Nominal rigidities, distribution costs and the dynamics of the real exchange rate: a Bayesian DSGE approach

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Abstract

In this paper we estimate several specifications of a two-country new open economy macroeconomics (NOEM) model with the objective of analyzing the dynamics of the euro-dollar real exchange rate. The model features home bias, nontradable goods and incomplete international financial markets; we estimate versions of it with and without international price discrimination, with and without a distribution sector (intensive in local nontradable goods), with and without nominal rigidities. Nominal rigidities, either in the form of LCP or PCP, turn out to be crucial to fit the data and, in particular, the high volatility of the real exchange rate; the PCP model achieves this result with an unrealistic degree of home bias. The exchange rate pass-through is estimated to be low at the border and at the consumer level and all the frictions introduced in the complete model - local currency pricing, distribution services and home bias - are empirically important. The variance decomposition of the real exchange rate shows that international price discrimination is the main economic driving force and that UIP shocks are the main exogenous forcing process behind its volatility. The other real and nominal variables are mainly driven by technology and preference shocks.

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1 Introduction

Following the path-breaking paper of Obstfeld and Rogoff (1995), several authors have built open economy models with imperfect competition, nominal rigidities and micro-founded agents behaviour. While much work has been done on the theoretical side of these 'New Open Economy Macroeconomics' (NOEM) models, the empirical side has only recently gained interest among researchers, thanks to the advances in computational and econometric techniques. This is a welcome development especially among policy circles since it will be the empirical performance of this new class of models to ultimately decide whether they will replace the time-honored Mundell-Fleming-Dornbusch framework as the main tool for understanding the international transmission of shocks and for formulating policy advice.

Recently there have been some important advances in the empirical literature. Bergin (2004) estimated, using maximum likelihood techniques, a model with local currency pricing, shocks to the uncovered interest parity and incomplete markets, and was able to explain the exchange rate dynamics to some extent. This particular empirical dimension has traditionally proved a tough test to pass with *pre-NOEM* models which, when taken to the data, were unable to explain the high exchange rate volatility apparently unrelated to the volatility of other macroeconomic variables (the so called 'disconnect puzzle'). In a well known paper, Meese and Rogoff (1983) showed how a range of macroeconomic models was unable to beat the random walk in forecasting the nominal exchange rate; more than 10 years later, Flood and Rose (1999) suggested that macroeconomic models should not be used to explain exchange rate movements.

Following Bergin's contribution we analyze the dynamics of the euro-dollar real exchange rate using a NOEM model estimated with Bayesian techniques. We contribute to the debate by trying to assess how empirically relevant the various features of a typical NOEM model are in order to explain the real exchange rate behaviour. We focus on three partly overlapping dimensions: (i) nominal rigidities, (ii) international price discrimination (iii) the presence of a distribution sector intensive in local non tradable goods. To do this we build a two-country NOEM model in which we include elements necessary to address the questions of interest and we estimate it with and without: (a) nominal rigidities, (b) international price discrimination in the tradable sector, (c) distribution services.

Two main features are common to all model speifications: home bias in preferences and non tradable goods: These features, together with international price discrimination, are the determinants of real exchange rate movements. Regarding home bias, several contributions in the literature emphasize its relevance to generate real exchange rate volatility with respect to fundamentals and deviations from the PPP condition. The role of non tradable goods in the explanation of the observed behaviour of prices and exchange rates is still debated. Chari, Kehoe and McGrattan (2002) in a fundamental contribution to the DSGE literature observe that empirically the real exchange rate dynamics is mainly determined by rigidities in tradable goods prices so that the inclusion of a non tradable sector in a model is unnecessary. Burnstein, Eichenbaum and Rebelo (2005), by carefully measuring import and export prices, reach opposite conclusions. Given this lack of consensus, we decided to allow for all three sources of real exchange rate dynamics and measure their relative importance by comparing results obtained with different model specifications.

The distribution sector is introduced as in Corsetti, Dedola and Leduc (2006): firms producing tradables need local nontradable goods to deliver their product to the final consumers and this introduces a wedge between producer and consumer prices of tradable goods. Firms in the tradable sector recognize the need to pay for this additional component and, given that the prices of nontradables need not be the same across countries, find it optimal to set different prices in the domestic and in the foreign markets.

Model specifications differ for the hypothesis concerning firms pricing behaviour, as well as with respect to the way in which nominal rigidities enter into the firms'pricing problem. A basic version of the model features flexible prices and wages, but still retains the assumption of a distribution sector, thus leaving a source of international price discrimination.

A second version simply adds sticky wages to this specification, since in estimated closed economy DSGE models the presence of wage rigidities proved to be an important feature to fit the data (see for example Smets and Wouters 2003).

The remaining three model specifications feature nominal price rigidities introduced in two different ways, depending on the assumption made concerning the currency in which prices are rigid. In one version exporters set their prices in their *home currency* and thus, when exchange rates fluctuate, imported goods prices move one-for-one with it (the *producer currency pricing* or **PCP** model). In the second and third versions exporters set their prices in the *buyers currency* so that the exchange rate pass-through is not complete.[1] Since in our setting international price discrimination can potentially come from two sources, local currency pricing and distribution services, in order to disentangle the differential effect of adding a distribution sector we estimate a version of the model without distribution services (the *local currency pricing* or **LCP** model) and one with both LCP and distribution costs (the *complete model*).

The contemporaneous presence of these two assumptions should limit the transmission of real exchange-rate swings into consumer price movements, consistently with empirical evidence, without assuming a counterfactually high level of import price stickiness. From the estimation of the complete model we also derive a direct measure of the degree of structural pass-through of nominal exchange rate into import prices, both at the consumer and at the producer price level (i.e. at the frontier). These results constitue additional evidence along which the goodness of fit and overall plausibility of the different model

[1] See Devereux & Engel (2000) and Obstfeld & Rogoff (2000) for a discussion of these alternative hypothesis.

specifications can be judged.[2]

The main results of the estimation are the following.

First, data support nominal rigidities: the three NOEM models do an equally good job in reproducing the features of the data, both in terms of overall goodness of fit (based on a Bayesian marginal density test) and in terms of specific moments of interest; on the contrary, the RBC model has the worst performance, given its limited capability of reproducing the empirical persistence found in the data.

Second, the real exchange rate variance breakdown into its main economic determinants along with parameters estimates prove that international price discrimination and home bias are the main determinants of real exchange rate deviations from PPP, at least for the complete and LCP models, where the incomplete pass-through limits the transmission of exchange rate fluctuations to other variables. In the case of the PCP model this is obtained through the home bias, whose estimated value becomes extremely high so as to limit the effects of import prices, which fully react to exchange rate movements, on consumer prices.

Third, the PCP model is the only one able to reproduce the positive correlation between the exchange rate and the terms of trade. In the models featuring local currency pricing, estimates suggest that import prices are indeed more flexible than nominal wages and nontradables prices, but not enough to reproduce the quoted moment.

Fourth, in the three models the relative prices of nontradable goods (which we termed the *internal* real exchange rate) play a limited role in generating real exchange rate fluctuations. However nontradable goods cannot be dismissed: in the complete model the estimate of the distribution margin is around 50%, suggesting that distribution services are an important component in the final sale price of tradables and hence an important source of international price discrimination.

Finally, a forecast error variance decomposition shows that in the complete model about 75% of the real exchange rate variability is explained by the shock to the uncovered interest parity, and the rest by shocks to preferences. Real consumptions, inflation rates and short-term interest rates are, on the contrary, mostly explained by technology and preference shocks. While these results can be seen as simply reaffirming the difficulty of explaining the real exchange rate in terms of "fundamental" shocks, when seen in conjunction with the economic decomposition of the real exchange rate variance they shed some light on the propagation channels built into NOEM models and provide a first (partial) step toward a better understanding of the exchange rate disconnect puzzle.

The paper is organized as follows. Section 2 illustrates the main features of the model in relation to the exchange rate determination. Section 3 describes the solution of the model and its estimation. Section 4 reports and discusses the estimation results. Section

[2]Other contributions that estimate NOEM models using Bayesian techniques are those of Lubik and Schorfheide (2005), Rabanal and Tuesta (2005), Adolfson *et al.* (2004). However, they do not introduce distribution costs or nontradable goods as we do.

5 concludes.

2 Main features of the model

The world economy is composed by two large countries of equal size (the Euro Area and the United States). The two countries are symmetric in terms of technology and tastes, with the notable exception of home bias in preferences. In each of them consumer maximize their utility with respect to leisure and a composite good resulting from the aggregation of non tradable and tradable commodities. The latter can be either imported or produced at home. Monopolistic firms in the two sectors produce a differentiated variety of either tradable or nontradable goods using a linear technology in labor.

The alternative model specifications that we estimate have many of the features proposed in the literature to explain the real exchange rate fluctuations. In this section we discuss how the real exchange rate dynamics can be decomposed into three parts, each one coming from relaxing a different hypothesis behind the purchasing power parity (PPP) condition: the symmetry of preferences across countries, the international law of one price, the possibility of trading all goods. Relaxing at least one of these assumptions guarantees that the PPP condition does not hold, i.e. that the real exchange rate is not constant at some predetermined level. Then we move on to a brief overview of the relevant features of the transmission mechanisms embedded in our economy, focusing on the structure of international financial markets, the monetary policy and the specification of the stochastic processes for the shocks.

2.1 Real exchange rate and nominal rigidities

The real exchange rate of the home country can be defined as[3]:

$$RS_t \equiv \frac{S_t P_t^*}{P_t} \tag{1}$$

where S_t is the nominal exchange rate (units of home currency per unit of foreign currency), P_t^* is the consumption based price index of foreign country (in units of foreign currency), while P_t is the corresponding index for the home country (in units of home currency). The consumption price index P_t^* has the following specification:

$$P_t^* = \left[a_T P_{T,t}^{*1-\phi} + (1 - a_T) P_{N,t}^{*1-\phi} \right]^{\frac{1}{1-\phi}} \qquad \phi > 0 \tag{2}$$

where a_T is the share of tradable goods in the foreign consumption bundle, $P_{T,t}^*$ is their price, $P_{N,t}^*$ is the price of foreign nontradable goods, ϕ is the elasticity of substitution

[3] We adopt the convention that starred variables are expressed in units of the foreign country currency.

between the two types of goods.[4] The corresponding home price index, P_t, has a similar structure (the weight a_T is the same). The utility-based price index of tradables, $P^*_{T,t}$, is:

$$P^*_{T,t} = \left[(1 - a_H)\, P^{*1-\rho}_{H,t} + a_H P^{*1-\rho}_{F,t} \right]^{\frac{1}{1-\rho}} \qquad \rho > 0 \tag{3}$$

where $P^*_{H,t}$ is the price of home country exports, $P^*_{F,t}$ the price of tradables produced and sold in the foreign country and ρ is the elasticity of substitution between domestic and imported goods. The parameter a_H is the weight of the domestic tradables in the tradable consumption expenditure, as long as $a_H > 1/2$, there is home bias in consumption (a similar relation holds for $P_{T,t}$).

We assume that each firm produces, in monopolistic competition, a differentiated brand j.[5] The prices of the brands belonging to the same sector are aggregated according to a Stiglitz-Spencer aggregator:

$$P_{M,t} = \left[\int_0^1 p(j)^{1-\theta_M} dj \right]^{\frac{1}{1-\theta_M}} \qquad \text{where} \quad \theta_M > 1 \quad \text{and} \quad M = H, F, N, N^*$$

where $p(j)$ is the price of the generic brand j and θ_M is the elasticity of substitution across brands of the same sector, which is greater than one.

Nominal rigidities are introduced as in Rotemberg (1996): each firm sets the price of its brand j to maximize the expected profits subject to a standard demand function and quadratic price-adjustment costs. Firms pay this adjustment cost by purchasing a CES aggregated basket of all the goods in the sector they belong to, $D_{M,t}$, with .[6]

$$AC^p_{M,t}(j) = \frac{\kappa^p_M}{2} \left(\frac{p_t(j)}{p_{t-1}(j)} - 1 \right)^2 D_{M,t}. \tag{4}$$

where κ^p_M is the parameter measuring the degree of price stickiness.

The representative household supplies labour under monopolistic competition; setting nominal wages to maximize expected utility, subject to a standard labour demand function and a quadratic wage adjustment cost:

$$AC^p_{W,t}(l) = \frac{\kappa^p_W}{2} \left(\frac{W_t(l)}{W_{t-1}(l)} - 1 \right)^2 D_{L,t} \tag{5}$$

With sticky wages, nominal marginal costs, and therefore prices, respond less to a given shock, increasing inflation persistence in the model.

[4] The price indices are standard. They represent the minimum expenditure needed to buy the corresponding consumption index.

[5] To save on space, in what follows we will refer to home firms. Similar equations hold for foreign firms.

[6] In models where local currency pricing is assumed, firms belonging to tradable sector set two prices, one for each country.

Wage and price rigidities together with LCP and distribution costs characterize the *complete model*. The other models differ for the assumptions on nominal rigidities, on the currency in which price are rigid and on the presence of distribution costs (see Table I)

Table I: Estimated models synoptic table

MODEL	Distribution services	Wages	Prices	Exports invoice currency
All models	Two sectors (T, NT), home bias, incomplete international financial markets			
RBC	*yes*	*flex*	*flex*	
LCP_SW	*yes*	*sticky*	*flex*	*buyers*
LCP	*yes*	*sticky*	*sticky*	*buyers*
PCP	*yes*	*sticky*	*sticky*	*seller*
Complete	*yes*	*sticky*	*sticky*	*buyers*

2.2 The components of the real exchange rate

The home real exchange rate can be decomposed into its main determinants (see Benigno and Thoenissen, 2006). After log-linearization and some algebra we obtain:

$$\begin{aligned} \Delta RS_t &= (1-a_T)(\pi^*_{N,t} - \pi^*_{T,t}) - (1-a_T)(\pi_{N,t} - \pi_{T,t}) + \qquad (6) \\ & \quad +(2a_H - 1)(\pi_{F,t} - \pi_{H,t}) \\ & \quad +a_H\left(\Delta S_t + \pi^*_{F,t} - \pi_{F,t}\right) + (1-a_H)\left(\Delta S_t + \pi^*_{H,t} - \pi_{H,t}\right) \qquad (7) \end{aligned}$$

where ΔRS_t and ΔS_t are the percentage change in the real and nominal exchange rate between period t and $t-1$, $\pi_{T,t}$, $\pi_{H,t}$, $\pi_{F,t}$, $\pi_{N,t}$ represent, respectively, the consumer price inflation rates in the home country of tradable, home tradable, foreign tradable and nontradable goods. The variables with a star represent the corresponding inflation rates in the foreign country. The first two terms in equation (6) can be called "*home*" and "*foreign*" *internal real exchange rate*, respectively; the second row shows the deviations from the international law of one price for the foreign and home tradable good, respectively; finally, the last term is the home bias component of the real exchange rate. We now consider each of them in turn.

2.2.1 The internal real exchange rate

The two terms in the first row of equation (6) represent the part of deviation from the purchasing power parity due to nontradable goods. The importance of nontradables in the explanation of the observed behaviour of the real exchange rate is disputed. Chari *et al.* (2002) find that the fraction of the variance of real exchange rate between U.S. and Europe due to relative prices of nontraded to traded goods is only 1.86 percent. On the contrary, Burstein *et al.* (2005) find that for a wider set of countries and through careful measurement of relative prices they account for roughly 50 percent of the cyclical movements in real exchange rates. In this work we try to give an empirical assessment of the role of relative prices in real exchange rate fluctuations.

In a symmetric equilibrium the optimal nontradable price condition, expressed in log-linearized form (variables with "hat" are log-deviations from steady state levels, variables without the time index are steady state values), has the following form:

$$\hat{\pi}_{N,t} = \beta E_t \hat{\pi}_{N,t+1} - \frac{\theta_N - 1}{\kappa_N} p_N \hat{p}_{N,t} + \frac{\theta_N - 1}{\kappa_N} w \hat{w}_t \tag{8}$$

The inflation rate of nontradable goods at time t, $\hat{\pi}_{N,t}$, is a function of its expected value $E_t\hat{\pi}_{N,t+1}$(β is the deterministic discount rate of the owner of the firm), of the relative price of nontradable goods $\hat{p}_{N,t}$ (in terms of the domestic consumption index) and of the real wage $\hat{w}_t$ (we assume labour is the only input in the productive process).

Note that in our model, the prices of nontradable goods affect the internal real exchange rate not only directly, but also indirectly through changes in tradables prices, induced by distribution costs intensive in local nontraded goods.

2.2.2 Home bias

The second term in equation (6), $(2a_H - 1)(\pi_{F,t} - \pi_{H,t})$, measures the home bias component of the real exchange rate. When the parameter a_H equals 0.5 (no home bias) this term vanishes; when a_H is greater than 0.5 then the higher the home bias, the wider are the changes in the price of the imported good (relative to that of the domestic tradable good) induced by changes in the real exchange rate.[7]

2.2.3 International price discrimination: distribution costs and nominal rigidities

The term $a_H \left(\Delta S_t + \pi^*_{F,t} - \pi_{F,t}\right) + (1 - a_H)\left(\Delta S_t + \pi^*_{H,t} - \pi_{H,t}\right)$ in equation (6) is a measure of international price discrimination: if the law of one price holds (so that the price of a tradable good, when expressed in a common currency, is the same in each country), each of the two terms would be equal to zero. In our model the law of one price does not hold because of two assumptions: distribution costs and price nominal rigidities.

We introduce distribution services as in Corsetti et al (2004): bringing one unit of traded goods to consumers in the home country requires η units of a basket of differentiated nontraded goods:

$$\eta \equiv \left[\int_0^1 \eta(n)^{\frac{\theta_N - 1}{\theta_N}} dn\right]^{\frac{\theta_N}{\theta_N - 1}} \tag{9}$$

[7]See Warnock(2003).

Let $\bar{p}_t(h)$ denote the price of the home tradable brand h expressed in the home currency, at *producer* level. With a competitive distribution sector, the *consumer* price of good h becomes:[8]

$$p_t(h) = \bar{p}_t(h) + \eta P_{N,t} \tag{10}$$

thus distribution services create a wedge between the producer and the consumer price of tradables. Firms in the tradable sector, when setting their prices, will consider the need to pay for additional distribution services intensive in local nontradable goods; since prices of nontradables are not the same across countries, firms producing tradables will discriminate the markets setting (optimally) two different prices, $\bar{p}_t(h)$ and $\bar{p}_t^*(h)$. Note that distribution costs are *per se* sufficient to have international price discrimination. To this real friction, however, we add more standard nominal ones. We also assume that each firm in the tradable sector faces a quadratic cost when adjusting the price $p(h)$ (or $p^*(h)$) where h is the brand sold in the home (foreign) country:

$$AC^p_{H,t}(h) = \frac{\kappa^p_H}{2}\left(\frac{\bar{p}_t(h)}{\bar{p}_{t-1}(h)} - \pi\right)^2 \tag{11}$$

$$AC^{p*}_{H,t}(h) = \frac{\kappa^{p*}_H}{2}\left(\frac{\bar{p}^*_t(h)}{\bar{p}^*_{t-1}(h)} - \pi\right)^2 \tag{12}$$

Note that the degree of stickiness can be different across countries ($\kappa^p_H \neq \kappa^{p*}_H$).

In a symmetric equilibrium, optimal prices satisfy the following log-linearized equations:

1. *Phillips Curve (domestic producer prices inflation)*

$$\begin{aligned} \widehat{\bar{\pi}}_{H,t} = {} & \beta\widehat{\bar{\pi}}_{H,t+1} \\ & -\frac{\theta_T}{\kappa^p_H}\left[\frac{\bar{p}_H}{(\bar{p}_H + \eta p_N)^2}(\eta p_N + w)\right]\widehat{\bar{p}}_{H,t} \\ & +\frac{\theta_T}{\kappa^p_H}\left[\frac{\theta_T \eta p_N}{(\bar{p}_H + \eta p_N)^2}(\bar{p}_H - w)\right]\hat{p}_{N,t} \\ & +\frac{\theta_T}{\kappa^p_H} w \frac{\widehat{w}_t}{\bar{p}_H + \eta p_N} \end{aligned} \tag{13}$$

2. *Home exports Phillips Curve (at the border):*

$$\begin{aligned} \widehat{\bar{\pi}}^*_{H,t} = {} & \beta\widehat{\bar{\pi}}^*_{H,t+1} \\ & -\frac{\theta_T}{\kappa^{p*}_H}\left[\frac{\bar{p}_H}{(\bar{p}_H + \eta p_N)^2}(\eta p_N + w)\right]\widehat{\bar{p}^*_{H,t}} \\ & +\frac{\theta_T}{\kappa^{p*}_H}\left[\frac{\theta_T \eta p_N}{(\bar{p}_H + \eta p_N)^2}(\bar{p}_H - w)\right]\widehat{p^*_{N,t}} \\ & +\frac{\theta_T}{\kappa^{p*}_H} w \frac{\widehat{w}_t}{\bar{p}_H + \eta p_N} - \frac{\theta_T}{\kappa^{p*}_H} w \frac{\widehat{RS}_t}{\bar{p}_H + \eta p_N} \end{aligned} \tag{14}$$

[8] Similar equations hold for the foreign tradable goods.

In each country the home good producer price inflation depends on the relative price of local nontradable goods. International price discrimination results from nominal rigidities and distribution services. In absence of distribution costs ($\eta = 0$), the only source of international price discrimination would be the LCP hypothesis.

From these pricing equations we can also derive a structural coefficient measuring the degree of the pass-through of nominal exchange rate into import prices (ERPT). From equation (13), after some algebra, a structural coefficient measuring the *short run pass-through at the border* can be obtained:

$$\widehat{p^*_{H,t}} = ... - \theta_T w \frac{1}{\bar{p}_H + \eta p_N} \left\{ [\kappa_H^{p*} (1+\beta)] + \theta_T \bar{p}_H \left[\frac{(\eta p_N + w)}{(\bar{p}_H + \eta p_N)^2} \right] \right\}^{-1} \hat{S}_t \qquad (15)$$

Structural ERPT is the percentage change in import prices - denominated in local currency - resulting from a one percent change in the bilateral exchange rate, **other things equal**. An higher pass-through implies that fluctuations of the nominal exchange rate are transmitted to a greater extent to import prices, in the limiting case, when the pass-through is complete (*i.e.* equal to 1) the fluctuations are transmitted one for one into import prices. In our framework, the degree of pass-through is affected by nominal rigidities and by distribution services. Each of these two features is *per se* sufficient to generate an incomplete pass-through. Estimating the model we are able to quantify the degree of short run pass-through and the role of nominal rigidities and distribution costs rather than just "calibrate" it. The *long run structural pass-through coefficients* do not depend upon nominal rigidities and can be obtained setting the adjustment costs parameters, κ_H^p and κ_H^{P*}, to zero, as we do in the "RBC" model.

2.3 Incomplete international financial markets

We assume that households belonging to the *home country* can allocate their wealth among *two bonds*. Both bonds are risk-free with one-period maturity. One is denominated in domestic currency and the other in foreign currency. In contrast, households that belonging to the *foreign country* can allocate their wealth only in *one risk-free nominal bond* denominated in the foreign currency.

The budget constraint of representative home agent is:

$$\begin{aligned} & \frac{B_{H,t}}{(1+R_t)} + \frac{S_t B_{F,t}}{(1+R_t^*)\Phi(\frac{S_t B_{F,t}}{P_t}) Z_{UIP,t}} \\ & - B_{H,t-1} - S_t B_{F,t-1} \\ \leq \; & \Pi_{H,t} + \Pi_{N,t} \\ & + W_t L_t - P_t C_t - AC_t^W L_t \end{aligned} \qquad (16)$$

B_H are the nominal holdings of "home" bond, which pay an interest rate R_t and B_F are the nominal holdings of the "foreign" bond, which pays a nominal interest R_t^*. Following

Benigno (2001), domestic households take $\Phi(.)$ as given when choosing foreign bonds' holdings. We introduce this additional cost, which can be interpreted as a risk premium, to pin down a well defined steady state for consumption and assets and add a risk premium shock $Z_{UIP,t}$ to allow for exogenous variations in international financial markets conditions.[9] Households derive income from interests on bond holdings, from labor L_t supplied in a monopolistic competitive regime (facing a quadratic adjustment cost AC_t^W in setting wages W_t) and from profits, $\Pi_{H,t} + \Pi_{N,t}$ arising from ownership of home country firms.

Given our financial structure, agents optimal decision concerning home and foreign bonds holdings lead to a modified uncovered interest parity rule:

$$\hat{R}_t - \hat{R}_t^* + \phi(\hat{b}_t) - Z_{UIP,t} = E_t\left(\Delta S_{t+1}\right)$$

that links the expected variations in nominal exchange rate to the interest rate differential and to the risk premium (UIP) shock. The term $\phi(\hat{b}_t)$ is the obtained by loglinearizing the risk premium term $\Phi(.)$. The uncovered interest parity allows the systematic part of monetary policy (the Taylor rule) to affect the behaviour of the nominal (and real) exchange rate[10].

When international asset trade is limited to riskless bonds, the relation between the real exchange rate and marginal utilities of consumption holds only in expected values and the log-linearized Euler equation derived from the solution of the consumer problem is:

$$\begin{aligned} E_t\left[\widehat{RS}_{t+1} - \widehat{RS}_t\right] &= E_t\left[\sigma_C(\hat{C}_{t+1} - \hat{C}_t) - (Z_{P,t+1} - Z_{P,t})\right] - \\ & \quad E_t\left[\sigma_C(\hat{C}_{t+1}^* - \hat{C}_t^*) - \left(Z_{P,t+1}^* - Z_{P,t}^*\right)\right] + \phi(\hat{b}_t) - Z_{UIP,t} \quad (17) \end{aligned}$$

where $Z_{UIP,t}$ is the autocorrelated risk premium shock while $Z_{P,t}$ and $Z_{P,t}^*$ are preference (demand) shocks, affecting directly the agents'utility. Since the bond is traded only after a given shock is realized, in the impact period the above equation does not necessarily hold and the correlation between real exchange rate and relative consumption can be, consistently with empirical evidence, negative. The sign of impact correlation depends on the parameters values.[11]

2.4 Monetary Policy

When monetary policy is conducted in an "inertial" way, so that the adjustment of the instrument toward its target is smoothed over time, the real exchange rate exhibits persistence because, through the interest rate differential (the uncovered interest parity con-

[9] See Schmitt-Grohé and Uribe (2000).

[10] In particular the persistence (more details are given in the next section).

[11] Corsetti et al.(2004) show that a sufficiently low degree of substitution between tradable goods, due also to the presence of distribution costs, is key to get a negative correlation on impact.

dition), its adjustment is also smoothed over time. The home monetary policy rule is given by:

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)\,\rho_\pi \hat{\pi}_t + (1-\rho_R)\,\rho_y \hat{y}_t + (1-\rho_R)\,\rho_S \widehat{\Delta S_t} + \varepsilon_{R,t} \tag{18}$$

where R_t is the interest rate set by the central bank, $\hat{\pi}_t$ is the consumer price inflation, $\hat{y}_t$ is total output and the coefficient ρ_R, which assumes values between zero and one, captures inertia in conducting monetary policy: the higher the coefficient, the more inertial is the monetary policy. $\varepsilon_{R,t}$ is an *iid* shock to the monetary policy function (an identical relation with starred variables holds for the foreign country).

2.5 The shock processes

We introduced eleven shocks in the model that are commonly used in calibrated DSGE models. Traditional explanations of the short run real exchange rate volatility rest upon nominal rigidities and monetary shocks, while a combination of preference and technology shocks proved useful in international real business cycle models to match observed correlations between relative prices and quantities.[12] The real exchange rate volatility depends in part on shocks other than the "fundamental" ones (technology and monetary shocks)[13] and the UIP shock, whose structural interpretation is not clear cut, is a convenient way of introducing an exogenous source of variability. We make the following assumptions about the shocks:

- Monetary shocks $\varepsilon_{R,t}$ and $\varepsilon^*_{R,t}$ are independently and identically distributed:

$$\varepsilon_{R,t} \sim iid(0, \sigma_R^2)$$

$$\varepsilon^*_{R,t} \sim iid(0, \sigma_R^{*2})$$

- Each preference shock follows a stationary AR(1) process:

$$Z_{P,t} = \rho_P Z_{P,t-1} + \varepsilon_{P,t}$$

$$Z^*_{P,t} = \rho^*_P Z^*_{P,t-1} + \varepsilon^*_{P,t}$$

  where:

$$\varepsilon_{P,t} \sim iid(0, \sigma_P^2)$$

$$\varepsilon^*_{P,t} \sim iid(0, \sigma_P^{*2})$$

[12] See Stockman and Tesar (1995).

[13] See Meese and Rogoff (1983) and Flood and Rose (1999).

- For simplicity, we assume that in each sector - home tradable, home nontradable, foreign tradable, foreign nontradable - the technology shock follows a stationary AR(1) process:

$$Z_{M,t} = \rho_M Z_{t-1} + \varepsilon_{M,t} \qquad M = H, N, F, N^*$$

where:

$$\varepsilon_{M,t} \sim iid(0, \sigma_M^2)$$

Technology shocks enter into the production functions, which are assumed linear in labour:

$$\hat{Y}_{M,t} = \hat{Z}_{M,t} + \hat{L}_{M,t} \qquad M = H, N, F, N^*$$

where Y_S is output and L_S is labour employed.

- The UIP shock follows an AR(1) process:

$$Z_{UIP,t} = \rho_{UIP} Z_{UIP,t-1} + \varepsilon_{UIP,t}$$

where

$$\varepsilon_{UIP,t} \sim iid(0, \sigma_{UIP}^2)$$

- The wage markup shocks are i.i.d:

$$\varepsilon_{W,t} \sim iid(0, \sigma_W^2)$$

$$\varepsilon_{W,t}^* \sim iid(0, \sigma_W^{*2})$$

3 The empirical analysis

Our analysis is based on the estimation of various models that differ in terms of assumptions on nominal rigidities: one model has sticky wages and prices with LCP (the *complete model*); a second model has the same nominal rigidities but PCP is assumed, a third model has LCP but with only sticky wages; finally we also considered a model with flexible wages and prices, that still has two sectors and distribution costs (the *RBC* model; see table I).[14]

3.1 Model solution

Since a closed form solution is not possible, the behaviour of the economy is studied by looking at a loglinear approximation to the model equations in the neighborhood of a deterministic steady state. In this steady state the shocks are set to their mean values,

[14]See Lubik and Schorfheide (2005), Smets and Wouters (2003, 2004a,b) for estimation of DSGE model using data for the euro area and the U. S.

price inflation, wage inflation and exchange rate depreciation are set to zero, interest rates are equal to the agents' discount rate, consumption is equalized across countries, the trade balance is zero. Given the presence of distribution costs, price of nontradable goods is different from that of traded goods; however, prices are symmetric between countries and the real exchange rate is one. The elasticities of substitution between tradable brands (θ_T) and between nontradables (θ_N) are calibrated so that the steady state mark-ups are equal across sectors.

3.2 The Bayesian estimation

The estimation procedure consists of various steps: the transformation of the data into a form suitable for the computation of the likelihood function using the stationary state-space representation of the model; the choice of appropriate prior distributions; the estimation of the posterior distribution with Monte Carlo methods. These steps are discussed in turn in this section.

The Bayesian approach starts form the assertion that *both* the data Y and of the parameters Θ are random variables. Starting from their joint probability distribution $P(Y, \Theta)$ one can derive the fundamental relationship between their marginal and conditional distributions known as Bayes theorem:

$$P(\Theta|Y) \propto P(Y|\Theta) * P(\Theta)$$

Reinterpreting these distributions, the Bayesian approach reduces to a procedure for combining the *a priori* information we have on the model, as summarized in the prior distributions for the parameters $P(\Theta)$, with the information that comes from the data, as summarized in the likelihood function for the observed time series $P(Y|\Theta)$. The resulting *posterior density* of the parameters $P(\Theta|Y)$ can then be used to draw statistical inference either on the parameters themselves or on any function of them or of the original data.

3.2.1 The data

Estimations is based on nine quarterly key macroeconomic variables sampled over the period 1983:1-2005:2: *real consumption*, *CPI inflation, nontradable inflation* and *nominal short-term interest rates* for both countries (the Euro area and the U.S.) and the $euro-dollar$ *real exchange rate*. The model has implications for the log deviations from steady state of all these variables, and thus we transformed them before estimating the model. All series are demeaned and real consumption is detrended by fitting a linear trend to the original series. Seasonality has been removed from those series that were available only in unadjusted form regressing them on a set of seasonal dummies. The euro area is the home country.

3.2.2 Prior distributions and calibrated parameters

A very small number of parameters have been calibrated (4 in the *complete* model) for all the other we have set the means and variances of the prior distributions.[15]

The discount factor β is calibrated at 0.99, implying an annual steady-state real interest of 4%; the elasticity of substitution between nontradable varieties, θ_N, is set equal to 6, while the elasticity of substitution between tradable varieties, θ_T , is endogenously determined so that $\theta_T = \theta_N (1 + \eta)$, which assures that markups are equal across sectors; the parameter of labour disutility, τ, is set equal to 2; the elasticity of substitution between labour varieties, θ_W, to 4.3.

The prior distributions for the estimated parameters in the complete model are shown in Table 1. We assume all distributions to be *a priori* independent.

The share of tradables in the consumption basket, a_T, is set equal to 0.45 (standard deviation 0.1).[16] The share of the home produced goods in the home tradable composite good, a_H, is set is set equal to 0.8 (standard deviation 0.1). The mean of intratemporal elasticity of substitution between home and foreign tradable goods, ϕ, is set equal to 1.14, while the mean of intratemporal elasticity of substitution between tradable and non tradable goods ρ is equal to 0.74. The standard deviation is both cases is set equal to 0.1. The parameter of the premium paid by home agents for their net foreign asset position has a mean equal to 0.01 and a standard deviation of 0.005. The elasticity of marginal utility with respect to consumption σ_C has a mean value equal to 2 (standard deviation 0.2), so that its inverse, which corresponds to the elasticity of intertemporal substitution, is 0.5.

The priors on the coefficients in the monetary policy reaction functions are standard: a relatively high prior mean on the inflation coefficient (1.5, with standard deviation equal to 0.1) helps to guarantee a unique solution path when solving the model, the persistence coefficient mean is set to 0.8 (standard deviation equal to 0.1), the output coefficient is set equal to 0.1 (standard deviation 0.1), the coefficient of nominal exchange rate variation is set equal to zero (with standard deviation equal to 0.1).

Parameters measuring the degree of price stickiness are assumed to have the same mean value, equal to 5.6, with standard deviation equal to 10. Parameter measuring the degree of wage stickiness have a mean value equal to 63, with standard deviation equal to 40.

The autoregressive parameters of the shocks are assumed to follow a beta distribution with mean values set to 0.9. The standard errors have a common value, equal to 0.05. The variances of all shocks and the cross-correlation coefficients of technology shocks have non informative distributions.

[15] The choice of the priors functional forms is rather standard, see table 1 in the appendix. Calibration can be seen as setting a very strict prior.

[16] Stockman and Tesar (1995) suggest that the share of nontradables in the consumption basket of the seven largest OECD countries is roughly 50 percent.

In the sticky wage model, we calibrate the parameters regulating nominal price rigidities to an extremely low value (0.0001). In the RBC model, we also calibrate parameters of wage stickiness equal to such a low value.

3.2.3 Simulating the posterior distribution of the parameters

The computation of the posterior distribution of the estimated parameters cannot be done analytically and thus we resort to Monte Carlo simulations in order to obtain a sample of draws from this distribution that can be used to compute all moments and quantities of interest.[17] We use a Metropolis-Hastings algorithm to explore the parameter space starting from a neighborhood of the posterior mode (found by maximizing the kernel of the posterior using a numerical routine) and then moving around using a random walk "jump distribution" whose covariance matrix is chosen so as to achieve an efficient exploration of the posterior. The algorithm defines a Markov Chain which eventually generates draws coming from the posterior distribution, although the sequence of draws will be correlated; keeping one every n-th draws results in a sub-sample of almost uncorrelated draws which can be used to approximate the posterior distribution.[18]

4 Results

In this section we report the main results of our estimation exercise. It is divided into five parts. First, we show the overall fit of the alternative model specifications and briefly discuss their ability to reproduce the main stylized facts of the real exchange rate dynamics. Then we analyse the posterior estimates of some "key" parameters and next their implications in terms of ERPT. In the fourth part we draw some conmclusion of the estimation results for what concerns the breakdown of the exchange rate volatility. Finally the role of the different shocks in driving the endogenous variables is discussed. Detailed results can be found in the tables in the appendix.

4.1 Goodness of fit and moment matching with real exchange rate

In Bayesian analysis the comparison among alternative models is typically carried out in terms of posterior odds ratio and we follow this approach. Let's assume that we are given two models M_1 and M_2 and that we assign prior probabilities $\pi_{1,0}$ and $\pi_{2,0}$ to the each of

[17] See An and Schorfheide (2005) for a review of Bayesian methods for estimation of DSGE models.

[18] Geweke (1999) reviews regularity conditions that guarantee the convergence to the posterior distribution of the Markov chains generated by the Metropolis-Hastings algorithm. More details on bayesian techniques and DSGE models are in Del Negro et al [2004], Schorfheide [2000], DeJong et al. [2000]. For an applicaton of maximum likelihood methods see Ireland [2004] and Kim [2000].

them, then the posterior odds ratio is defined as the product of the prior odds and the Bayes factor:

$$\frac{\pi_{1,T}}{\pi_{2,T}} = \frac{\pi_{1,0}}{\pi_{2,0}} \times \underbrace{\frac{p\left(Y^T/M_1\right)}{p\left(Y^T/M_2\right)}}_{\textit{Bayes factor}}$$

where $P\left(Y^T/M_i\right)$ is the marginal data density, obtained integrating the posterior kernel over all possible parameters values. Assuming the models are *a priori* equally weighed and adopting Geweke's (1999) harmonic mean approximation to evaluate $P\left(Y^T/M_i\right)$ we obtain the results reported in table 2. There appear to be two clusters: a first group of models, those with nominal price rigidities, have a better overall "fit" compared to the "fully flexible specification" or to the one with only wage stickiness. From this preliminary evidence we can conclude that the data clearly favour models with price rigidities.

Since nominal rigidities seem to be required to achieve a better fit, in the following we focus on the first three specifications (which we name the "complete" model, the "PCP" model and the "LCP" model) and ask whether they are equally able to reproduce the stylized facts concerning the real exchange rate dynamics. As shown in table 3 all three models perform equally well in terms of volatility and persistence of the real exchange rate. Incomplete markets and price rigidities are sufficient to obtain negative correlation between relative consumption and real exchange rate, as in the data, thus avoiding the Backus - Smith puzzle.

Overall, these results show that the models with nominal rigidities are a fairly accurate description of the data and of the real exchange rate movements.

4.2 Posterior estimates

Parameter estimates are overall quite similar across the three specifications (see Table 4).

The home bias parameter estimates are high, and range from 0.9 (complete model) to 0.97 (PCP model). Especially for the PCP model, such a high value is suspicious and should be taken with care: in fact in this case import prices adjust one-for-one with movements of the nominal exchange rate (by hypothesis) and pushing the share of imports in the consumption basket toward one is the model's way to neutralize their effect on domestic inflation. On the other hand, many previous attempts to estimate or calibrate this parameter ended up in the same ballpark of our numbers: both Rabanal and Tuesta (2004) and Lubik and Schorfheide (2005) find a value of 0.87, while Chari et al. (2004) choose 0.984 in their calibration.

The estimates of the LCP and complete models lend strong support to international price discrimination: posterior estimates of the price-adjustment cost parameters for exporting firms (κ_H^* for European exporters and κ_F for U.S. exporters) confirm the empirical relevance of local currency pricing (see Table 5). The frequency of price adjustments in all sectors of the economy are reported in Table 6. In the complete model U.S. import prices at the border change on average once every two quarters (1.5 in the PCP model), while in the Euro area import prices change once every quarter (1.5 in the PCP model). Our numbers are roughly half of those found for the US by Gopinath and Rigobon (2006), who report a trade-weighted average price duration of four quarters for imports; for the Euro area Faruquee et al. (2004) in a VAR analysis reports an average duration of import prices of around three quarters.

International price discrimination is also due to the presence of distribution services. 95% of the probabily mass for the parameter η lies between 0.92 and 1.27 in the complete model, with a median value of 1.08. Corsetti et al. (2006), following Burstein et al. (2003), set η equal to 1.22, to match the share of the retail price of traded goods accounted for by local distribution services in the U.S. (approximately equal to 50%). Nontradable prices are, as expected, more rigid than tradable ones in both countries (and consistently so across specifications; see Table 4). Nontradable goods are relevant not only for their role as distributive services, but also as consumption goods: their median weight in the consumer preferences, $(1 - a_T)$, is not negligible and ranges from 0.37 (PCP model) to 0.46 (LCP model).

As shown in the literature, the preference side of the model is crucial in determining the dynamics of the real exchange rate. The data tend to push the elasticity of substitution between home and foreign tradables (ϕ) slightly above its prior mean (1.1) to 1.2 in all three models, getting close to the value 1.5 set by Chari et al. (2002). Data are also informative about the degree of substitutability between tradable and nontradable goods: ρ is pushed below the prior mean (1.2) to 0.91 in the complete model and 0.75 in the LCP and PCP models. This result is in line with the 0.74 estimated by Mendoza (1991) for a sample of industrialized countries. The coefficient of relative risk aversion σ_C is slightly higher than 2 in all three models.[19]

The ability of the model to reproduce the persistence of the real exchange rate and of other variables hinges, among other things, on the interplay between the degree of monetary policy inertia, the degree of nominal rigidities and the persistence provided exogenously by the shocks. Regarding monetary policy, in both countries the parameter regulating nominal interest rate inertia is pushed up by the data, while they are not informative on the response of U.S. monetary policy to inflation and output. The estimates of wage-adjustment cost parameters are high: according to the PCP and complete models, in both the euro area and the U.S. wages are adjusted every two years and a half; according to the LCP model, they are adjusted roughly once every five quarters.[20] The estimated structural shocks are rather persistent and their volatilities are in line with values used in the literature. In particular, the variances of technology shocks and preferences have roughly the same magnitude as in Stockman and Tesar (1995).

[19]Lubik and Schorfheide (2005) estimate a posterior mean value of σ_C slightly below 4.0; Chari et al. (2002) set it equal to 5.0.

[20]Smets and Weuters (2004) for the U.S. estimate an average length of wage contract equal to five quarters, for the euroarea equal to three quarters.

4.3 The Exchange Rate Pass-Through

To get a sense of what the parameters imply for international relative prices and exchange rate pass-through, we plot the responses to a UIP shock in the complete model.

Figure 1 presents evidence of incomplete ERPT and of international price discrimination. First, pass-through incompleteness at the border is confirmed by the reaction of import prices $\bar{p}^*(h)$ and $\bar{p}(f)$, which is lower than that of the nominal exchange rate. Second, ERPT is even lower at the consumer level: consumer prices of imported goods $p^*(h)$ and $p(f)$ move less than their border counterparts, given the presence of distribution costs. Finally, domestic prices of tradable goods, contrary to export prices, are not significantly affected by the UIP shock.

In Table 7 we report the structural ERPT coefficients (see equation 15). In the short run in the complete model ERPT to import prices at the border is 40 per cent for euro area and 10 per cent for the U.S.; the presence of distribution costs halves the ERPT at the consumer level in both countries. In the long run, as suggested by the RBC model, pass-through is higher and almost complete at the border (90 percent); at consumer level, it is incomplete and roughly equal to 40 percent.

4.4 Decomposing the dynamics of the real exchange rate

Incomplete ERPT at the border and at the consumer level is related to international price discrimination. Table 8 shows the variance breakdown for the real exchange rate changes using equation 6[21]. The main result is the importance of tradable goods price fluctuations: the variance term attributable to the international price discrimination explains around 56 per cent of the whole variance in the complete model, 25 per cent in the LCP model. Home bias is also not negligible, given that it weighs 7.5 per cent in the complete model, 36 per cent in the LCP model and almost 100 per cent in the PCP case. The covariance between home bias and international price discrimination terms plays a significant role in the first two models. The contribution of the internal real exchange rate is small, as shown by the variance and covariance terms in which they are involved. These results are in line with Chari *et al.* (2002) but in our case the importance of nontradable goods is also related to international price discrimination via price setting decisions in tradables sector.

4.5 The role of the different shocks in driving fluctuations

In order to gain some insight on which shocks are driving fluctuations in the model, we computed the asymptotic variance decomposition, which is reported in Table 9.

[21] Variances and covariances, divided by the variance of the real exchange rate changes, are obtained simulating the models.

Slightly more than three quarters of the real exchange rate variance are accounted for by the UIP shock. The remaining part is explained by preference shocks (around 20 per cent). Technology and interest rate shocks are not relevant for RER fluctuations. To the contrary, consumption and nominal interest rate fluctuations are mainly driven by domestic preference shocks, while inflation rates by domestic technology shocks (in particular by the domestic tradable technology shock). Wage shocks are not important, while monetary policy shocks are, to some extent, only relevant for their country interest rate fluctuations.

The prominent role played by the UIP shock in RER volatility is in line with previous empirical results as well as with strong deviations from UIP observed in the data. Also shocks to preferences are to some extent relevant in explaining the RER fluctuations.The UIP shocks do not greatly affect variables other than the RER; this is in line with the empirical evidence of an 'exchange rate disconnect puzzle'.

5 Concluding remarks

This paper gives a contribution to the estimation of New Open Economy Macroeconomic models, fitting several versions of a two-country model to data from the U.S. and the Euro area. The models are able to reproduce the stylized facts of the real exchange rate without sacrificing the matching of other variables. Nominal price rigidities seem an essential part of the story: if they are not introduced, the model lacks the persistence found in the data. The frictions introduced to limit the transmission of the high volatility of the exchange rate to the fundamentals - home bias, local currency pricing and distribution services - are all empirically relevant. As a further and related result, the pass-through is estimated to be rather low at the border and even lower at the consumer level. When pass-through at the border is assumed to be complete (PCP model) the home bias is estimated to be extremely and implausibly high, so as to compensate for the lack of international price discrimination.

When looking at the economic determinants of the real exchange rate variance, pricing-to-market and home bias emerge as empirically relevant mechanisms, while the internal real exchange rate plays almost no role. The "disconnect" between real exchange rate and fundamentals and the capability of the models to reproduce it, is reaffirmed when looking at the forecast error variance decomposition, in which the UIP shock is estimated to be the main forcing process behind real exchange rate fluctuations, followed by preference shocks.

These results stimulate further work. In this paper, consistently with the theoretical NOEM literature, we focused on the relationship between real exchange rate and nominal prices. However more empirical work is needed to test recent development on the relationship between international relative prices and quantities. To this end, we would need to take to the data a richer model with endogenous capital accumulation and investment. This is left for future research.

References

[1] An, Sungbae, and Frank Schorfeide [2005]. “Bayesian Analysis of DSGE Models”, University of Pennsylvania, unpublished.

[2] Adjémian, Stéphane, Matthieu Darracq Pariès, and Frank Smets [2005]. “Structural Analysis of US and EA Businness Cycle”, unpublished.

[3] Adolfson, Malin, Stefan Laseen, Jesper Linde, and Mattias Villani [2004]. “Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through,” Manuscript, Sveriges Riksbank.

[4] Ambler, Steve, Ali Dib and N. Rebei [2004]. “Optimal Taylor Rules in an Estimated Model of a Small Open Economy,” Manuscript, Bank of Canada.

[5] Backus, David K. and Gregory W. Smith [1993]. ”Consumption and Real Exchange Rate in Dynamic Economies with Non Traded Goods”, Journal of International Economics, Vol. 35, pp. 297-316.

[6] Batini, Nicoletta, Alejandro Justiniano, Paul Levine, and Joseph Pearlman [2005]. “Model Uncertainty and the Gains from Coordinating Monetary Rules”, unpublished.

[7] Benigno Gianluca [2004]. “Real Exchange Rate Persistence and Monetary Policy Rules,” Journal of Monetary Economics, 51, 473-502.

[8] Benigno, Pierpaolo [2001]. “Price Stability with Imperfect Financial Integration,” New York University, unpublished.

[9] Benigno, Gianluca and Christoph Thoenissen [2006] “Consumption and Real Exchange Rates with Incomplete Markets and Non-Traded Goods”, CEP Discussion Papers.

[10] Bergin, Paul R. [2003]. “Putting the ‘New Open Economy Macroeconomics’ to a Test,” Journal of International Economics, 60, 3-34.

[11] Bergin, Paul R. [2004]. “How Well Can the New Open Economy Macroeconomics Explain the Exchange Rate and the Current Account?,” Journal of International Money and Finance.

[12] Burstein, Ariel, Martin Eichenbaum and Sergio Rebelo [2005] “The Importance of Nontradable Goods’ Prices in Cyclical Real Exchange Rate Fluctuations”, September, mimeo.

[13] Campa, José M. and Linda S. Goldberg [2002]. ”Exchange Rate Pass-Through into Import Prices: A Macro or Micro Phenomenon ?”, NBER Working Paper No. 8934.

[14] Clarida, Richard, and Jordi Gali [1994]. “Sources of Real Exchange Rate Fluctuations: How Important Are Nominal Shocks?”, Carnegie-Rochester Series in Public Policy 41, 1-56.

[15] Chari, V.V., Patrick Kehoe, Ellen McGrattan [2002]. “Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rate,” Review of Economic Studies, 69, 533-563.

[16] Corsetti, Giancarlo, Luca Dedola and Sylvain Leduc [2004]. “International Risk-Sharing and The Transmission of Productivity Shocks”, Manuscript, European University Institute.

[17] Dedola, Luca, and Sylvain Leduc [2001]. “Why Is the Business-Cycle Behavior of Fundamentals Alike across Exchange-Rate Regimes?,” International Journal of Finance & Economics, 6(4), 401-19.

[18] DeJong, David N., Beth F. Ingram, and Charles H. Whiteman [2000]. “A Bayesian Approach to Dynamic Macroeconomics,” Journal of Econometrics 98, 203-223.

[19] Del Negro, Marco, Frank Schorfheide, Frank Smets, and Raf Wouters [2004]. “On the Fit and Forecasting Performance of New-Keynesian Models,” Federal Reserve Bank of Atlanta, manuscript.

[20] Devereux, Michael B., and Charles Engle [2002]. ”Exchange Rate Pass-Though, Exchange Rate Volatility and Exchange Rate Disconnect”, Journal of Monetary Economics, Vol. 49, pp. 913-940.

[21] Dib, Ali [2003]. “Monetary Policy in Estimated Models of Small Open and Closed Economies,” Bank of Canada Working Paper, 2003-27.

[22] Dornbusch, Rudi [1976]. “Expectations and exchange rate dynamics,” Journal of Political Economy 84, 1161–1176.

[23] Faruquee, Hamid, Douglas Laxton, Dirk Muir and Paolo Pesenti [2005]. ”Smooth Landing or Crash ? Model-based Scenarios of Global Current Account Rebalancing”, mimeo, December.

[24] Flood, Robert, P., Andrew K. Rose [1999]. ”Understanding Exchange Rate Volatility without the Contrivance of Macroeconomics”. The Economic Journal, Vol. 109, No. 459.

[25] Geweke, John [1999]. “Using Simulation Methods for Bayesian Econometric Models: Inference, Development and Communication,” Econometric Reviews, 18, 1-126.

[26] Hairault, Jean-Olivier and Franck Portier [1993]. “Money, New-Keynesian macroeconomics and the business cycle,” European Economic Review, 37(8), 1533-1568.

[27] Ireland, Peter [1997]. "A small, structural, quarterly model for monetary policy evaluation", Carnegie-Rochester Conference Series on Public Policy, 47, 83-108.

[28] Ireland, Peter [2004]. "A Method for Taking Models to the Data," Journal of Economic Dynamics and Control 28(6), 1205-1226.

[29] Justiniano, Alejandro and Bruce Preston [2004]. "Small Open Economy DSGE Models - Specification, Estimation, and Model Fit," Manuscript, International Monetary Fund and Department of Economics,Columbia University.

[30] Lane, Philip [2001]. "The New Open Economy Macroeconomics: A Survey," Journal of International Economics 54, 235-266.

[31] Kim, Jinill, [2000]. "Constructing and estimating a realistic optimizing model of monetary policy," Journal of Monetary Economics 45, 329-359.

[32] Laxton, Doug and Paolo Pesenti [2003]. "Monetary Policy Rules for Small, Open, Emerging Economies," Journal of Monetary Economics, 50, 1109-1146.

[33] Lubik, Thomas, and Frank Schorfheide [2005]. "A Bayesian Look at New Open Economy Macroeconomics," NBER Macroeconomics Annual.

[34] Meese, Richard, A., Kenneth Rogoff [1983]. "Empirical Exchange Rate Models of the Seventies. Do They Fit Out of Sample ?", Journal of International Economics, Vol. 14, pp. 3-24.

[35] Rotemberg, Julio [1996]. "Prices, output and hours: An empirical analysis based on a sticky price model," Journal of Monetary Economics 37 (1996), 505-33.

[36] Schmitt-Grohe, Stephanie and Martin Uribe [2003]. "Closing small open economy models," Journal of International Economics, 61, 163-185.

[37] Schorfheide, Frank [2000]. "Loss Function-Based Evaluation of DSGE Models," Journal of Applied Econometrics, 15, 645-670.

[38] Smets, Frank and Raf Wouters [2003] "An Estimated Stochastic Dynamic General Equilibrium Model for the Euro Area," Journal of the European Economic Association, 1, 1123-1175.

[39] Smets, Frank and Raf Wouters [2004]. "Comparing Shocks and Frictions in U.S. and Euro Area Business Cycles: A Bayesian DSGE Approach," National Bank of Belgium Working Paper, 61.

[40] Stockman, Alan C., and Linda Tesar [1995]. "Tastes and Technology in a Two-Country Model of the Business Cycle: Explaining International Comovements," American Economic Review, 83, 473-86.

[41] Tesar, Linda [1993]. "International Risk Sharing and Non-Traded Goods," Journal of International Economics, 35 (1-2), 69-89.

[42] Warnock, Francis [2003]. "Exchange rate dynamics and the welfare effects of monetary policy in a two-country model with home-product bias," Journal of International Money and Finance, 22, 343-363.

[43] Woodford, Michael [1998]. "Doing without Money: Controlling Inflation in a Post-monetary World," Review of Economic Dynamics, 1, 173-219.

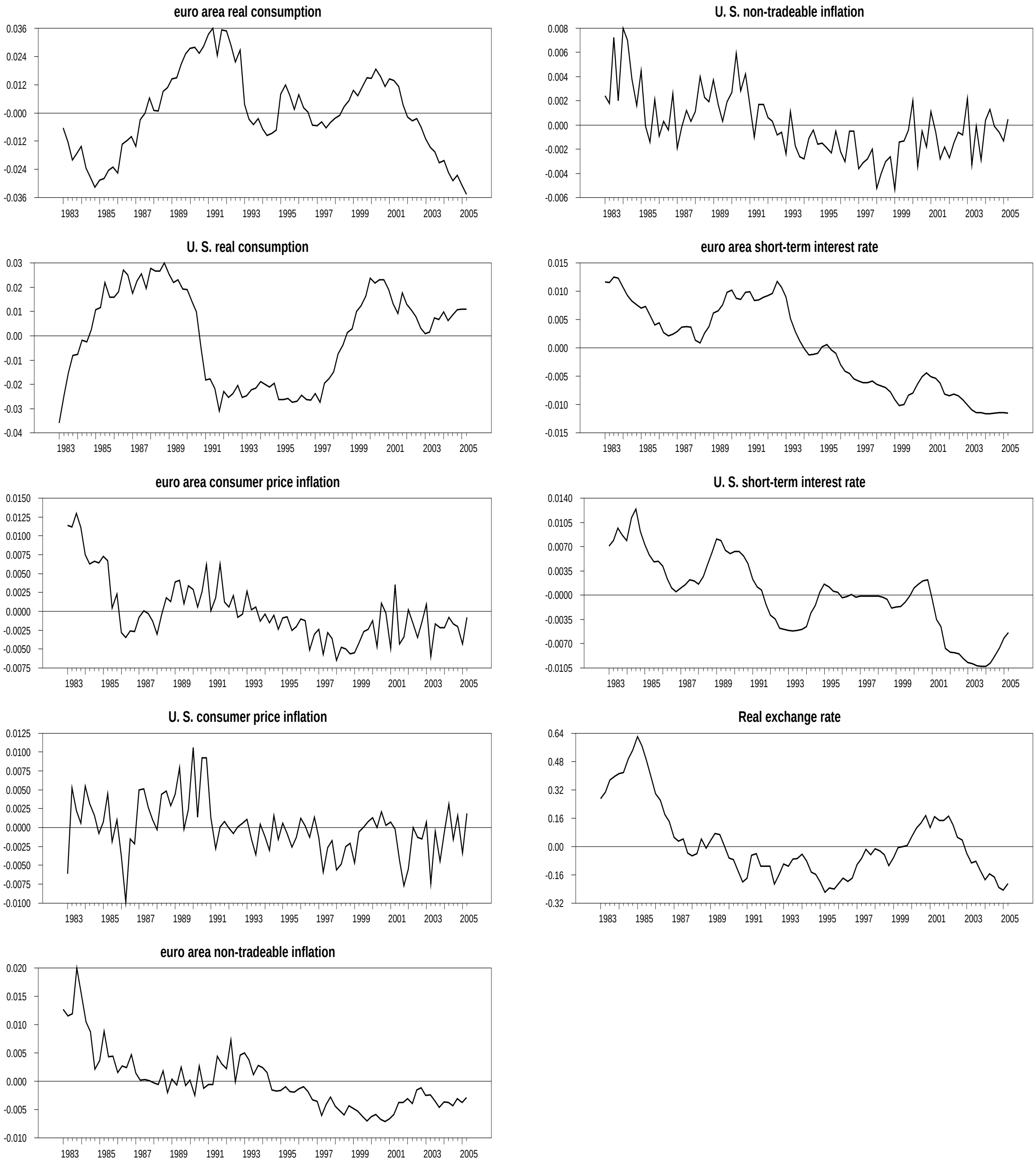

Figure 1. Data

Figure 2. Real exchange rate between the euro area and the U. S. (top panel) and its autocorrelation function (bottom panel)

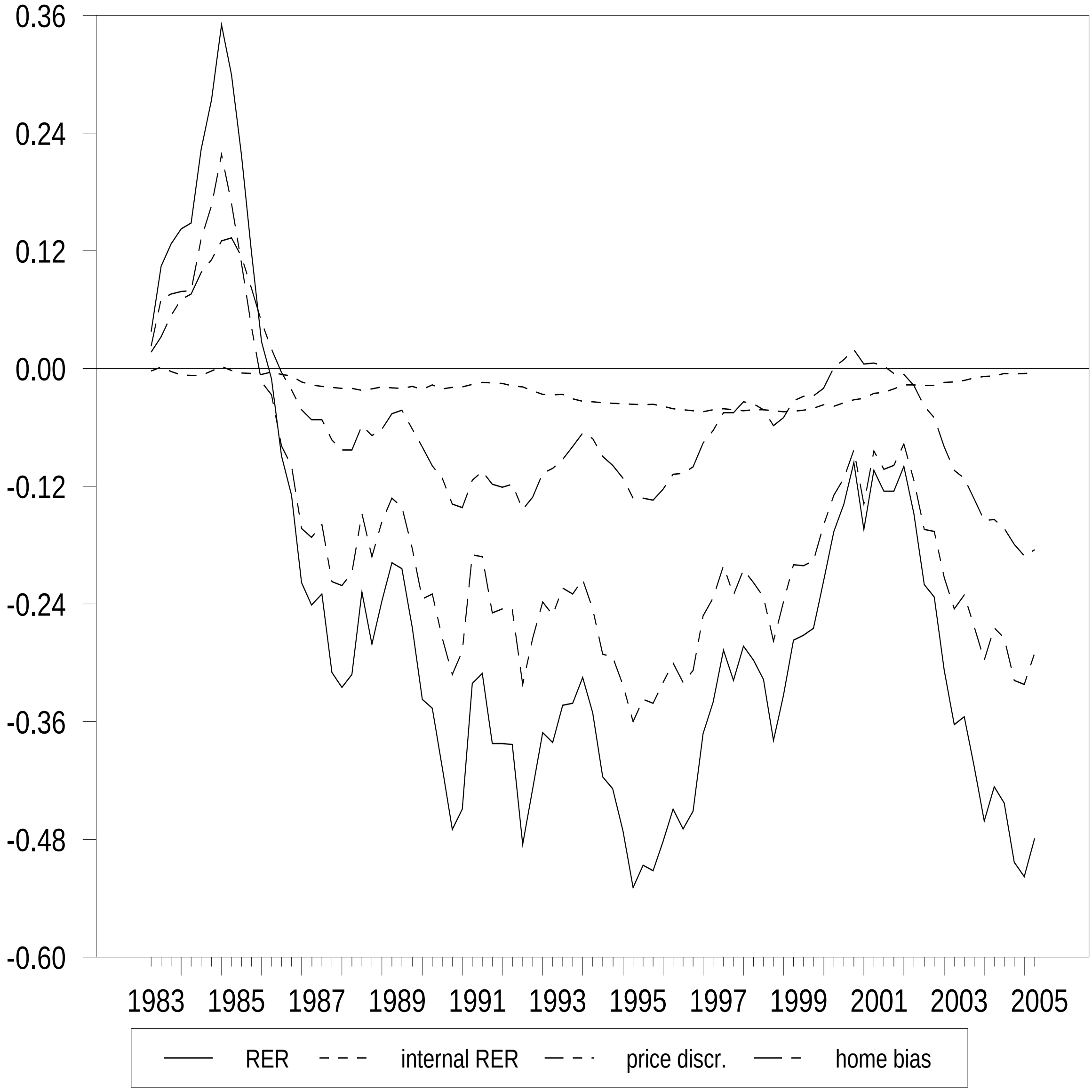

Figure 3. Decomposition of the real exchange rate between the euro area and the U. S.: complete model

Table 1A. Calibrated parameters

parameter	symbol	value
intertemporal discount factor	β	0.99
labour disutility	τ	2
elasticity of substitution (NON tradables)	θ_N	6
elasticity of substitution (labour inputs)	θ_W	4.3

Table 1B. Prior distributions of the estimated parameters

param	type	mean	st. dev	param	type	mean	st. dev
κ_0	Gamma	0.01	0.005	ρ_U	Beta	0.90	0.05
ϕ	Gamma	1.14	0.10	ρ_U^*	Beta	0.90	0.05
ρ	Gamma	0.74	0.10	ρ_{UIP}	Beta	0.90	0.05
σ_C	Gamma	2.0	0.20	ρ_T^*	Beta	0.90	0.05
ρ_R	Beta	0.80	0.10	ρ_N^*	Beta	0.90	0.05
ρ_π	Gamma	1.50	0.10	ρ_T^*	Beta	0.90	0.05
ρ_Y	Normal	0.0	0.10	ρ_N^*	Beta	0.90	0.05
ρ_S	Normal	0.0	0.10	σ_U	Uniform[0,1]	0.50	0.29
ρ_R^*	Beta	0.80	0.10	σ_U^*	Uniform[0,1]	0.50	0.29
ρ_π^*	Gamma	1.50	0.10	σ_{UIP}	Uniform[0,1]	0.50	0.29
ρ_Y^*	Normal	0.0	0.10	σ_R^*	Uniform[0,1]	0.50	0.29
ρ_S^*	Normal	0.0	0.10	σ_R^*	Uniform[0,1]	0.50	0.29
κ_H	Gamma	5.6	10.0	σ_T^*	Uniform[0,1]	0.50	0.29
κ_F	Gamma	5.6	10.0	σ_N^*	Uniform[0,1]	0.50	0.29
κ_N	Gamma	5.6	10.0	σ_T^*	Uniform[0,1]	0.50	0.29
κ_H^*	Gamma	5.6	10.0	σ_N^*	Uniform[0,1]	0.50	0.29
κ_F^*	Gamma	5.6	10.0	σ_W	Uniform[0,1]	0.50	0.29
κ_N^*	Gamma	5.6	10.0	σ_W^*	Uniform[0,1]	0.50	0.29
κ_W	Gamma	63.0	40.0	eta	Gamma	1.20	0.10
κ_W^*	Gamma	63.0	40.0	a_H	Beta	0.80	0.10
				a_T	Beta	0.45	0.10

Table 2. Overall goodness of fit

Model	Marginal density
LCP with DC	2977
PCP without DC	2974
LCP without DC	2970
LCP with sticky wages only	2902
"RBC" (no nominal rigidities) with DC	2803

Notes: The marginal density is computed using the harmonic mean estimator proposed by Geweke (1999).

Table 3. Performance of models with nominal rigidities in reproducing the main properties and stylized facts of the euroarea-US real exchange rate

Moment	LCP with DC	PCP without DC	LCP without DC
$Volatility$	14.71	14.51	14.21
$Persistence$	0.93	0.93	0.93
$corr\left(RS_t, \frac{C}{C^*}\right)$	-0.39	-0.51	-0.36

Table 4. Posterior median estimates for models with price rigidities

parameter	Complete model	LCP	PCP
η	1.08	-	-
a_H	0.90	0.95	0.97
a_T	0.61	0.54	0.63
ϕ	1.22	1.17	1.22
ρ	0.91	0.75	0.74
k_H	10.13	9.01	3.52
k_F	3.27	5.32	-
k_N	53.63	71.11	19.62
k_H^*	22.65	3.25	-
k_F^*	2.83	5.31	3.31
k_N^*	26.79	61.35	5.65
k_W	283.88	74.09	342.28
k_W^*	348.96	56.05	366.35
σ_C	2.35	2.27	2.17
ρ_R	0.87	0.86	0.86
ρ_π	1.67	1.75	1.65
ρ_y	0.20	0.01	0.23
ρ_e	-0.02	-0.01	-0.02
ρ_r^*	0.90	0.87	0.91
ρ_π^*	1.52	1.60	1.49
ρ_Y^*	0.10	0.09	0.10
ρ_e^*	-0.02	-0.01	-0.01
k_0	0.01	0.01	0.01
ρ_{u^b}	0.92	0.94	0.91
$\rho_{u_{b^*}}$	0.93	0.93	0.91
ρ_{uip}	0.93	0.95	0.95
ρ_{z_T}	0.92	0.96	0.96
ρ_{z_N}	0.92	0.97	0.95
$\rho_{z_T^*}$	0.89	0.95	0.90
$\rho_{z_N^*}$	0.94	0.94	0.97
σ_{u_b}	0.03	0.03	0.03
$\sigma_{u_b^*}$	0.02	0.02	0.02
σ_{uip}	0.00	0.00	0.00
σ_R	0.00	0.00	0.00
σ_R^*	0.00	0.00	0.00
σ_{Z_T}	0.02	0.01	0.01
σ_{Z_N}	0.01	0.01	0.01
$\sigma_{Z_T^*}$	0.02	0.01	0.01
$\sigma_{Z_N^*}$	0.01	0.01	0.00
σ_{Z_W}	0.46	0.08	0.28
$\sigma_{Z_W^*}$	0.41	0.04	0.22

Table 6. Nominal rigidities in the complete model

Nominal rigidities	cost	probability	frequency
Euro area			
Import (border)	3.27	0.19	1.2
Domestic tradable (wholesale)	10.13	0.36	1.6
Nontradable	53.63	0.74	3.8
Wages	283.88	0.9	10.0
U.S.			
Import (border)	22.65	0.5	2.0
Domestic tradable (wholesale)	2.83	0.17	1.2
Nontradable	26.79	0.65	2.9
Wages	348.96	0.91	11.1

Notes: The column denoted with cost reports the parameter measuring the cost for adjusting prices. The column denoted with probability reports the implicit Calvo probability for a firm of not being able to reset prices optimally. The column denoted with frequency reports the average duration of prices, computed on the basis of the Calvo probability. All figures are based on the output of the Metropolis-Hastings algorithm with 1,000,000 draws.

Table 7. Nominal exchange rate pass-through into import prices (%)

Exchange rate pass-through		
at the:	**Short Run**	**Long Run**
Border EA	41	91
Consumer EA	20	43
Border U.S.	10	90
Consumer U.S.	5	4

Table 8. Real exchange rate fluctuations: economic decomposition

(% of variance of Rer explained)

Component	Complete	LCP	PCP
Var(Internal Rer)	0.2	0.7	0.2
Var(Home bias)	7.5	35.7	96.6
Var(IPD)	55.9	24.9	0.0
cov(Int Rer,Homebias)	-0.1	1.7	3.1
cov(Int Rer,IPD)	2.2	1.9	0.0
cov(Home bias,IPD)	34.0	34.6	0.0
Total	99.8	99.4	100.0

Table 9. Variance decomposition: complete model

Variable	z_H	z_F^*	z_N	z_N^*	z_R	z_R^*	z_U	z_U^*	z_{UIP}	z_W	z_W^*	tot
UEM C	10.2	0.3	13.3	0	5.4	0	63.9	0.7	5.9	0.3	0	100
UEM π_c	47.8	0.4	29.3	0	0.7	0.1	15.5	0.2	4.8	1.1	0	100
UEM $\pi_n t$	14.8	0	59.7	0	0.8	0	21.6	0.2	1.7	1.2	0	100
UEM re	1.5	0.6	0.5	0.3	0.2	0.3	11.1	8	77.5	0	0	100
UEM R	16.7	0.1	16.2	0	8.4	0	56.2	0.2	1.8	0.4	0	100
U. S. C	0.8	3.8	0	8.3	0	13.1	1.4	64.2	8.2	0	0.2	100
U. S. π_c	0.4	53	0	28	0	1.7	0.7	10.4	4.4	0	1.4	100
U. S. $\pi_n t$	0.1	8.2	0	64.2	0	2.4	1.1	17.2	5.2	0	1.7	100
U. S. R	0.1	7.6	0	14.2	0	18.2	1.1	53.1	5.4	0	0.3	100

Table 10. Volatility, persistence e cross-correlations of selected variables

Variable	**Volatility**		**Persistence**	
	Data	**model**	**Data**	**model**
UEM real exchange rate	20.74	15.66	0.97	0.93
UEM CPI inflation	0.41	0.48	0.75	0.61
U. S. CPI inflation	0.36	0.46	0.4	0.50
UEM nontradable inflation	0.55	0.41	0.85	0.79
U. S. nontradable inflation	0.36	0.36	0.57	0.73
UEM interest rate	0.77	0.48	0.98	0.95
U. S. interest rate	0.55	0.36	0.97	0.93
UEM consumption	1.94	1.39	0.49	0.85
U. S. Consumption	1.78	1.13	0.96	0.83
UEM import inflation	1.85	3.26	0.62	0.32
U. S. import inflation	1.51	2.44	0.29	0.50

Variables	**Cross-correlations**	
	Data	**model**
Rer, relative consumption	-0.48	-0.43
Rer, CPI inflation	0.54	-0.11
Rer, U.S. inflation	0.03	0.11
Rer, nontradable inflation	0.52	-0.18
Rer, U.S. nontradable inflation	0.38	0.19
Rer, import price inflation	-0.24	0.23
Rer, U.S. import price inflation	-0.11	-0.27
Consumptions	-0.1	-0.11
UEM trade balance, output		-0.37