Up to a (log-) linear approximation, (20) implies $E_t \ln(e_{t+1}/e_t) \equiv_{t} t^f - (\varphi_t - 1)$.)

Frankel and Froot (1989), i.a., document biases in exchange rate forecasts by market participants. Structural models with UIP shocks have i.a. been studied by Mark and Wu (1998) and Jeanne and Rose (2000) who interpret these shocks as "fads", and by McCallum and Nelson (1999, 2000) and Taylor (1993b) who refer to them as a "risk premium".

10
currency bonds requires that the household’s net stock of bonds of this type is zero:

\[ A_t = 0. \]  

(22)

The interest rate which the country receives on foreign currency bonds, \( i_t^f \), equals the exogenous world interest rate, \( i_t^* \), plus a 'spread' that is a decreasing function of the country’s net foreign asset position:

\[ \frac{(1+i_t^f)}{\Pi^*} = \frac{(1+i_t^*)}{\Pi^*} - \lambda \left( \frac{B_{t+1}^f}{P_t^*} \right) / \chi, \quad \lambda > 0, \]  

(23)

where \( \chi \) represent steady state exports, in units of foreign output (i.e. \( \chi \) is the steady state value of \( P_t^* / P_t^* \)). \( \lambda \) captures the degree of capital mobility—a lower \( \lambda \) represents higher capital mobility. Under perfect mobility (\( \lambda = 0 \)) the country would attract an infinite supply of foreign funds when \( i_t^f < i_t^* \) (demand for bonds issued by the country would be infinite when \( i_t^f < i_t^* \)). The model assumes that financial capital is not perfectly mobile (due to transaction costs, capital controls or other frictions): the (net) supply schedule of foreign funds faced by the country slopes upwards, \( \lambda > 0 \). This ensures the existence of a unique steady state, and of an equilibrium characterized by stationary fluctuations around that steady state, which allows to solve the model using the second-order accurate method presented below.\(^{10}\)

Empirical support for (32) is provided by Lane and Milesi-Ferretti (2001) [LMF] who show that, among OECD economies, there is a negative relation between a country’s net foreign asset position (normalized by exports), and the domestic-foreign interest differential; as discussed below, the slope coefficient of that relation corresponds to the parameter \( \lambda \) in (23). (I follow LMF in normalizing net assets by exports in (23).)

---

\(^{10}\) When \( \lambda = 0 \), the model here is a version of the permanent income theory of consumption, and (as is familiar from that theory) the economy does not have a unique steady state, and consumption and net foreign assets are non-stationary (see Kollmann (1996) who studies a linearized open economy model with \( \lambda = 0 \)).

Conditions similar to (23) have widely been assumed in the literature (see Mankiw (2000), ch.8 for a textbook discussion); dynamic-optimizing models with such a schedule have i.a. been studied by Murphy (1991), Senhadji (1987), Schmitt-Grohé and Uribe (2001a) and Benigno (2001).
2.6. Exogenous variables

Productivity, the UIP shock, the foreign price level, and the world interest rate follow these processes:

\[
\theta_t = (1 - \rho \theta) + \theta \theta_{t-1} + \epsilon_\theta, \quad 0 < \rho \theta < 1, \quad (24)
\]

\[
\psi_t = (1 - \rho \psi) + \psi \psi_{t-1} + \epsilon_\psi, \quad 0 < \rho \psi < 1, \quad (25)
\]

\[
\Pi^* = (1 - \rho \Pi^*) + \rho \Pi^*_{t-1} + \Pi^* \epsilon_\Pi, \quad \text{where } \Pi_t = P_t / P_{t-1}, \quad 0 < \rho \Pi < 1, \quad (26)
\]

\[
i_t^* = (1 - \rho i^*) + \rho i^*_{t-1} + \Pi^* \epsilon_i, \quad 0 < \rho i^* < 1, \quad (27)
\]

where \( \epsilon_\theta, \epsilon_\psi, \epsilon_\Pi, \text{ and } \epsilon_i \) are independent white noises with standard deviations \( \sigma_\theta, \sigma_\psi, \sigma_\Pi, \text{ and } \sigma_i \), respectively. The mean values of productivity, and of the UIP shock have been set at unity (UIP holds in steady state). The mean values the world nominal interest rate, and of the growth factor of foreign prices are \( i^* \) and \( \Pi^* \), respectively. 11

2.7. The monetary policy rule

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)). The baseline rule considered here is a Taylor-type rule:

\[
i_t = 1 + \Gamma_\pi (\Pi_t / \Pi - 1) + \Gamma_y (Y_t / Y - 1), \quad (28)
\]

where \( \Pi_t = P_t / P_{t-1} \) is the the growth factor of the domestic price level, while \( Y_t \) is real GDP. \( i \) and \( Y \) are the steady state nominal interest rate and steady state GDP, respectively. (Henceforth variables without time subscripts are steady state values.) \( \Gamma_\pi \) and \( \Gamma_y \) are parameters. As prices in the domestic market are indexed to \( \Pi \), the behavior of real variables—and hence welfare—is independent of \( \Pi \).

The central bank sets \( \Gamma_\pi \) and \( \Gamma_y \) at the values that maximize the unconditional expected value of household welfare, \( E(U(C_t, L_t)) \). 12

11The innovations to foreign inflation and the world interest rate are scaled by \( \Pi^* \). This assumption (combined with indexing of export prices at \( \Pi^* \)) ensures that changes in \( \Pi^* \) have no effect on the behavior of real variables.

12The model abstracts from money. Money could, for example, be introduced by assuming that household utility depends on real balances. If the utility function is additively separable between real balances and its other arguments, then real balances have no effect on the remaining variables; provided the weight of real balances in the utility function is
monetary authority irrevocably and credibly commits to a given interest rate rule. Note that feedback rule (28) is not the optimal rule in the set of all possible feedback rules: in general, the optimal rule would stipulate a response to all current and lagged state variables (e.g., Clarida et al. (1999), Rotemberg and Woodford (1997)). The focus on a "simple" rule such as (28) can be justified as follows: (i) Simple rules appear to capture quite well actual central bank behavior (e.g. Taylor (1993a, 1999)); a key advantage of a simple rule is that the public can easily understand the rule and monitor whether the monetary authority sticks to it—the adoption of a simple rule thus makes commitment possible. (ii) Computationally, it does not seem feasible to determine the fully optimal rule, for the complex non-linear model considered here.13

2.8. Equilibrium and solution method
The solution method to be used here requires to write the model as a system of first-order expectational difference equations. The model can be brought into such a format by defining 8 new state variables: $\pi^d_t, \pi^d_{t-1}, \pi^x_t, \pi^x_{t-1}, \pi^m_t, \pi^m_{t-1}$ that correspond to the numerators and denominators of the formulae for $\rho^d_{t,t}$, $\rho^x_{t,t}$ and $\rho^m_{t,t}$, (8)-(10); and two additional price indices, for domestic intermediate goods, $P^d_t$ and $P^x_t$, with $P^i_t = \int_0^1 \rho^i_t(s)\nu ds^{-1/\nu}$, $i=d,x$.

Nominal variables in this economy are non-stationary. The economy is transformed into a stationary one by dividing nominal variables by domestic or foreign price level (or by functions of these price levels). Let $\pi^d_{t,t} = \pi^d_t / P^d_t$, close to zero, the monetary authority can neglect the effect of changes in real balances on household welfare—i.e. the decision problem of the monetary authority is the same as that discussed in the text.

13The optimal rule can, in principle, be determined by selecting the path of the nominal interest rate (and of the remaining endogenous variables) that maximizes the welfare of the representative household subject to 'implementability constraints' consisting of the equations that describe household behavior (Clarida et al. (1999), Smets and Wouters (2000)). Solving this 'Ramsey problem' is straightforward when the utility function is quadratic and the implementability constraints are linear. In the present model, the Ramsey problem is not a concave programming problem—the implementability conditions are not convex functions. Disregarding this reservation, I considered the system of equations obtained by setting to zero the derivatives of the Lagrangian associated with the Ramsey problem for the economy here. Solving this system of equations is not feasible using the Sims algorithm.
\[ E_t 5(\omega_t, \omega_t, \epsilon_t) = 0, \]  
(29)

where \( \omega_t \) is a vector of 21 endogenous and exogenous variables that are known at date \( t \), and \( \epsilon_t \) is the vector of date \( t \) innovations in the exogenous variables.

Given initial values \( \hat{\epsilon}_t \) and the stochastic process \( \{ \epsilon_t \}_{t \geq 0} \), an equilibrium is a stochastic process \( \{ \omega_t \}_{t \geq 0} \) that satisfies (29) for all \( t \geq 0 \).

Sims (2000) shows how to compute a second-order accurate solution of a model of this type. Sims' algorithm is based on a second-order Taylor expansion of (29) around a (deterministic) steady state given by:

\[ \delta(\omega, \omega, 0) = 0. \]

In what follows, \( d z_t = z_{t+1} - z_t \) denotes the deviation of a variable \( z_t \) from its steady state value, \( z \), and \( \tilde{z}_t = dz_t / z \) is the relative deviation of \( z_t \) from \( z \). Under conditions described by Sims (2000), there exists a unique, stationary, second-order accurate solution to (29) that has the following form:

\[ \begin{align*}
    dw_h, t &= F_{1h} F_{2h} (ds_{t-1} \epsilon_t) + (ds_{t-1} \epsilon_t) F_{3h} (ds_{t-1} \epsilon_t), \quad h = 1, \ldots, H \\
    dx_j, t &= M_{1j} d s_t + M_{2j} d s_t, \quad j = 1, \ldots, J.
\end{align*} \]

(30)

Here \( s_t = (s_{1, t}, \ldots, s_{H, t})' \) and \( x_t = (x_{1, t}, \ldots, x_{J, t})' \) are column vectors (with \( H \) and \( J \) elements, respectively, where \( H+J \) equals the number of equations in the model) that are functions of the vector \( \omega_t \):

\[ (s_{t}', x_{t}') = Z \omega_t. \]

(31)

\[ Z, F_{1h}, F_{2h}, F_{3h}, M_{1j}, \text{ and } M_{2j} \] are matrices/vectors that are functions of the parameters of the model (\( Z \) is non-singular). The intercepts in (30) are

---

14I implement the Sims method using computer code posted on Sims' web page (www.princeton.edu/~sims). I thoroughly checked and tested the Sims code and discovered several bugs. The corrected code is available from me. As far as I am aware, this is the first paper that applies the Sims method...
linear functions of the variances of the exogenous shocks; the remaining coefficients do not depend on these variances.

(30) and (31) can be used to compute the first and second moments of \(d\omega_t\): \(Ed_\omega_t\) and \(Ed_\omega_t d\omega_t'\). For the purpose of obtaining second-order accurate expressions, terms in \(ds_t, dx_t, \epsilon_t\) that are of order greater than two and the intercepts in (30) can be neglected when computing \(Ed_\omega_t\) and \(Ed_\omega_t d\omega_t'\). Hours and GDP (and other variables not included in \(\omega_t\)) are functions of \(\omega_t\). Their first and second moments can be computed using a second-order Taylor expansion, once \(E(d\omega_t)\) and \(E(d\omega_t d\omega_t')\) have been determined.

A second-order Taylor expansion of the period utility function around the steady state gives:

\[
E(U(C_t, L_t)) \approx U(C, L) + E(\bar{C}_t) - L E(\bar{L}_t) - \text{Var}(\bar{C}_t) \tag{33}
\]

where \(\text{Var}(\bar{C}_t)\) is the variance of \(\bar{C}_t = (C_t - C)/C\). For the parameter values used below, \(L=0.74\).

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

\[
U((1+\zeta)C, L) = U(C, L) + E(\bar{C}_t) - L E(\bar{L}_t) - \text{Var}(\bar{C}_t) \tag{34}
\]

The monetary policy regime may affect welfare by changing the expected values of consumption and hours worked, as well as the variance of consumption (the variance of hours worked does not affect welfare, as the utility function is linear in hours). The welfare measure \(\zeta\) can be decomposed into components, denoted \(\zeta^m\) and \(\zeta^v\), that reflect these two effects:

\[
U((1+\zeta^m)C, L) = U(C, L) + E(\bar{C}_t) - L E(\bar{L}_t), \tag{35}
\]

and

\[
U((1+\zeta^v)C, L) = U(C, L) - \text{Var}(d\bar{C}_t). \tag{36}
\]

to a fully-fledged business cycle model. Collard and Juillard (2001) and Schmitt-Grohé and Uribe (2001b) have also recently developed solutions of dynamic models based on second-order Taylor expansions.

\[15\) Strictly speaking, the Taylor expansion of the utility function is: \(E(U(C_t, L_t)) = U(C, L) + E(\bar{C}_t) - L E(\bar{L}_t) - E(\bar{C}_t^2)\). Note that \(\text{Var}(C_t) = E(\bar{C}_t^2) - (E\bar{C}_t)^2\). \(E(\bar{C}_t)\) is of the same order as the variances of the exogenous variables. Thus, up to a second-order accurate approximation, \(E(\bar{C}_t^2) = \text{Var}(\bar{C}_t)\). Replacing \(E(\bar{C}_t^2)\) by \(\text{Var}(\bar{C}_t)\) in the Taylor expansion gives (33).
It can be verified that \(\ln(1+\zeta)=(\bar{c}_t)-LE(\bar{l}_t)-\text{Var}(\bar{c}_t),\) \(\ln(1+\zeta^m)=E(\bar{c}_t)-LE(\bar{l}_t),\) and \(\ln(1+\zeta^y)=\text{Var}(\bar{c}_t)\) and thus \((1+\zeta)=(1+\zeta^m)(1+\zeta^y).\)

A numerical optimization routine is used to find the policy parameters \(\Gamma_\pi\) and \(\Gamma_y\) that maximize \(\zeta\) (attention is restricted to parameter values for which a unique stationary equilibrium exists).

2.9. Parameters (non-policy)

The values of most structural parameters are taken from Kollmann (2000) who calibrated a quarterly small open economy model to post-Bretton Woods data for Japan, Germany and the U.K. (G3). (These parameter values are also relevant for other OECD economies.)

Preference and technology parameters

The steady state domestic and foreign real interest rates are assumed to be identical, \(r=(1+1)/\Pi-1=(1+1^*)/\Pi^*-1,\) and set at \(r=0.01,\) a value that is standard in models calibrated to quarterly data (\(r=0.01\) corresponds roughly to the long-run average return on capital). The subjective discount factor is hence set at \(1/(1.01),\) as \(\beta(1+r)=1\) holds in steady state. The assumption that domestic and foreign real interest rates are identical implies that the steady state net foreign asset position is zero.

The price elasticities of the country's aggregate imports and exports (see (2), (5)) are set at \(\phi=\eta=0.6;\) this is the median value of the estimates of \(\phi\) and \(\eta\) for the G3 countries reported by Hooper and Marquez (1995). \(\alpha^m\) (see (1)) is set so that the steady state imports/GDP ratio is 30\%, consistent with U.K. and German data (for Japan, \(\alpha^m=0.1).\) (The key results continue to hold when \(\alpha^m=0.1\) is assumed.) \(\alpha^x\) (see (5)) is set so that the country's trade balance is zero, in steady state.

The steady state markup of price over marginal cost for intermediate goods is set at \(1/(\nu-1)=0.2,\) consistent with the findings of Martins et al. (1996) for the G3. The technology parameter \(\psi\) (see (4)) is set at \(\psi=0.24,\) which entails a 60\% steady state labor income/GDP ratio, consistent with G3 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 \(\phi=15,\) in order to match the fact that the standard deviation of Hodrick-Prescott (HP) filtered log investment is three to four times larger than that of GDP in G3 countries.
For a cross-section of 21 OECD countries (sample period: 1970-98), Lane and Milesi-Ferretti [LMF] (2001, p.37) document that the real interest differential (of these countries) vis-à-vis the U.S. is inversely related to their net foreign asset positions. A panel regression of the interest rate differential (expressed in percentage points per annum) on net foreign assets (normalized by annual exports) yields a statistically significant regression coefficients of about -3. In terms of the relation between quarterly interest rate differentials (in percentage points) and the ratio of net assets to quarterly exports, this estimate implies a coefficient of (normalized) net assets of \(-3/(4.4)\approx-0.19\). Accordingly, \(\lambda\) (see (23)) is set at \(\lambda=0.0019\).\(^{16}\)

Price adjustment

Lopez-Salido (2000) fits a Calvo-style price setting equation to data for Germany and the U.K.; his estimates suggest that the average price-change-interval is about 4 quarters. Hence, \(\delta\) is set at \(\delta=0.75\). The steady state growth factors of the domestic and foreign price levels are set at \(\Pi_0=\Pi_0^*=1\) (as discussed above, \(\Pi\) and \(\Pi^*\) have no effect on real variables, due to indexing).

Exogenous variables

For the G3 countries, fitting (24) to (geometrically detrended) quarterly total factor productivity (TFP) yields (for 1973-94) \(\rho^\theta=0.9\), \(\sigma^\theta=0.01\). Using the U.S. CPI and the U.S. 3-month CD rate (Citibase series FYUSCD) as measures of the foreign price level and the world nominal interest rate \(i^*\), and fitting (26), (27) to quarterly series for these variables (1973-94) yields \(\rho^*=0.8\), \(\sigma^*=0.005\), \(\rho^i=0.75\), \(\sigma^i=0.004\). These parameter values are used in the simulations. Kollmann (2001b) provides estimates of quarterly deviations from UIP, between the U.S. and an aggregate of the three largest

---

\(^{16}\)To see that the LMF estimate can be used to calibrate \(\lambda\), note that, up to a (log-)linear approximation, (16), (17) and (23) imply: \(r_t^*-r_t=-\lambda(B_{t+1}/P_t^*)/\chi + E_t\ln(RER_{t+1}/RER_t) + (\varphi_t-1)\), where \(r_t=E_t\ln(P_{t+1}/P_t)\) and \(r_t^*=E_t\ln(P_t^*/P_{t+1}^*)\) are the expected domestic and world real interest rates. Apart from the UIP shock \(\varphi_t\) (that is not considered by LMF), this equation corresponds to the regression equation estimated by LMF.
continental European economies (Germany, France, Italy). Fitting (25) to that estimated \( \varphi_t \) series (for 1973-97) yields: \( \rho^\varphi = 0.5, \sigma^\varphi = 0.033 \). Taylor (1993b) provides estimates of the standard deviation of UIP innovations for bilateral exchange rates between the U.S. and the remaining G7 countries; these estimates range between 0.037 and 0.101. The simulations use \( \rho^\varphi = 0.5, \sigma^\varphi = 0.033 \).

3. Results

Tables 1-4 report the results. For each variant of the model, standard deviations and mean values of selected variables are reported, as well as the welfare measure \( \zeta_m, \zeta^Y \) and \( \zeta^Y \). Statistics regarding the current account (CA) and the net foreign asset position (NFA) refer to \( \left( (B_{t+1} - B_t)/P_t^* \right) / (RER \cdot \hat{p}^d Y) \) and \( (B_{t+1}/P_t^*)/(RER \cdot \hat{p}^d Y) \), respectively, i.e. CA and NFA are expressed in units of the aggregate import good (valued at the foreign purchase price \( P_t^* \)) and normalized by steady state GDP (where the latter is likewise expressed in units of the import good). \( dP_t \) and \( de_t \) refer to the growth rates of the final good prices and of the nominal exchange rate, respectively. \( \mu^m_{t} = \frac{p_t^d}{e_t} \) and \( \mu^X_{t} = \frac{p_t^X}{e_t} \) are the price-cost markups charged by an average domestic producer, in the domestic market and in the export market, respectively; \( \mu^m_{t} = \frac{m_t^d}{e_t} \) is the markup charged by an average importer. The moments of GDP (\( Y_t \)), consumption (\( C_t \)), investment (\( I_t \)), the real exchange rate (\( RER = \frac{e_t}{P_t^*} \)), domestic intermediate good output (\( Q^m_t \)), imports (\( Q^m_t \)), exports (\( Q^X_t \)), hours worked (\( L_t \)) and capital (\( K_t \)) pertain to relative deviations from steady state. The remaining statistics pertain to arithmetic differences from steady state.

Table 1 reports results for the sticky-prices and flex-prices variants of the baseline model. Table 2 considers a variant with a pegged exchange rate. Table 3 reports impulse responses. Table 4 considers additional variants of the sticky-prices model.

---

17 In the economy here, nominal GDP equals the sales revenue of domestic intermediate good producers. Evaluating the output of these producers at the prices of some baseline period yields real GDP. Let the baseline prices equal steady state prices and normalize these prices at unity (steady state prices of all domestic intermediate goods are identical, as all domestic firms are symmetric). Then: \( Y_t = \int_{t=0}^{s} q_t^d(s) + q_t^X(s) ds \).
Results are presented for simulations in which the economy is subjected to just one type of shocks (see Cols. labelled "Shocks to $\theta$", "Shocks to $i$", "Shocks to $\phi$", "Shocks to $P$") and for simulations in which the economy is simultaneously subjected to the four shocks (Cols. labelled "Shocks to $\theta$, $i$, $\phi$, $P$†").

3.1. Results for the baseline sticky-prices model (Cols. 1-5, Table 1)

*Combined effect of shocks (Col. 1, Table 1)*

The optimized policy rule, with the four simultaneous shocks, has inflation and output coefficients of 4.16 and -0.01, respectively: the rule thus prescribes a strong rise in the interest rate, in response to an increase in inflation; by contrast, the response coefficient on output is close to zero. The implied standard deviation of quarterly inflation is low: 0.17%

The optimized rule has thus a rather strict anti-inflation stance.

With the four simultaneous shocks (and the optimized rule), the predicted standard deviations of output, consumption and the current account are about 2%; the predicted standard deviations of the nominal and real exchange rates (about 6.5%) are much higher. The net foreign asset position (normalized by steady state GDP) has the highest standard deviation, among the variables considered in the Table: 16.5%.

Mean GDP and mean hours worked only differ very slightly from steady state values. Mean consumption and the mean capital stock are about 0.3% higher than in steady state, and the stock of foreign assets increases by an amount that corresponds to 21.7% of steady state GDP. The mean real exchange rate appreciates by 0.62% relative to steady state. About 80% of the increase in (mean) consumption is met out of increased imports (of intermediate goods)—mean imports are 0.92% higher than in steady state.†

---

† A Taylor expansion of (1) gives $E\tilde{Z}_t = (1 - \alpha^m)E_{t+1}^d + \alpha^m E_{t+1}^m$ (second order terms of expansion are negligible due to the small variances of $\tilde{Z}_t$, $\tilde{Q}_t$); (NB $Z_t = C_t + I_t$: final good output). Let $Q_{t^d} = Q_t^d / (C_t + I_t)$, $Q_{t^m} = Q_t^m / (C_t + I_t)$ be the amount of domestic and imported intermediates incorporated into the consumption good. Note that $E_{t^c} = E_{t^d} + (I / (C + I)) (E_{t^c} - E_{t^d})$, $i = d, m$ and $E_{t^c} = (1 - \alpha^m)E_{t+1}^d + \alpha^m E_{t+1}^m$. A fraction $\alpha^m E_{t+1}^m = 0.77\%$ of the rise in mean consumption is met out of increased imports.
Welfare is higher in the stochastic economy (under the optimized policy rule) than in steady state: the welfare change amounts to a permanent $\zeta=0.39\%$ increase in consumption. The welfare gain is mainly driven by the increase in mean consumption ($\zeta^m=0.41\%$); by contrast, the welfare cost of consumption variance is negligible ($\zeta^v=-0.02\%$).

Separately subjecting the sticky-prices economy to each type of shocks
In order to interpret the preceding results, it is useful to consider the behavior of the economy when it is separately subjected to each of the four types of shocks—see Cols. 2-5, Table 1. (Cols. 2-5 assume the same policy rule as Col. 1, i.e. the optimized rule under four simultaneous shocks). These simulations show that domestic productivity shocks are the main source of fluctuations in output and consumption, followed by UIP shocks: productivity shocks account for 87\% of the variance of GDP and for about 50\% of the variances of consumption and investment (under four simultaneous shocks). UIP shocks account for less than 10\% of the variance of GDP, but explain about 35\% of the variance of consumption and investment; however, UIP shocks are the dominant source of movements in the remaining variables: e.g. these shocks explain about 80\% of the variance of nominal and real exchange rates, the nominal interest rate and inflation. Shocks to the world interest rate and to the foreign price level have a comparatively small effect on the variables in Table 1.

UIP shocks also explain the bulk of the changes in mean assets, consumption and welfare: with just UIP shocks, mean foreign assets, consumption and welfare are (in terms of deviations from steady state) 17.1\%, 0.21\%, and 0.22\%, respectively. Shocks to the foreign price level too have a non-negligible positive effect on mean asset holdings, mean consumption and welfare (3.44\%, 0.12\%, 0.14\%). By contrast, the effect of shocks to domestic productivity and to the world interest rate on the mean values of macro variables and on welfare is negligible.

Explaining the welfare effects
Although UIP and foreign inflation shocks raise macroeconomic variability, these shocks increase welfare. As discussed below, the exchange rate volatility caused by these shocks: (i) induces an increase in the net foreign asset position; (ii) raises the volatility of import markups, which
increases the country's mean export revenue. The country is, hence, wealthier (on average), and it enjoys higher (mean) imports and consumption. It appears that the rise in interest income (due to the rise in assets) and the increase in export revenue each 'finance' roughly half of the increase in (mean) imports (that drives the rise in consumption). For a detailed discussion of these channels see Appendix B. Only the key intuition is presented here.

Exchange rate volatility raises the expected value of the household's intertemporal marginal rate of substitution regarding foreign currency; this increases its demand for foreign bonds. UIP shocks induce the highest variance of the real exchange rate, and thus have the strongest effect on mean asset holdings (among the four types of shocks). Euler condition (17) implies:

$$1 = E[(1+\frac{f_t}{t}) q_{t+1} \sigma_t],$$

where $$q_{t+1} = \frac{\beta (\text{RER}_t)}{\text{RER}_t} (\frac{C_t}{C_{t+1}} \frac{1}{\Pi_t^*}).$$

$$q_{t+1}$$ is the marginal rate of substitution between units of the foreign currency available at $$t$$ and $$t+1$$. An increase in the variance of the real exchange rate ($$\text{RER}_t$$) raises the expected value $$E_{t+1}^f$$, and thus leads to a fall in the expected nominal return $$E_{t}^f$$; the latter is brought about by an increase in the mean asset position (NB $$E_{t}^f = E_{t+1}^* - \lambda E_{t+1}^* P_t^*/\bar{X}$$ from (23)).

The country's export revenue (in units of the aggregate import good) is:

$$X_t = X_t M^{x/m}_t T^x_t T^m_t (\mu_t^{-})^{-\phi},$$

where $$T^x_t = \frac{p^x_t}{p^m_t}$$ represents the country's terms of trade (recall that $$\mu_t$$ is the import markup). UIP shocks induce high exchange rate volatility, which (under sticky prices) translates into wide swings in import markups (standard deviation of $$\mu_t$$ with just UIP shocks: 7.25%). $$X_t$$ is a convex function of $$\mu_t^{-}$$—hence, mean export revenue $$E X_t$$ is positively linked to the volatility of $$\mu_t$$. 19

Comparing predicted and historical standard deviations

Col. 11 in Table 1 reports standard deviations of G3 time series for the period 1973-97 (these statistics are arithmetic averages of standard

---

19 An increase in exchange rate volatility also raises the volatility of the terms of trade, $$T_t$$; as $$X_t$$ is a concave function of $$T_t$$ (here $$\phi = 0.75$$ is assumed), this lowers $$E X_t$$; however, for values of $$\phi$$ close to unity, the effect of positive effect of $$\text{Var}(\mu_t^m)$$ on $$E X_t$$ dominates.
deviations computed separately for Japan, Germany and the U.K.; most standard deviations are quite similar across these countries. All data are quarterly (except the data on net foreign assets, NFA, that are annual). Exchange rates are bilateral exchange rates between the G3 countries and the U.S.. NFA and the current account (CA) are normalized by GDP.20 The historical time series were passed through the HP filter (prior to filtering, GDP, consumption, investment and the real exchange rate were logged).21

The (average) standard deviation of detrended post-Bretton Woods (BW) G3 GDP is 1.4%. Consumption, the current account, inflation and the interest rate are less volatile than GDP, while investment is more volatile. Post-BW nominal and real exchange rates have been markedly more volatile than GDP (standard deviation of real exchange rate: 8.6%). The post-BW NFA series has the highest standard deviation (13.8%) among the variables considered in the Table.

The theoretical statistics discussed so far pertain to variables that have not been filtered—these statistics are thus not fully comparable to the historical statistics. For the baseline sticky-prices model with the optimized policy rule (driven by four shocks), the following Table reports theoretical standard deviations for variables that have been normalized and detrended in exactly the same manner as the historical series:22

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>C</th>
<th>I</th>
<th>dP</th>
<th>I</th>
<th>de</th>
<th>RER</th>
<th>CA</th>
<th>NFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.16%</td>
<td>1.42%</td>
<td>3.48%</td>
<td>0.17%</td>
<td>0.63%</td>
<td>6.41%</td>
<td>5.76%</td>
<td>2.11%</td>
<td>8.75%</td>
</tr>
</tbody>
</table>

The standard deviations mostly seem broadly consistent with the historical

---

20. The consumption and inflation series represent total private consumption and CPI inflation; the real exchange rate is CPI based. The data are taken from International Financial Statistics and OECD Main Economic Indicators (see Kollmann (2000) for details), except the NFA series that were transcribed from plots shown in Lane and Milesi-Ferretti (2001) [LMF]. LMF's NFA series are normalized by annual GDP; I multiplied these series by 4, to facilitate the comparison with the theoretical NFA variable considered in cols. 1-10, Table 1 (NB that variable is normalized by quarterly GDP).

21. As is standard practice, the HP smoothing parameter was set at 1600 for quarterly series and at 400 for annual series.

22. Accordingly, the theoretical statistic for NFA reported in the Table pertains to an NFA series sampled at an annual frequency (i.e. every four periods).
statistics shown in Col. 11, Table 1. The predicted standard deviation of inflation (0.17%) is lower than the corresponding historical standard deviation (0.67%); compared to the model with optimized policy, historical post-BW inflation has thus been too volatile.\(^{23}\)

The model matches very closely the historical standard deviation of the interest rate; it overpredicts slightly the variability of the rate of depreciation of the nominal exchange rate (de), but underpredicts the standard deviation of the real exchange rate. Finally, note that the predicted standard deviations of net foreign assets (8.57%) is in the range of the corresponding historical statistic (13.84%). This suggests that the degree of capital mobility assumed here (i.e. the slope parameter \(\lambda\) in (23)) is appropriate (as shown below, the variability of NFA is a decreasing function of \(\lambda\)).

3.2. Results for the flex-prices variant of model (Cols. 6-10, Table 1)
In the flex-prices variant, monetary policy does not affect real variables (in Cols. 6-10, the coefficients of the policy rule have been set at \(\Gamma_\pi = 4.16\) and \(\Gamma_y = -0.01\), i.e. at the values that maximize welfare under sticky prices).

The means and variances of real variables are mostly rather similar across the sticky- and flex-prices variants of the model (however, markups are constant in the latter). Note, in particular that in the flex-prices variant too, UIP shocks induce significant nominal and real exchange rate volatility (UIP shocks again are the dominant source of fluctuations in nominal and real exchange rates) and increase markedly the country's demand for foreign bonds. Welfare, with the four simultaneous shocks, is only slightly higher under flexible prices, \(\zeta = 0.46\%\), than under sticky-prices, \(\zeta = 0.39\%\).

**Impulse responses**
The impulse responses in Table 3 (Panels a,b) shed light on dynamic properties of the sticky- and flex-prices structures. In both structures, \(^{23}\)The standard deviation of inflation differs noticeably across the G3 countries (Japan: 0.72%, Germany: 0.34%, UK: 0.95%). Inflation variability in Germany has thus been closest to the theoretical benchmark.
positive productivity, world interest rate and UIP shocks induce, on impact, a nominal and real exchange rate depreciation, while a positive foreign inflation shock induces an appreciation; the domestic interest rate falls in response to positive productivity and foreign inflation shocks, and it rises in response to positive world interest rate and UIP shocks.

Under an exchange rate peg, the gross domestic interest rate has to adjust (roughly) one-to-one to UIP shocks and to foreign interest rate shocks (see discussion below). The optimized policy rule entails only a partial adjustment of the domestic interest rate (on impact, the domestic interest rate increases by 0.56 percentage points in response to a 3.3% UIP shock); therefore, the (nominal and real) exchange rate responds strongly to these shocks (a 1 standard deviation, 3.3%, UIP shock induces a nominal and real depreciation of roughly 5%, on impact; after the shock, the exchange rate appreciates sharply and thus reverts towards its pre-shock value). The similarity of the interest rate responses across the two structures explains why the responses of consumption and investment are likewise qualitatively similar (across these structures): on impact, consumption rises in response to positive shocks to productivity and to foreign inflation, and falls, in response to positive UIP and foreign interest rate shocks.

In both structures, a positive productivity shock raises GDP (the impact response of GDP is weaker under sticky prices, 0.6%, than under flexible prices, 1.0%). However, the impact responses of GDP to the other shocks differ in sign, across the two structures (under sticky prices, GDP falls, on impact, in response to positive world interest rate and UIP shocks, and rises, in response to a positive foreign inflation shock).

\[ \hat{Y}_t = Z_t + \alpha^m (\hat{Q}_t^X - \hat{Q}_t^m), \]

where \( Z_t = C_t + I_t \).

The exchange rate depreciations induced by positive foreign interest rate and UIP shocks are accompanied by an increase in net exports \( (\hat{Q}_t^X - \hat{Q}_t^m) \), while the exchange rate appreciation induced by a positive shock to foreign inflation is accompanied by a fall in net exports. Note that the responses of net exports differ in sign from those of absorption \( (Z_t) \). The responses of net exports are much stronger in the flex-prices structure (than under sticky prices)—in fact, under flexible prices, the response of GDP is dominated by the response of net exports. This helps to understand why the (impact) responses of GDP differ qualitatively across the two structures.

\[ \text{24} \]
The finding that an optimized monetary policy rule entails a procyclical response to productivity shocks is consistent with the previous literature (e.g., Ireland (1996)): economic efficiency requires an immediate increase in output when the economy receives a positive productivity shock; price stickiness dampens the (immediate) expansion of aggregate demand for goods; procyclical monetary policy helps overcome that sluggishness of the output response.

3.3. Adding the exchange rate to the interest rate rule

As the optimized Taylor rule entails substantial exchange rate variability, it seems interesting to consider a rule that includes the exchange rate as an argument, as such a rule permits a direct response to the exchange rate. The following extension of rule (28) was considered:

\[ i_t = 1 + \pi_t (\pi / \pi - 1) + \gamma_t (y_t / y - 1) + \gamma_e (e_t / e_{t-1} - 1). \]  

(38)

Holding constant \( \gamma_\pi \) and \( \gamma_y \), an increase in \( \gamma_e \) reduces the variance of the rate of depreciation of the nominal exchange rate, \( e_t / e_{t-1} \). Setting \( \gamma_e \) at a very high positive value pegs the nominal exchange rate.

The welfare maximizing response coefficients (for the sticky-prices structure with four shocks) are: \( \gamma_\pi = 3.22 \), \( \gamma_y = -0.04 \), \( \gamma_e = -0.13 \). Interestingly, the response coefficient of the rate of exchange rate depreciation is negative.\(^{25}\) The first and second moments of macro variables (not reported in Tables) change little (compared to the baseline rule) when rule (38) is used. The welfare gain (from using (38) instead of (28)) is very small (\( \zeta = 0.396\% \), compared to \( \zeta = 0.390\% \)).

3.4. Exchange rate peg

As the optimized rule implies significant nominal and real exchange rate volatility, one might suspect that pegging the exchange rate markedly lowers welfare. This is confirmed by Cols. 1-6, Table 2 where a variant of

\(^{25}\) Setting \( \gamma_e < 0 \) permits a stronger immediate drop in the the nominal interest rate, in response to a positive productive shock, which induces a stronger rise in output, on impact. Setting \( \gamma_e < 0 \) thus permits to better mimic the output response to a productivity shock that is observed under flexible prices.
the sticky-prices model with a peg is considered. With the four simultaneous shocks, welfare is \( \zeta = -0.38\% \) under the peg, compared to \( \zeta = 0.38\% \) under the optimal rule. Interestingly, both the level component of the welfare measure (\( \zeta^m = -0.16\% \)) and the variance component (\( \zeta^v = -0.22\% \)) are lower under the peg.

The peg greatly raises the variability of consumption and of output. Under the peg, the gross domestic interest rate responds (virtually) one-to-one to UIP shocks and to foreign interest rate shocks—that response is thus much stronger than under the optimized rule. ((16), (17), (23) imply that \( (1 + r_t) = (1 + r_t^* - \bar{\Pi} \bar{\lambda} \bar{B}_{t+1} / \bar{X}) \varphi_t \), under the peg.) This explains why these shocks (especially the UIP shocks, because of the higher standard deviation of the latter) have a much more destabilizing effect under the peg.\(^{26}\)

Mean foreign assets (and mean imports) under the peg (with the four simultaneous shocks) are about as high as under the optimized policy rule—in both policy regimes, this mainly reflects the influence of UIP shocks.\(^{27}\) However, mean consumption is noticeably lower (\( \bar{E}_c_t = -0.17\% \) under peg; \( \bar{E}_c_t = 0.39\% \) under float). This is due to a reduction in the (mean) production of domestic intermediate goods, compared to the float (\( \bar{E}_d^d = -0.47\% \) under peg; \( \bar{E}_d^d = 0.13\% \) under float). The latter results from the fact that the mean markup charged by domestic firms is higher under the peg (\( \bar{E}_m^d = 1.45\% \) under peg; \( \bar{E}_m^d = 0.04\% \) under float).

\(^{26}\) Foreign inflation shocks are also much more destabilizing under the peg: in that regime, a positive foreign inflation shock has a marked positive effect on domestic (CPI) inflation; this lowers the domestic (expected) real interest rate (the domestic nominal interest rate does not respond to a foreign inflation shock), which stimulates consumption and investment. (Under the optimized policy rule, a positive foreign inflation shock induces an appreciation of the nominal exchange rate, and the effect on the domestic price level, the real interest rate, and consumption is much weaker).

\(^{27}\) Under the optimized rule, UIP shocks greatly raise the demand for foreign bonds, because the significant real exchange rate volatility caused by these shocks increases the expected intertemporal marginal rate of substitution of foreign currency, \( \bar{E}_{t+1} \) (see (37)). Under the peg, the real exchange rate is markedly less volatile; however, consumption is much more volatile (when there are UIP shocks)—and \( \bar{E}_{t+1} \) is roughly as high as under the optimized rule (this is why the country's demand for foreign assets remains sizable).
Note that, under price flexibility ($\delta=0$), intermediate goods prices equal current marginal cost, multiplied by the constant markup factor $\nu/(\nu-1)>1$ (see (8)). When prices are sticky ($\delta>0$), prices set at a given date depend also on the (distribution of) future marginal costs: prices are higher, the higher the covariance between future marginal cost and future demand for their good (see discussion in Appendix C). Under a peg, UIP shocks induce very sizable responses of output and marginal cost, as well as of the demand for intermediate goods; furthermore these responses are highly positively correlated—in other words, firms typically face high [low] marginal costs in states of the world in which the demand for their good (and hence their output) is high [low].  

**Effects of a peg when the latter 'eliminates' UIP shocks**

A key question regarding the effect of an exchange rate peg is whether the latter affects the properties of the UIP shocks. The data suggest that departures from interest rate parity were markedly smaller in the Bretton Woods [BW] era than in the post-BW period (e.g., Kollmann (2001b)). This finding is not surprising: under a (credible) peg there is much less scope for irrational exchange rate forecasts than when the exchange rate floats. (Macro models that allow for UIP shocks, under a float, often assume that the variance of these shocks becomes zero when a peg is adopted; see, e.g., Taylor (1993b)).

Col. 2 in Table 2 shows that pegging the exchange rate continues to reduce welfare (compared to the optimized rule) when it is assumed that the peg eliminates the UIP shocks (in Col. 2, the sticky-prices, pegged-rate model is simultaneously subjected to productivity, foreign interest rate and foreign inflation shocks, but not to UIP shocks): under that assumption, the standard deviation of consumption ($2.92\%$) is higher, while mean consumption (EC$-0.15\%$) is lower than under the float (with UIP shocks and the optimized policy rule); the latter is, i.a., due to the fact that mean assets are markedly lower when the variance of the UIP shocks is zero.

---

28 For example, a one-standard deviation ($3.3\%$) UIP shock lowers aggregate output by $4.3\%$ on impact; the aggregate demand for domestic intermediate goods and marginal cost fall by $6.5\%$ and $7.2\%$, respectively.
3.5. Other variants of the sticky-prices model (Table 4)

3.5.1. Degree of capital mobility

In the versions of the model discussed so far, a key channel via which macroeconomic variability affects welfare is the effect of variability on the country's net foreign asset position (NFA). It appears that welfare is an increasing function of the degree of capital mobility. Higher capital mobility (a smaller slope of the supply schedule of foreign funds, \( \lambda \); see (23)) implies that the economy holds (on average) a higher stock of foreign assets and, thus, enjoys higher (mean) consumption. However, the key findings that the optimized policy rule prescribes an aggressive anti-inflation stance and that an exchange rate peg reduces welfare are not sensitive to the degree of capital mobility.

Cols. 1-2 in Table 4 show this for a variant of the sticky-prices model in which \( \lambda \) is set at \( \lambda = 0.1 \) (a value about 50 higher than the baseline value). For \( \lambda = 0.1 \), the coefficients of the optimized rule are: \( \Gamma_\pi = 4.97 \), \( \Gamma_y = -0.02 \). Note that the mean asset position is now close to zero, and that mean consumption and welfare are lower than in steady state (welfare under the optimized rule is \( \zeta = -0.17\% \), compared to \( \zeta = -0.25\% \) under a peg).

3.5.2 Alternative assumptions about price adjustment

Motivated by the empirical failure of the Law of One Price (LOP), the baseline model has assumed pricing-to-market (PTM) behavior (price discrimination between the domestic and the foreign market, and price setting in buyer currency).

By contrast, previous NOEM research on optimal monetary policy has generally postulated that prices are set in producer currency and that firms cannot price discriminate across markets, an arrangement referred to as producer currency pricing (PCP) by Devereux and Engel (2000); PCP implies that the LOP holds and that exchange rate movements are fully and immediately passed through into import prices (expressed in buyer currency). Prior research shows that when there is PCP and price stickiness is the only economic distortion, then welfare maximizing monetary policy entails perfect stabilization of the (domestic) producer price index, PPI (Devereux and Engel (2000), Galí and Monacelli (2000)); that policy replicates the flex-price equilibrium of the economy.

Col. 3 in Table 4 considers a variant of the model with PCP. The
optimized rule (28) under PCP has response coefficients on inflation and output of $\Gamma_\pi = 2.42$ and $\Gamma_y = 0.13$, respectively. As PCP entails full exchange rate pass through, the standard deviation of CPI inflation (1.47%) is markedly higher than under PTM (0.17%). Note that PPI inflation, $(\Pi^d_t = \Pi^d_{t-1})$ is also markedly more volatile than under PTM. Output, consumption and investment are likewise more volatile than under PTM, while nominal and real exchange rates are less volatile. Welfare ($\zeta = 0.34\%$) is slightly lower than under PTM ($\zeta = 0.39\%$), which mainly is due to the greater volatility of consumption (under PCP).

Cols. 4-5, Table 4 consider variants of the PTM and PCP models with an interest rate rule that prescribes a response to PPI inflation (and not to CPI inflation, as under the baseline rule (28)): \[ i_t = i + \Gamma^d_\pi (\Pi^d_t - 1) + \Gamma^d_y (Y_t / Y - 1). \] (39)

Complete PPI stabilization can be achieved by setting $\Gamma^d_\pi = 0$. The optimized rule (39) does not entail complete PPI stabilization, although it implies a very low standard deviation of PPI inflation (0.07%)--this is the case both under PTM and under PCP (the optimized $\Gamma^d_\pi$ coefficient is 3.01 under PTM and 1.52 under PCP).

When PTM is assumed, the optimized rules (28) and (39) yield virtually identical welfare. Under PCP, by contrast, rule (39) yields higher welfare ($\zeta = 0.47\%$, instead of $\zeta = 0.34\%$ under (28)); welfare and the behavior of real variables (under PCP and optimized rule (39)) very closely resemble the outcome under flexible prices (Col. 7, Table 1).

Complete PPI stabilization yields only minimally lower welfare than the optimized rule (39) (e.g. welfare is merely 0.0072% [0.0025%] lower under PCP [PTM]).

Despite the fact that the economy here departs in several key dimensions from the models considered in previous normative policy analyses, the results here lend support to a policy of PPI stabilization. Interestingly, this holds irrespective of whether PTM or PCP is assumed.

3.6. Bretton Woods vs. post-Bretton Woods

Standard flex-prices RBC models driven solely by money and productivity shocks exhibit 'nominal exchange rate neutrality' (Mussa (1990)): in these models an exchange rate peg does not affect real variables. In a flex-prices variant of the model here, by contrast, real variables are
affected by a peg, under the reasonable assumption (discussed above) that the peg eliminates (or at least reduces) the variance of the UIP shocks (the subsequent discussion is based on that assumption). Like the sticky-prices variant, the flex-prices variant predicts that a peg reduces welfare (under the above assumption).  

Flex-prices and sticky-prices variants of the model here both generate the following predictions: (i) The standard deviation of the real exchange rates is about twice as high under the float (about 6%) than under the peg; under the float, nominal and real exchange rates are predicted to be about equally volatile. (ii) The volatility of output, consumption and investment is much less affected by the exchange rate regime (e.g. the predicted standard deviation of GDP ranges between 2.2% and 2.8% across the structures with pegged/floating exchange rates and sticky/flexible prices). 

Flex- and sticky-prices variants of the model both capture thus the widely-discussed fact that the volatility of nominal and real exchange rates between the major currency blocs (U.S., Europe, Japan) has risen sharply after the end of the Bretton-Woods (BW) system, whereas the volatility of output showed little change (i.a., Baxter and Stockman (1989), Flood and Rose (1995)).

---

29 With flexible prices, welfare under the peg is 0.14%, compared to 0.46% under the float (see Col. 8, Table 2). As in the sticky-prices structure, the household holds less bonds (and enjoys lower mean consumption) when the variance of the UIP shocks is set at zero (due to the adoption of a peg).

30 Recall that, under the float, UIP shocks induce sizable nominal and real exchange rate volatility, irrespective of whether prices are sticky or flexible.

31 In the sticky-prices variant, the adoption of a peg implies that output responds more strongly to shocks to the foreign interest rate and to foreign inflation (than under the optimized rule), but that output responds less strongly to productivity shocks (the elimination of the UIP shocks likewise stabilizes output); the net effect is that the variability of output is slightly higher under the peg. In the flex-prices variant, the peg only affects output because (by assumption) it eliminates the UIP shocks—however, this only has a small effect on output variability (productivity shock are the main source of output fluctuations).

32 Tables 1 and 2 (Cols. 11, 9) document this fact, for the G3 economies; the standard deviation of real bilateral G3-US exchange rates (HP filtered) rose from 1.9% under BW to 8.6% during the post-BW era; the
The rise in real exchange rate volatility that accompanied the rise in nominal exchange rate volatility after the end of BW has often been viewed as reflecting price stickiness—and used to justify sticky-prices models; see, e.g., Mussa (1986), Dornbusch and Giovannini (1990), Caves et al. (1993), and Obstfeld and Rogoff (1996). The results presented here cast doubts on this view (as flex- and sticky-prices variants of the present model both capture this fact). That view seems to be based on the assumption that monetary policy shocks are the main source of exchange rate fluctuations (standard theory predicts that such shocks have no effect on the real exchange rate under price flexibility, but induce real exchange rate movements that closely track the nominal exchange rate when prices are (sufficiently) sticky). However, that view is inconsistent with the empirical finding (discussed in the introduction) that monetary policy has little explanatory power for short-run exchange rate movements (Meese and Rogoff (1983), Rogoff (2000)). This is why the model here considers UIP shocks. When one allows for UIP shocks, price stickiness is not critical for capturing the cross-exchange rate regime facts discussed above.

4. Conclusions
This paper has computed welfare-maximizing Taylor-style interest rate rules, in a business cycle model of a small open economy with staggered price setting. Shocks to domestic productivity, to the world interest rate, to world inflation and to the uncovered interest rate parity condition are assumed. Optimized policy rules have a strict anti-inflation stance and imply significant nominal and real exchange rate volatility. The country responds to an increase in external volatility by holding more foreign assets. The exchange rate regime affects the net foreign asset position and the mean values of macro variables, as well as their variances—the effect on mean values generally matters more for economic welfare than the effect on variances.

standard deviations of GDP was roughly 1.5% in both periods.
Appendix A. The current account equation, imports and the asset position

This Appendix provides further analysis of the key facts discussed in Sect. 3.1: in the baseline sticky-prices economy (with the optimized policy rule), the mean asset position, mean imports, mean consumption and welfare are higher than in steady state. As reported in Sect. 3.1, the increase in mean consumption is largely driven by an increase in mean imports.

The country's current account equation helps to understand what drives the change in mean imports. Substituting (7), (21) and (22) into the budget constraint (15) yields the following current account equation:

\[ Q_t^m = e_t X_t^m / X_t^m + e_t B_{t-t+1} / X_t^m. \]

This equation can be written as:

\[ Q_t^m = RER_t X_t^m / \mu_t^m + (B_t / \Pi^*_t - B_t / \Pi^*_t - B_t / \Pi^*_t - B_t / \Pi^*_t + B_t / \Pi^*_t - B_t / \Pi^*_t) / \mu_t^m. \]  

(B.1)

The three terms on the right-hand side are the country's export revenue, interest income, and current account deficit, respectively (each of these terms is expressed in units of the aggregate import good, valued at the import price index \( P_t^m \)). Let \( x_t = \text{RER}_t X_t^m / \mu_t^m, \ 3_t = (B_t / \Pi^*_t - B_t / \Pi^*_t - B_t / \Pi^*_t - B_t / \Pi^*_t - B_t / \Pi^*_t) / \mu_t^m. \)

(B.1) implies: \( E_t^m = E_t x_t^m + E_t^m / \mu_t^m \). With the four simultaneous shocks, \( E_t^m = 0.92^m, \ E_t^m = 0.51^m, \ E_t^m / \mu_t^m \) and \( E_t^m / \mu_t^m \). (With just UIP shocks: \( E_t^m = 0.53^m, \ E_t^m = 0.32^m, \ E_t^m / \mu_t^m = 0.54^m, \ E_t^m / \mu_t^m = 0.33^m. \) The increase in mean imports (relative to steady state) is thus "financed" by a rise in foreign interest income and in export revenue; these effects are partly counterbalanced by a reduction in the mean current account deficit \( E_t^m < 0 \) because \( \mu_t^m \) is negatively correlated with \( B_t / \Pi^*_t - B_t / \Pi^*_t + B_t / \Pi^*_t. \)

The demand for foreign assets

The increase in the country's mean interest income is driven by the increase in its (mean) stock of foreign assets. As discussed in Sect. 3.1 the Euler condition for foreign bonds (17) implies: \( 1 = E [[1 + f_t^m q_{t+1}^m / f_t^m q_{t+1}^m \varphi_t]], \) where \( q_{t+1}^m = \beta (\text{RER}_{t+1} / \text{RER}_t) (C_t/C_{t+1}) / \Pi_t^*. \) is the household's marginal rate of substitution between units of the Foreign currency at \( t \) and \( t+1 \) (see (37)). Substituting (23) into the (unconditional) Euler equation and taking a second order Taylor expansion gives:

\[ E_t^m = X (A^*_t)^{-1} (E_t^m q_t^m + \beta \text{Cov}(f_t^m q_{t+1}^m + \varphi_t) + \text{Cov}(\varphi_t, q_{t+1}^m)), \]  

(B.2)

and \( E_t^m = 0.5 \text{Var}(q_{t+1}^m) + \text{Var}(\Pi_t^*) \),

where \( \text{Cov}(x_t, z_t) \): covariance between \( x_t \) and \( z_t \).

Thus, \( E_t^m > 0 \): the expected intertemporal marginal rate of substitution of foreign currency is higher in the stochastic economy than in steady state; furthermore, \( E_t^m \) is increasing in \( \text{Var}(q_{t+1}^m) \). It appears that the covariance terms on the right-hand side of (B.2) are negative. (A positive UIP shock raises the real exchange rate, on impact--in subsequent periods the real exchange rate reverts to its pre-shock level; on impact, a positive UIP shock induced thus a fall in the (expected) rate of exchange rate depreciation, which explains why \( \text{Cov}(\varphi_t, q_{t+1}^m) < 0. \) However, these terms are dominated by \( E_t^m q_{t+1}^m \), as \( \Delta q_{t+1}^m \) is markedly more volatile than \( f_t^m \) and \( \Pi_t^* \) and
\[ \varphi_t (\text{e.g.: } \text{Cov}(\varphi_t, \tilde{q}_{t+1}) = \text{Var}(\varphi_t) \text{Var}(\tilde{q}_{t+1}) - 5 \times \text{Var}^2(\tilde{q}_{t+1})). \] Thus \( \tilde{E}_{t+1} > 0 \), i.e. average net foreign assets in the stochastic economy exceed steady state net assets. UIP shocks are the main source of real exchange rate fluctuations, and as a result, UIP shocks have a much stronger effect on \( \tilde{E}_{t+1} \) and the mean net foreign asset position than the other three types of shocks (in the baseline case with just UIP shocks, \( \tilde{E}_{t} = 0.12\% \); with the four simultaneous shocks, \( \tilde{E}_{t+1} = 0.15\% \).

**Export revenue**

As indicated in Sect. 3.1, the country's export revenue (in units of the aggregate import good) is:

\[ \tilde{x}_t = \frac{\mathcal{P}X_t \mathcal{Q}}{\mathcal{P}^m_t \mathcal{Q}^m}, \]

where \( \mathcal{T}_t = \mathcal{Q}X_t \mathcal{P}^m_t \mathcal{Q}^m_t \) is the country's terms of trade (\( \mu^m_t \) is the markup charged by the average importer). A second Taylor expansion of this expression yields:

\[ \tilde{E}_t = (1-\theta) \tilde{E}_t + \frac{1}{2} \theta \text{Var}(\tilde{E}_t) + \frac{1}{2} \theta \text{Var}(\tilde{E}_t) + \frac{1}{2} \theta \text{Cov}(\tilde{E}_t, \tilde{E}_t). \]

As \( \tilde{x}_t \) is a convex function of \( \mu^m_t \), an increase in the volatility of \( \mu^m_t \) raises the mean of \( \tilde{x}_t \). For values of the elasticity of substitution between domestic and imported intermediate goods, \( \theta \), that are close to unity (the simulations assume \( \theta = 0.75 \)), \( \text{Var}(\mu^m_t) \) is the most important determinant of \( \tilde{E}_t \). (Note that \( \tilde{E}_t = \mathcal{E}_t + \text{Var}(\mu^m_t) \) when \( \theta = 1 \).) UIP shocks induce sizable exchange rate volatility—and thus produce a highly volatile imports markup (\( \text{Var}(\mu^m_t) = 0.66\% \) in the case with four simultaneous shocks). (By contrast, UIP shocks only have a negligible effect on the expected value of the imports markup.)

Appendix B. Price setting in intermediate goods sector

Intermediate goods prices set at date \( t \) are a weighted average of current and future marginal costs. Regarding the prices set by domestic producers in the domestic market, we see from (9) that

\[ \rho^d_{t,t} = (\nu/(\nu-1)) \left( \sum_{\tau=0}^{\tau=\omega} \lambda_{t-t+\tau} E_{t+\tau} \right) + \left( \nu/(\nu-1) \right) \left( \sum_{\tau=0}^{\tau=\omega} (\delta \Pi^{t-v}) \text{Cov}(\xi_{t-t+\tau}, \xi_{t+\tau}) \right) / \left( \sum_{\tau=0}^{\tau=\omega} (\delta \Pi^{t-v}) E_{t+\tau} \right), \]

where \( \xi_{t-t+\tau} = \theta_{t-t+\tau}/\Pi^t \) and \( \lambda_{t-t+\tau} = (\delta \Pi^{t-v}) E_{t+\tau} \) with \( \sum_{\tau=0}^{\tau=\omega} \lambda_{t-t+\tau} = 1 \). Hence, \( \rho^d_{t,t} \) equals the steady state markup factor \( (\nu/(\nu-1)) \) times a weighted average of expected future (geometrically detrended) marginal costs plus a weighted sum of covariances between future marginal costs and future values of \( \xi_{t-t+\tau} = \rho_{t,t+\tau} (\xi_{t+\tau})^\nu P_{t+\tau} \text{Cov}(\xi_{t-t+\tau}, \xi_{t+\tau}) \) (and \( \rho^d_{t,t} \)) high if marginal cost at date \( t+\tau \) tends to be high in states of the world in which consumption and the price level are low and/or if marginal costs tend to be high in states in which demand for the firm’s product (which is proportional to \( Q_{t+\tau}(\mathcal{P}^d_{t+\tau})^\nu \)) is high (see (2)).
Table 1. Baseline model. Optimized policy rule: $1_{t} = 1 + 4.16(\Pi_{t}/\Pi - 1) - 0.01(Y_{t}/Y - 1)$

<table>
<thead>
<tr>
<th>Sticky prices</th>
<th>Flexible prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shocks to</td>
<td>Shocks to</td>
</tr>
<tr>
<td>$\theta$, $1*_{i}$</td>
<td>$\theta$, $1*_{i}$</td>
</tr>
<tr>
<td>$\varphi$, $P$</td>
<td>$\varphi$, $P$</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>(7)</td>
<td>(8)</td>
</tr>
<tr>
<td>(10)</td>
<td>(11)</td>
</tr>
</tbody>
</table>

### Standard deviations (in %)

| Y  | 2.20 | 2.05 | 0.23 | 0.63 | 0.41 | 2.57 | 2.44 | 0.21 | 0.71 | 0.28 | 1.43 |
| C  | 2.13 | 1.49 | 0.49 | 1.25 | 0.69 | 2.87 | 1.39 | 0.65 | 2.26 | 0.87 | 1.42 |
| I  | 4.56 | 3.06 | 1.11 | 2.77 | 1.57 | 6.92 | 2.98 | 1.56 | 5.69 | 2.03 | 5.38 |
| $\Pi$ | 0.17 | 0.04 | 0.03 | 0.16 | 0.04 | 0.34 | 0.03 | 0.05 | 0.33 | 0.06 | 0.67 |
| $\Pi_{d}$ | 0.23 | 0.13 | 0.06 | 0.15 | 0.08 | 2.10 | 0.39 | 0.41 | 1.95 | 0.50 | 0.74 |
| i  | 0.74 | 0.20 | 0.15 | 0.67 | 0.18 | 1.42 | 0.18 | 0.22 | 1.37 | 0.25 | 0.71 |
| de | 6.46 | 0.87 | 1.12 | 6.06 | 1.73 | 5.48 | 0.88 | 1.02 | 5.04 | 1.67 | 5.25 |
| RER | 6.75 | 2.33 | 1.49 | 5.83 | 1.96 | 5.86 | 2.51 | 1.36 | 4.79 | 1.81 | 8.63 |
| CA | 2.18 | 0.14 | 0.53 | 1.99 | 0.71 | 1.54 | 0.24 | 0.39 | 1.37 | 0.51 | 0.95 |
| NFA | 16.50 | 3.22 | 5.22 | 12.97 | 8.42 | 13.52 | 4.51 | 4.33 | 10.06 | 6.51 | 13.84 |
| $\mu_{d}$ | 1.50 | 0.60 | 0.43 | 1.18 | 0.55 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $\mu_{x}$ | 8.18 | 1.76 | 1.76 | 7.25 | 2.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $\mu_{m}$ | 6.56 | 1.16 | 1.33 | 6.11 | 6.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

### Means (% change relative to deterministic steady state)

| Y  | 0.01 | -0.01 | -0.00 | 0.02 | -0.00 | -0.05 | 0.00 | -0.01 | -0.01 | -0.03 | -0.02 |
| C  | 0.36 | -0.01 | 0.03 | 0.21 | 0.12 | 0.39 | -0.01 | 0.03 | 0.27 | 0.09 |
| I  | 0.33 | 0.01 | 0.02 | 0.20 | 0.09 | 0.33 | 0.01 | 0.02 | 0.24 | 0.06 |
| Q$^{d}$ | 0.13 | -0.01 | 0.01 | 0.08 | 0.04 | 0.15 | 0.00 | 0.01 | 0.10 | 0.03 |
| Q$^{m}$ | 0.92 | 0.01 | 0.08 | 0.53 | 0.29 | 1.10 | 0.01 | 0.08 | 0.77 | 0.23 |
| Q$^{x}$ | -0.75 | -0.07 | -0.06 | -0.26 | -0.35 | -0.54 | 0.00 | -0.05 | -0.34 | -0.15 |
| L  | -0.06 | 0.00 | -0.01 | -0.02 | -0.03 | -0.15 | -0.00 | -0.01 | -0.09 | -0.04 |
| K  | 0.29 | -0.00 | 0.02 | 0.19 | 0.09 | 0.25 | -0.00 | 0.02 | 0.18 | 0.05 |
| RER | -0.62 | -0.06 | -0.06 | -0.29 | -0.20 | -0.71 | -0.03 | -0.06 | -0.45 | -0.16 |
| NFA | 21.72 | 0.03 | 1.12 | 17.12 | 3.44 | 23.50 | 0.05 | 1.21 | 18.43 | 3.79 |
| $\mu_{d}$ | 0.04 | 0.01 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $\mu_{x}$ | 0.47 | 0.07 | 0.01 | 0.13 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $\mu_{m}$ | 0.05 | 0.03 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

### Welfare (% equivalent variation in consumption)

| $\zeta$ | 0.39 | -0.02 | 0.04 | 0.22 | 0.14 | 0.46 | -0.02 | 0.04 | 0.31 | 0.12 |
| $\zeta^{m}$ | 0.41 | -0.01 | 0.04 | 0.23 | 0.14 | 0.50 | -0.01 | 0.04 | 0.34 | 0.12 |
| $\zeta^{v}$ | -0.02 | -0.01 | -0.00 | -0.01 | -0.00 | -0.04 | -0.01 | -0.00 | -0.03 | -0.00 |

Notes: Y: GDP; C: consumption; I: investment; $\Pi$: inflation rate (final good); $\Pi$: growth rate of domestic producer price index; $i$: nominal interest rate; $\Pi$: nominal exchange rate depreciation; RER: real exchange rate; CA: current account; NFA: net foreign assets (CA and NFA: expressed in in units of foreign good (valued at P) and normalized by steady state GDP). $\mu$, $\mu^{d}$, $\mu^{x}$: markups of average domestic producers in the domestic market and in the export markets and markup of average importer; $Q^{d}$: domestic intermediate goods sold domestically and exported; $Q^{m}$: imports; L: hours worked; K: capital stock; $\zeta$, $\zeta^{m}$, $\zeta^{v}$: welfare measures. G3 Data (Col. 11): average of statistics for Japan, Germany and U.K.
Table 2. Baseline sticky prices structure with fixed exchange rate

<table>
<thead>
<tr>
<th></th>
<th>Sticky prices</th>
<th>Flex-prices</th>
<th></th>
<th></th>
<th>G3 Data 1959-70</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shocks to</td>
<td>Shocks to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\psi_P$, $\theta_i$, $\theta^<em>_{i</em>}$</td>
<td>$\psi_P$, $\theta_i$, $\theta^<em>_{i</em>}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>($1$)</td>
<td>($2$)</td>
<td>($3$)</td>
<td>($4$)</td>
<td>($5$)</td>
</tr>
<tr>
<td>Standard deviations (in %)</td>
<td>($7$)</td>
<td>($8$)</td>
<td>($9$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Y$</td>
<td>5.52</td>
<td>2.78</td>
<td>1.61</td>
<td>1.11</td>
<td>4.76</td>
</tr>
<tr>
<td>$C$</td>
<td>6.66</td>
<td>2.92</td>
<td>0.89</td>
<td>1.49</td>
<td>5.98</td>
</tr>
<tr>
<td>$I$</td>
<td>16.95</td>
<td>7.42</td>
<td>1.81</td>
<td>3.75</td>
<td>15.24</td>
</tr>
<tr>
<td>$\Pi$</td>
<td>0.96</td>
<td>0.81</td>
<td>0.25</td>
<td>0.16</td>
<td>0.51</td>
</tr>
<tr>
<td>$\Pi^d$</td>
<td>1.17</td>
<td>0.91</td>
<td>0.36</td>
<td>0.23</td>
<td>0.73</td>
</tr>
<tr>
<td>$i$</td>
<td>3.86</td>
<td>0.59</td>
<td>0.02</td>
<td>0.59</td>
<td>3.82</td>
</tr>
<tr>
<td>$de$</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>$RER$</td>
<td>3.01</td>
<td>2.36</td>
<td>1.72</td>
<td>0.71</td>
<td>1.96</td>
</tr>
<tr>
<td>$CA$</td>
<td>2.49</td>
<td>1.00</td>
<td>0.14</td>
<td>0.58</td>
<td>2.27</td>
</tr>
<tr>
<td>$NFA$</td>
<td>18.00</td>
<td>11.23</td>
<td>2.91</td>
<td>5.55</td>
<td>14.07</td>
</tr>
<tr>
<td>$\mu^d$</td>
<td>9.58</td>
<td>4.22</td>
<td>1.94</td>
<td>2.01</td>
<td>8.60</td>
</tr>
<tr>
<td>$\mu^X$</td>
<td>9.58</td>
<td>4.22</td>
<td>1.94</td>
<td>2.01</td>
<td>8.60</td>
</tr>
<tr>
<td>$\mu^m$</td>
<td>1.16</td>
<td>1.16</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Means (% change relative to deterministic steady state)

|                  | ($1$)        | ($2$)        | ($3$)            | ($4$)            | ($5$)          | ($6$)          | ($7$)        | ($8$)        | ($9$)        |
| $Y$              | -0.09        | -0.08        | -0.03            | -0.01            | -0.01          | -0.05          | -0.05        | -0.03        |                 |
| $C$              | -0.17        | -0.15        | -0.04            | 0.02             | -0.01          | -0.13          | 0.39         | 0.12         |                 |
| $I$              | 0.44         | -0.06        | -0.03            | 0.04             | 0.50           | -0.07          | 0.33         | 0.09         |                 |
| $Q^d$            | -0.47        | -0.29        | -0.06            | -0.01            | -0.17          | -0.22          | 0.15         | 0.05         |                 |
| $Q^m$            | 0.85         | 0.23         | 0.04             | 0.10             | 0.61           | 0.09           | 1.10         | 0.33         |                 |
| $Q^X$            | -0.87        | -0.58        | -0.09            | -0.07            | -0.28          | -0.41          | -0.54        | -0.20        |                 |
| $L$              | -0.01        | -0.02        | 0.00             | -0.01            | 0.01           | -0.01          | -0.15        | -0.06        |                 |
| $K$              | -0.10        | -0.16        | -0.03            | 0.01             | 0.06           | -0.14          | 0.25         | 0.06         |                 |
| $RER$            | -1.39        | -0.72        | -0.11            | -0.09            | -0.67          | -0.51          | -0.71        | -0.25        |                 |
| $NFA$            | 20.85        | 4.38         | 0.02             | 1.08             | 16.46          | 3.27           | 23.50        | 5.06         |                 |
| $\mu^d$          | 1.45         | 0.50         | 0.08             | 0.06             | 0.95           | 0.35           | 0.00         | 0.00         |                 |
| $\mu^X$          | 0.66         | 0.37         | 0.08             | 0.02             | 0.29           | 0.27           | 0.00         | 0.00         |                 |
| $\mu^m$          | 0.29         | 0.29         | 0.00             | 0.00             | 0.00           | 0.29           | 0.00         | 0.00         |                 |

Welfare (% equivalent variation in consumption)

|                  | ($1$)        | ($2$)        | ($3$)            | ($4$)            | ($5$)          | ($6$)          | ($7$)        | ($8$)        | ($9$)        |
| $\zeta^y$        | -0.38        | -0.18        | -0.04            | 0.02             | -0.20          | -0.15          | 0.46         | 0.14         |                 |
| $\zeta^m$        | -0.16        | -0.14        | -0.04            | 0.03             | -0.02          | -0.12          | 0.50         | 0.16         |                 |
| $\zeta^v$        | -0.22        | -0.04        | -0.00            | -0.01            | -0.18          | -0.02          | -0.04        | -0.01        |                 |

Notes: The pegged rate model assumes $\Gamma_{\pi}=\Gamma_{\gamma}=0$, $\Gamma_{\epsilon}=10^8$ (see (38)).
See Table 1 for further information.
Table 3. Baseline model: % responses to 1 standard deviation innovations

(a) Baseline sticky-prices model

| (i) Productivity shock | $\tau=0$ | 0.66 | 0.69 | 1.50 | -0.43 | -0.02 | -0.09 | -0.01 | 0.85 | 0.87 | -0.11 | 1.00 |
| (i) Productivity shock | $\tau=4$ | 0.58 | 0.42 | 0.87 | -0.13 | -0.07 | -0.26 | -0.16 | 0.54 | 0.61 | -0.05 | 0.65 |
| (i) Productivity shock | $\tau=24$ | 0.13 | 0.04 | -0.00 | 0.01 | -0.15 | -0.23 | -0.50 | 0.02 | 0.17 | -0.01 | 0.08 |
| (ii) World interest rate shock | $\tau=0$ | -0.18 | -0.29 | -0.76 | -0.24 | 0.02 | -0.02 | 0.38 | 1.03 | 1.01 | 0.10 | 0.40 |
| (ii) World interest rate shock | $\tau=4$ | 0.02 | -0.06 | -0.14 | 0.03 | 0.07 | 0.02 | 1.02 | 0.25 | 0.18 | 0.03 | 0.12 |
| (ii) World interest rate shock | $\tau=24$ | -0.02 | 0.05 | 0.06 | -0.02 | 0.10 | 0.13 | 0.69 | -0.00 | -0.10 | -0.00 | 0.00 |
| (iii) UIP shock | $\tau=0$ | -0.53 | -0.87 | -2.30 | -0.70 | 0.13 | -0.02 | 1.70 | 5.15 | 5.02 | 0.56 | 3.30 |
| (iii) UIP shock | $\tau=4$ | 0.12 | 0.08 | 0.15 | 0.19 | 0.27 | 0.24 | 2.77 | 0.19 | -0.08 | 0.04 | 0.20 |
| (iii) UIP shock | $\tau=24$ | -0.04 | 0.10 | 0.12 | -0.05 | 0.26 | 0.34 | 1.44 | 0.06 | -0.20 | -0.00 | 0.00 |
| (iv) Shock to foreign price level | $\tau=0$ | 0.28 | 0.35 | 1.01 | 0.37 | -0.02 | 0.04 | -0.48 | -1.71 | -1.19 | -0.11 | 0.50 |
| (iv) Shock to foreign price level | $\tau=4$ | 0.09 | 0.07 | 0.26 | 0.09 | -0.09 | -0.01 | -1.43 | -2.07 | -0.30 | -0.05 | 1.68 |
| (iv) Shock to foreign price level | $\tau=24$ | 0.04 | -0.08 | -0.11 | 0.05 | -0.11 | -0.18 | -1.20 | -2.44 | 0.16 | 0.00 | 2.49 |

(b) Flex-prices variant of model

| (i) Productivity shock | $\tau=0$ | 1.00 | 0.63 | 1.45 | 0.01 | -0.01 | -0.39 | -0.11 | 0.87 | 0.88 | -0.09 | 1.00 |
| (i) Productivity shock | $\tau=4$ | 0.68 | 0.40 | 0.87 | 0.01 | -0.06 | -0.34 | -0.45 | 0.59 | 0.65 | -0.05 | 0.65 |
| (i) Productivity shock | $\tau=24$ | 0.12 | 0.03 | 0.01 | -0.01 | -0.14 | -0.22 | -0.68 | 0.06 | 0.20 | -0.01 | 0.08 |
| (ii) World interest rate shock | $\tau=0$ | 0.13 | -0.44 | -1.10 | 0.17 | 0.04 | -0.35 | 0.26 | 0.94 | 0.90 | 0.16 | 0.40 |
| (ii) World interest rate shock | $\tau=4$ | 0.01 | -0.10 | -0.25 | 0.03 | 0.11 | 0.03 | 0.77 | 0.28 | 0.17 | 0.05 | 0.12 |
| (ii) World interest rate shock | $\tau=24$ | -0.02 | 0.04 | 0.07 | -0.02 | 0.14 | 0.17 | 0.60 | 0.05 | -0.09 | -0.00 | 0.00 |
| (iii) UIP shock | $\tau=0$ | 0.61 | -1.98 | -5.09 | 0.80 | 0.29 | -1.46 | 1.15 | 4.33 | 4.04 | 1.22 | 3.30 |
| (iii) UIP shock | $\tau=4$ | -0.05 | -0.02 | -0.03 | -0.00 | 0.05 | 0.58 | 2.07 | 0.48 | -0.07 | 0.07 | 0.20 |
| (iii) UIP shock | $\tau=24$ | 0.04 | 0.07 | 0.14 | -0.04 | 0.56 | 0.63 | 1.19 | 0.38 | -0.18 | -0.00 | 0.00 |
| (iv) Shock to foreign price level | $\tau=0$ | 0.16 | 0.54 | 1.32 | -0.21 | -0.04 | 0.44 | -0.32 | -1.65 | -1.11 | -0.16 | 0.50 |
| (iv) Shock to foreign price level | $\tau=4$ | -0.03 | 0.17 | 0.41 | -0.06 | 0.12 | 0.01 | -1.03 | -2.11 | -0.31 | -0.06 | 1.68 |
| (iv) Shock to foreign price level | $\tau=24$ | 0.03 | -0.05 | -0.10 | 0.03 | -0.17 | -0.23 | -0.94 | -2.53 | 0.13 | 0.00 | 2.49 |

Notes--\(\tau\); periods after shock. Columns labelled Y, C etc. show responses of corresponding variables. Y: GDP; C: consumption; I: investment; L: hours; P: price level (price final good); $P^d$: domestic producer price index; NFA: net foreign assets, in units of foreign good (valued at $P$), normalized by steady state GDP; e/RER: nominal/real exchange rate; i/w: domestic/world interest rate; $\theta$: productivity; $\varphi$: UIP shock; $P$: foreign price level. At given date, say T, all state variables are set at steady state values. For each variable, a 'baseline trajectory' is computed (using (30), (31)) by setting all exogenous innovations to zero in periods $t>T$. Then responses to a one-time 1 standard deviation innovation at T are computed (no further innovations in $t>T$). Responses are expressed as relative (%) deviations from baseline (NFA responses: expressed in % units of steady state GDP; interest rate responses: absolute difference from baseline). (Responses for non-linear system closely resemble responses based on linearized model.)
Table 4. Further variants of sticky-prices model

<table>
<thead>
<tr>
<th>Policy parameters</th>
<th>$\lambda=0.1$</th>
<th>PCP</th>
<th>$\Pi^3$ Targeting</th>
<th>PTM</th>
<th>PCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G$</td>
<td>4.97</td>
<td>2.42</td>
<td>3.01</td>
<td>1.52</td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td>-0.02</td>
<td>0.13</td>
<td>-0.01</td>
<td>-0.06</td>
<td></td>
</tr>
<tr>
<td>$\Gamma_e$</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard deviations (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y$</td>
</tr>
<tr>
<td>$C$</td>
</tr>
<tr>
<td>$I$</td>
</tr>
<tr>
<td>$\Pi^d$</td>
</tr>
<tr>
<td>$\Pi^d$</td>
</tr>
<tr>
<td>$i$</td>
</tr>
<tr>
<td>$de$</td>
</tr>
<tr>
<td>$RER$</td>
</tr>
<tr>
<td>$CA$</td>
</tr>
<tr>
<td>$NFA$</td>
</tr>
<tr>
<td>$\mu^d$</td>
</tr>
<tr>
<td>$\mu^x$</td>
</tr>
<tr>
<td>$\mu^m$</td>
</tr>
</tbody>
</table>

Means (% change relative to deterministic steady state)

<table>
<thead>
<tr>
<th>$y$</th>
<th>0.07</th>
<th>-0.05</th>
<th>-0.06</th>
<th>0.01</th>
<th>-0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C$</td>
<td>-0.08</td>
<td>-0.22</td>
<td>0.33</td>
<td>0.35</td>
<td>0.38</td>
</tr>
<tr>
<td>$I$</td>
<td>0.04</td>
<td>-0.17</td>
<td>0.39</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>$Q^d$</td>
<td>-0.03</td>
<td>-0.26</td>
<td>0.02</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>$Q^m$</td>
<td>-0.12</td>
<td>-0.09</td>
<td>1.21</td>
<td>0.86</td>
<td>1.12</td>
</tr>
<tr>
<td>$Q^x$</td>
<td>0.02</td>
<td>-0.30</td>
<td>-0.85</td>
<td>-0.74</td>
<td>-0.56</td>
</tr>
<tr>
<td>$L$</td>
<td>0.10</td>
<td>0.02</td>
<td>0.12</td>
<td>-0.07</td>
<td>-0.16</td>
</tr>
<tr>
<td>$K$</td>
<td>0.02</td>
<td>-0.20</td>
<td>0.22</td>
<td>0.28</td>
<td>0.23</td>
</tr>
<tr>
<td>$RER$</td>
<td>0.10</td>
<td>-0.38</td>
<td>-0.82</td>
<td>7.63</td>
<td>-0.74</td>
</tr>
<tr>
<td>$NFA$</td>
<td>0.01</td>
<td>0.02</td>
<td>23.97</td>
<td>21.79</td>
<td>23.65</td>
</tr>
<tr>
<td>$\mu^d$</td>
<td>0.02</td>
<td>0.30</td>
<td>0.31</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>$\mu^x$</td>
<td>0.32</td>
<td>0.28</td>
<td>0.31</td>
<td>0.45</td>
<td>0.01</td>
</tr>
<tr>
<td>$\mu^m$</td>
<td>0.04</td>
<td>0.27</td>
<td>0.31</td>
<td>0.19</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Welfare (% equivalent variation in consumption)

<table>
<thead>
<tr>
<th>$\zeta$</th>
<th>-0.17</th>
<th>-0.25</th>
<th>0.34</th>
<th>0.39</th>
<th>0.47</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\zeta^m$</td>
<td>-0.16</td>
<td>-0.24</td>
<td>0.42</td>
<td>0.41</td>
<td>0.51</td>
</tr>
<tr>
<td>$\zeta^v$</td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.08</td>
<td>-0.02</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

Col. 1, 3, 5, 6: optimized Taylor-rule policy rule (four shocks).
Col. 2, 4: pegged exchange rate (no UIP shocks).
See Table 1 for further information.
REFERENCES


Rogoff, K., 2000, Monetary Models of Dollar/Yen/Euro Nominal Exchange Rates: Dead or UnDead?, manuscript, Dept. of Economics, Harvard University.


