The dynamics of the real exchange rate: a Bayesian DSGE approach

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Abstract

This paper empirically analyzes the importance of various features introduced in models belonging to the new open economy macroeconomics (NOEM) literature in reproducing the main stylised facts of the real exchange rate and accounting for its dynamics. Different models are estimated using euro-area and US data. First, the data support the model featuring incomplete pass-through due to a combination of nominal rigidities and distribution costs. Second, international price discrimination and home bias are the main determinants of real exchange rate dynamics. Third, shocks to either the uncovered interest rate parity condition (UIP) or to preferences are necessary to reproduce the negative correlation between the real exchange rate and consumption differentials (the well-known Backus-Smith correlation). Finally, the volatility of the real exchange rate is mainly explained by the UIP shock and, to a smaller extent, by shocks to preferences. Fundamentals are, on the contrary, mostly explained by technology and preference shocks.

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1 Introduction

Three main stylized facts of the open economy are related to the real exchange rate. Its fluctuations are extremely volatile and persistent but they do not affect significatively other macroeconomic variables (the so-called "exchange rate disconnect"). Several contributions in the new open economy macroeconomics (NOEM) literature have extended the Obstfeld and Rogoff sticky-price general equilibrium model, in which the real exchange rate is constant and the purchasing power parity (PPP henceforth) holds, to account for the above mentioned stylized facts (see Obstfeld and Rogoff, 1995). These extensions include, among others, sticky prices (Chari, Kehoe and McGrattan, 2004) and wages (Hau, 2000 and Obstfeld and Rogoff, 2000), pricing-to-market (Betts and Devereux, 2000), non-traded goods (Hau, 2000 and Obstfeld and Rogoff, 2000) and distribution services (Corsetti and Dedola, 2005). The use of Bayesian techniques for estimating general equilibrium models have also allowed researchers to estimate NOEM models (see among others, Bergin, 2003, Lubik and Schorfheide, 2005, de Walke, Smets and Wouters, 2005 and Rabanal and Tuesta, 2006). Even more recently, these models have been developed at central banks such as the Riksbank, the Federal Reserve, the European Central Bank and the Bank of Canada.

The goal of this paper is to empirically investigate these extensions by estimating a class of models using Bayesian techniques and data on euro-area and US macroeconomic variables. In the first model ("complete" model) we relax all the three assumptions at the basis of the PPP condition: international law of one price, symmetric preferences, tradability of all goods.

We make two assumption to remove the international law of one price and introduce international price discrimination. One is the local currency pricing (LCP) assumption. Contrary to the producer currency pricing (PCP) case, exporters face costs of adjusting prices not only in their own currency, but also in the currency of the importing country. Hence, import prices are sticky in the currency of the destination market. Chari *et al.* (2004) show that a high degree of sticky prices is necessary to reproduce the volatility of the real exchange rate when there are monetary shocks.[1] The other source is that of distribution services intensive in local nontradable goods (Corsetti and Dedola, 2005). Distribution services induce differences in demand elasticity across countries.[2] Thus, with monopolistic producers the law of one price does not hold in general, even in a flexible price equilibrium. Hence, firms in the tradable sector would optimally charge different wholesale prices in the two countries. The advantage of introducing distribution services is that, when combined with standard preferences, they contribute to generate a low price

[1]Kollman (2001) studies a small open economy model in which nominal prices and wages are set two or four periods in advance, and in which monetary shocks are the dominant source of exchange rate fluctuations. His model generates variability in the real and nominal exchange rate not much different from that in the data.

[2]Campa and Goldberg (2004) provide evidence that the presence of distribution services helps explain a lower exchange rate pass-through at the consumer level than at the producer level.

elasticity of imports. Thanks to the price discrimination, fluctuations in the nominal exchange rate are not fully transmitted to the price of imports (assumption of incomplete exchange rate pass-through into import prices). Hence, large exchange-rate swings do not translate into large consumer prices movements.

We also relax the assumption of symmetric preferences, imposing home bias in consumption. Finally we assume that some goods are nontradable.[3] All these assumptions can contribute to increasing the volatility of the real exchange rate.

We also assume that financial markets are incomplete and introduce a shock to the uncovered interest parity (UIP from now on) as a stochastic change in the cost of holding foreign bonds along the lines of Turnovsky (1987) and Benigno (2001). In fact, incomplete exchange rate pass-through and nominal rigidities *per se* are not sufficient to replicate the high volatility of the real exchange rate. When international financial markets are complete, there is a risk sharing condition linking the real exchange rate to the cross-country ratio of consumption marginal utilities. According to this condition, the volatility of the real exchange rate is proportional to that of the fundamentals. The risk sharing condition can be removed by assuming that only a riskless bond is internationally traded. Incomplete financial market are not able to reproduce the high volatility of the exchange rate. In fact, the uncovered interest rate parity links real exchange rate fluctuations to the real interest rate differential; the related tilting of the consumption path and current account adjustment will limit the volatility of the real exchange rate. One possible solution is to assume that the coefficient of risk aversion is high as in Chari *et al.* (2004). Another is to introduce a low elasticity of intratemporal substitution between domestic tradable and imported goods using, as we do, distribution services. Alternatively, it is possible to add an uncovered interest parity shock that drives a wedge between the real interest rates. The result is the weakening of the link between exchange rate and fundamentals. The introduction of the UIP shock is justified by the empirical evidence on the failure of the UIP condition as well as by its long-standing use in the theoretical literature.[4]

To help the model in reproducing the persistence of the real exchange rate, we assume the existence of nominal rigidities and inertia in interest rate setting by the central banks. Benigno (2004) shows that with staggered prices and inertial monetary policy the real exchange rate is persistent because the adjustment of the interest rate differential is smoothed over time.

We consider two alternative models. In the first, incomplete pass-through is due only

[3]The role of non tradable goods in the explanation of the observed behaviour of prices and exchange rates is still debated. Chari *et al.* (2004) 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) reach opposite conclusions. Given this lack of consensus, and the presence of distribution services intensive in local nontradable goods in our model, we include them.

[4]Duarte and Stockman (2001), Jeanne and Rose (2002), Devereux and Engel (2002) show how deviation from the UIP condition, as well as from the complete pass-through assumption, are required to reproduce the high real exchange rate volatility in a monetary model.

to local currency pricing (LCP) and there are no distribution services. In the second the pass-through is complete because we assume that prices are set in the currency of the producer (PCP).

The main results of the estimation are the following. First, incomplete pass-through resulting from LCP and distribution services is the aspect which is more supported by the data. Second, the decomposition of the variance of the real exchange rate into its main economic determinants shows that international price discrimination – and hence incomplete pass-through – and home bias are the main determinants of real exchange rate deviations from PPP, at least for the complete and LCP models. The PCP model explains the dynamics of the exchange rate by exploiting the home bias, which becomes so high that it limits effects of import prices, fully reacting to exchange rate movements, onto consumer prices. Third, in the three models the relative price of nontradable goods (the *internal* real exchange rate) plays a very small role in generating real exchange rate fluctuations. However nontradable goods cannot be dismissed. Indeed, in the complete model (the one that better fits the data) the estimate of the distribution margin is around 50 per cent, 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, the decomposition of the variance of the forecast error shows that in the complete model about 75 per cent of the real exchange rate variability is explained by the shock to the UIP, and the rest by shocks to preferences. Consumptions, inflation rates and short-term interest rates are, on the contrary, mostly explained by technology and preference shocks.

The paper is organized as follows. Section 2 illustrates the setup of the model. Section 3 illustrates the relationship between the features we have in the models and the moments of the real exchange rate. Section 4 describes the solution of the model and its estimation procedure. Section 5 reports the results. Section 6 concludes.

2 The Model

The world economy is composed by two large countries of equal size (Home and Foreign country). The two countries are symmetric in terms of technology and tastes, with the exception of home bias in preferences for consumption goods. Each representative household maximizes her 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 labor as the only productive input.

2.1 The representative household

2.1.1 Preferences

In each country there is a continuum $[0,1]$ of households. The expected value of household j lifetime utility is given by:

$$E_0\left\{\sum_{t=0}^{\infty}\beta^t Z_{p,t}\left[\frac{C_t(j)^{1-\sigma}}{1-\sigma}-\frac{\kappa}{\tau}L_t(j)^{\tau}\right]\right\} \quad \sigma,\kappa,\tau>0$$

where E_0 denotes the expectation conditional on information set at date 0 and β is the intertemporal discount rate $(0<\beta<1)$ The household obtains utility from consumption $C(j)$ ($1/\sigma$ is the elasticity of intertemporal substitution), and receives disutility from labor supply $L(j)$. Each household is a monopolistic supplier of differentiated labor services to firms. The shock Z_p is a country-specific preference shifter, common to all households, that scales the overall period utility and follows an autoregressive process of order one:

$$\ln Z_{p,t}=\rho_{Z_p}\ln Z_{p,t-1}+\epsilon_{p,t}$$

where $0<\rho_p<1$ and $\epsilon_{P,t}$ is an independently and identically distributed shock with mean and variance respectively equal to 0 and σ^2.[5]

The aggregate consumption index $C_t(j)$ is defined as follows:

$$C_t(j)=\left[a_T C_{T,t}(j)^{\frac{1-\phi}{\phi}}+(1-a_T)\,C_{N,t}(j)^{\frac{1-\phi}{\phi}}\right]^{\frac{\phi}{1-\phi}} \qquad \phi>0 \tag{1}$$

$C_{T,t}(j)$ is the bundle of tradable goods, while $C_{N,t}(j)$ is the that of nontradable goods. The parameter ϕ is the elasticity of substitution between the two bundles. The parameters a_T and $(1-a_T)$ are the weights on the consumption of traded and nontraded goods, respectively. The index of traded goods $C_T(j)$ is given by:

$$C_{T,t}(j)=\left[a_H C_{H,t}(j)^{\frac{1-\rho}{\rho}}+(1-a_H)\,C_{F,t}(j)^{\frac{1-\rho}{\rho}}\right]^{\frac{\rho}{1-\rho}} \qquad \rho>0 \tag{2}$$

where ρ is the elasticity of substitution between the consumption of the Home good $C_H(j)$and the Foreign good $C_F(j)$.

The parameter a_H $(a_H>1/2)$ weighs the consumption of "local" tradables in the home and foreign countries This assumption of "mirror symmetric" baskets generates a

[5]We do not model money explicitly, but we interpret this model as a cash-less limiting economy, in the spirit of Woodford (1998), in which the role of money balances in facilitating transactions is negligible.

home bias in consumption tradable goods.[6] The elasticity of substitution among brands in both Home and Foreign tradable sectors is $\theta_T > 1$ while $\theta_N > 1$ is the elasticity of substitution among brands in the nontradable sectors.

2.1.2 Budget Constraint

Households in the home country can invest their financial wealth in two risk-free bonds with a one-period maturity. One is denominated in domestic currency and the other in Foreign currency. In contrast, foreign households can allocate their wealth only in the bond denominated in the foreign currency.

The budget constraint of household j in the Home country is:[7]

$$\begin{aligned} & \frac{B_{H,t}(j)}{(1+R_t)} + \frac{S_t B_{F,t}(j)}{(1+R_t^*)\Phi(\frac{S_t B_{F,t}}{P_t})Z_{UIP,t}} \\ & -B_{H,t-1}(j) - S_t B_{F,t-1}(j) \\ \leq & \int_0^1 \Pi_t(h)\,dh + \int_0^1 \Pi_t(n)\,dn \\ & +W_t(j)L_t(j) - P_t C_t(j) - AC_t^W W_t(j) L_t(j) \end{aligned} \tag{3}$$

where $B_H(j)$ is household j's holding of the risk-free one-period nominal bond denominated in units of Home currency. This bond pays a nominal interest rate R_t. The holding of the risk-free one-period nominal bond denominated in units of foreign currency is denoted with $B_F(j)$. S_t is the nominal exchange rate, expressed as a number of Home currency units per unit of Foreign currency. It pays a nominal interest R_t^*. The nominal rates R_t and R_t^* are paid at the beginning of period $t+1$ and are known at time t. They are directly controlled by the national monetary authorities. Following Benigno (2001), the function $\Phi(\frac{S_t B_{F,t}}{P_t})$ captures the costs of undertaking positions in the international asset market for home country households. As borrowers, they will be charged a premium on the foreign interest rate; as lenders, they will receive a remuneration lower than the foreign interest rate.[8] We introduce this additional cost to pin down a well defined steady state.[9] The payment of this cost is rebated to agents belonging to the Foreign country. We adopt the following function form:

[6]The variables $C_{H,t}(j)$, $C_{F,t}(j)$, $C_{N,t}(j)$ are indexes of consumption across the continuum of differentiated goods produced respectively in the home tradable, foreign tradable and home nontradable sectors.

[7]See Benigno (2001) for a similar financial structure.

[8]The function $\Phi(\frac{S_t B_{F,t}}{P_t})$ depends on real holdings of the foreign assets in the entire home economy. Hence, domestic households take it as given when deciding on the optimal holding of the foreign bond. We require that $\Phi(0) = 1$ and that $\Phi(.) = 1$ only if $B_{F,t} = 0$. $\Phi(.)$ is a, differentiable, (at least) decreasing function in the neighborhood of zero. See also Schmitt-Grohé and Uribe (2003).

[9]See Turnovsky (1985).

$$\Phi(\frac{S_t B_{F,t}}{P_t}) = \exp(\phi_{B1}\frac{S_t B_{F,t}}{P_t})$$

where $0 \leq \phi_{B1} \leq 1$. The parameter ϕ_{B1} controls the speed of convergence to the steady state.

A risk premium shock $Z_{u,t}$ is added to the model to allow for exogenous variations in international financial markets conditions. It evolves as:

$$\ln Z_{u,t} = \rho_u \ln Z_{u,t-1} + \epsilon_{u,t}$$

where $0 < \rho_{Z_u} < 1$ and $\epsilon_{Z_{u,t}}$ is an independently and identically distributed shock with mean and variance respectively equal to 0 and σ_u^2.

Households derives income from two sources: nominal wages $W_t(j)$ and profits of domestic tradable and nontradable firms, respectively $\int_0^1 \Pi_t(h)\,dh$ and $\int_0^1 \Pi_t(n)\,dn$. The consumer price index (CPI from now on) for the home country is denoted by P_t. Changes of nominal wages are subjeted to quadratic adjustment costs:

$$AC_t^W(j) = \frac{\kappa^W}{2}\left(\frac{W_t(j)}{W_{t-1}(j)} - 1\right)^2 \quad \kappa^W \geq 0 \tag{4}$$

where the parameter κ^W measures the degree of nominal wage rigidity.

We assume that all the households belonging to the same country have the same initial level of wealth and share the profits of domestic firms in equal proportion. Hence, within a country all the households face the same budget constraint. In their optimal decisions, they will choose the same path of bonds, consumption and wages.

2.2 Firms

2.2.1 Production

There is a $[0,1]$ continuum of firms in each sector. Home firm x's output at time t is denoted by $y_t^S(x)$, $x = H, N$ (H is for home tradable sector, N for Home nontradable sector) and is obtained using the following technology:

$$y_t^S(x) = Z_{X,t} L_t(x) \;\; x = h,\; n;\; X = H,\; N \tag{5}$$

where $Z_{X,t}$ is a technology shock common to all the firms belonging to the same sector that follows a stationary autoregressive process:

$$\ln Z_{X,t} = \rho_X \ln Z_{X,t-1} + \epsilon_{Z_{X,t}}$$

where $0 < \rho_{Z_X} < 1$ and ϵ_{Z_X} is an independently and identically distributed shock with mean and variance respectively equal to 0 and $\sigma^2_{Z_x}$. The labour input used in the production is a CES combination of differentiated labor inputs (where $\theta_{L,t}$ the elasticity of substitution among labor inputs, is subject to an independently and identically distributed shock with mean and variance respectively equal to 0 and σ^2_L). Firms take the wages as given. Cost minimization also yields the following marginal cost $MC_t(x)$ function:

$$MC_t(x) = \frac{W_t}{Z_{X,t}}$$

which is the same for all firms belonging to a given sector.

2.2.2 Price setting

All firms face a quadratic price adjustment denoted (following Rotemberg, 1982) by $AC^p_{X,t}(x)$:

$$AC^p_{X,t}(x) = \frac{\kappa^p_X}{2}\left(\frac{\bar{p}_t(x)}{\bar{p}_{t-1}(x)} - 1\right)^2 \quad x = h,f,n \quad X = H,F,N$$

where the parameter $\kappa^p_X \geq 0$ measures the degree of price rigidity.

Nontradable sector Each firm n in the nontradable sector takes into account the demand for its product and sets the nominal price $p_t(n)$ by maximizing the present discounted value of real profits. Demand comes not only from consumers but also from the firms in the local competitive distribution sector. These firms purchase home and foreign tradable goods and distribute them domestically using a Leontief technology: they combine one unit of the tradable good with $\eta \geq 0$ units of a basket of nontradable goods. The distribution costs introduce a wedge between wholesale and consumer prices. It follows that:

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

where p is the consumer price of a tradable good, $\bar{p}$ its wholesale price and $P_{N,t}$ the price of the non-tradeable good.

Tradable sector Firm producing the generic brand h optimally set a price $\bar{p}_t(h)$ (in Home currency) in the home market subject to the demand constraint

$$C^d_t(h) = \left(\frac{\bar{p}_t(h) + \eta P_{N,t}}{P_{H,\tau}}\right)^{-\theta_T}\left(\int_0^1 C^D_t(h,j)\,dj\right)$$

and a price $\bar{p}_t^*(h)$ (in foreign currency) in the foreign market, subject to the demand constraint:

$$C_t^{d*}(h) = \left(\frac{\bar{p}_t^*(h) + \eta P_{N,t}^*}{P_{H,t}^*} \right)^{-\theta_T} \left(\int_0^1 C_t^D(h, j^*)\, dj^* \right)$$

and face a quadratic cost for adjusting their prices.

From the optimal pricing conditions it is possible to derive a measure of the degree of the pass-through of nominal exchange rate changes into import prices (ERPT), *other things equal*. Starting from these optimality conditions and after some algebra, a structural coefficient measuring the pass-through at the border can be derived:

$$\widehat{\bar{p}_{H,t}^*} = ... - \theta_T w \frac{1}{\bar{p}_H + \eta p_N} \left\{ \left[\kappa_H^{p*}(1+\beta) \right] + \theta_T \bar{p}_H \left[\frac{(\eta p_N + w)}{(\bar{p}_H + \eta p_N)^2} \right] \right\}^{-1} \hat{S}_t \tag{6}$$

which shows that the law of one price does not hold for two reasons. First, prices are sticky in the currency of the consumer (LCP). Second, distribution services intensive in local nontradable goods implies that the elasticity of demand for any brand is not necessarily the same across markets. Hence pass-through is less than complete even if prices are fully flexible.

2.3 Monetary policy

In the each country, the monetary authority sets the nominal interest according to the following rule:

$$\left(\frac{1+R_t}{1+R} \right) = \left(\frac{1+R_{t-1}}{1+R} \right)^{\rho_R} \left(\frac{P_t}{P_{t-1}} \right)^{(1-\rho_R)\rho_\pi} \left(\frac{Y_t}{Y} \right)^{(1-\rho_R)\rho_Y (1-\rho_R)\rho_\pi} \left(\frac{S_t}{S_{t-1}} \right)^{(1-\rho_R)\rho_S} Z_{R,t} \tag{7}$$

where R_t is the short-term nominal interest rate, P_t/P_{t-1} is the inflation rate based on the consumer price index, Y_t is total output and the coefficient, S_t/S_{t-1} is depreciation rate of the nominal exchange rate, R and Y are the steady state levels of interest rate and output, respectively. The parameter 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. The monetary policy shock is denoted with $Z_{r,t}$ and follows an i.i.d process with variance equal to σ_R^2. A similar monetary policy function holds for the foreign country.

3 The determinants of the real exchange rate

In this Section we analyse the implication of our model for the real exchange rate dynamics and we discuss a decomposition of the real exchange rate deviations from PPP in their three major determinants (international price discrimination, relative price of nontradable goods, home-bias). Next we draw attention on the implications of assuming incomplete international financial markets for the real exchange rate.

3.1 The components of real exchange rate fluctuations

The real exchange rate ($RS_t henceforth$) can be defined as:

$$RS \equiv \frac{S_t P_t^*}{P_t} \tag{8}$$

while the CPI of the home country P_t is equal to:

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

where $P_{T,t}$ is consumer price of tradable goods in the Home country and $P_{N,t}$ that of the nontradable goods.The price indexes of tradable and non tradable goods in the Home and Foreign countries, $P_{T,t}, P_{N,t}$, $P_{T,t}^*$ and $P_{N,t}^*$, are defined by a similar CES aggregators (with import price elasticity of substitution given by ρ and home bias governed by the parameter a_H).

The assumption of distribution services intensive in local nontraded good introduces a non trivial distinction between wholesale (producer) and retail (consumer) prices for the traded good; hence, in the case of the Home tradable good (similar relations hold for the Foreign traded good), we can write:

$$P_{H,t} = \bar{P}_{H,t} + \eta P_{N,t} \quad , \quad P_{H,t}^* = \bar{P}_{H,t}^* + \eta P_{N,t}^*$$

Given that there is market segmentation, the law of one price for tradable goods does not hold; hence at the wholesale level we have $\bar{P}_{F,t} \neq S_t \bar{P}_{F,t}^*$ and $\bar{P}_{H,t}^* \neq \bar{P}_{H,t}/S_t$. Similar inequalities hold at the consumer level.

The above relations can be used to decompose the real exchange rate into its main determinants (see Benigno and Thoenissen, 2006). After log-linearizing the price indexes around the steady state and some algebraic manipulation we obtain:

$$\begin{aligned} \Delta RS_t &= (1 - a_T)(\pi_{N,t}^* - \pi_{T,t}^*) - (1 - a_T)(\pi_{N,t} - \pi_{T,t}) + \\ &\quad +(2a_H - 1)(\pi_{F,t} - \pi_{H,t}) \\ &\quad +a_H \left(\Delta S_t + \pi_{F,t}^* - \pi_{F,t} \right) + (1 - a_H) \left(\Delta S_t + \pi_{H,t}^* - \pi_{H,t} \right) \end{aligned} \tag{9}$$

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.[10] The variables with a star are the corresponding inflation rates in the Foreign country. The first two terms in equation (9) can be called "*Home*" and "*Foreign*" *internal real exchange rate*, respectively; the second row is the home-bias; finally, the last two terms show the deviations from the international law of one price for the Foreign and Home tradable good, respectively. In the absence of non tradables ($a_T = 1$), without home bias ($a_H = \frac{1}{2}$) and assuming that the law of one price holds (no market segmentation $\Delta S_t + \pi^*_{F,t} = \pi_{F,t}$ and $\Delta S_t + \pi^*_{H,t} = \pi_{H,t}$) one would have a constant real exchange rate (PPP). We now consider each of the components responsible for the deviation from PPP in our theoretical model.

3.1.1 The internal real exchange rate

The two terms in the first row of equation (9) represent the part of deviation from the PPP due to nontradable goods, their presence into the bundle of the agents limits the transmission of nominal exchange rate fluctuations to the relative prices faced by the consumers.[11] Hence larger real exchange rate fluctuations are needed for an economy with a high share of nontradable goods ($(1-a_T)$ in our model) in order to achieve the same degree of relative price adjustment which accommodates asymmetric shocks. 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.

3.1.2 Home-bias

The second term in equation (9), $(2a_H - 1)(\pi_{F,t} - \pi_{H,t})$, measures the home-bias component of the real exchange rate dynamics. 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 real exchange rate induced by changes in the relative price of the imported good.[12]

3.1.3 International price discrimination

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 (9) 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

[10]We use the following definition: $\pi_{.,t} \approx \ln(1+\pi_{.,t}) \equiv \ln(P_{.,t}/P_{.,t-1})$.
[11]See Hau (2000, 2002) and Benigno and Thoenissen (2006).
[12]See Warnock(2003).

hold because of the assumptions of market segmentation (distribution costs and nominal rigidities in local currency).

3.2 Incomplete financial markets and elasticities of substitution

Several authors have shown the assumption of complete international financial market limits the ability of a model in replicating the real exchange rate dynamics.[13] When a complete set of state contingent nominal assets is traded, the following risk-sharing condition holds in every state of nature:

$$RS_t = \Gamma_0 \left(\frac{C_t}{C_t^*} \right)^\sigma$$

where Γ_0 is a constant that depends on initial conditions (the assumption of power utility can be relaxed and the argument would still hold). Log-linearizing around a given steady-state, we get:

$$\widehat{RS}_t = \sigma(\hat{C}_t - \hat{C}_t^*)$$

where the hat "ˆ" denotes log-deviation from the steady-state value. This condition says that the real exchange rate is proportional to the relative marginal utility of consumption, and hence, given the specification of preferences, to the relative consumption. The drawback is that it is hard to replicate the exchange rate volatility without assuming a sufficiently high level of the coefficient of risk aversion σ (i.e., a relatively low intertemporal elasticity of substitution).

We weaken the risk-sharing condition by assuming that international financial market are incomplete, so that the relation between the real exchange rate and marginal utilities of consumption holds only in expected values. In fact, the combination of the Home and Foreign agent's (log-linearized) first order conditions with respect to the internationally traded bond $B_{F,t}$ gives:

$$\begin{aligned} E_t\left[\widehat{RS}_{t+1} - \widehat{RS}_t\right] &= E_t\left[\sigma(\hat{C}_{t+1} - \hat{C}_t) - (\ln Z_{p,t+1} - \ln Z_{p,t})\right] - \\ &\quad E_t\left[\sigma(\hat{C}^*_{t+1} - \hat{C}^*_t) - \left(\ln Z^*_{p,t+1} - \ln Z^*_{p,t}\right)\right] \\ &\quad +\phi\left(\frac{S_t B_{F,t}}{P_t}\right) - \ln Z_{u,t} \end{aligned} \tag{10}$$

where $Z_{p,t}$, $Z^*_{p,t}$ and $Z_{u,t}$ are, respetively, preference shocks in the home and foreign country and the shock to the UIP condition. The assumption of incomplete markets has other

[13]See Chari *et al.* (2004) and Devereux and Engel (2002).

two advantages. These shocks, together with the assumption of incomplete markets, may be of help help in generating a negative correlation between the real exchange rate and consumption differentials as it is in the data (Backus and Smith, 1993). However, the sign of the correlation depends also on the values of some parameters such as the elasticity of substitution between home and imported tradable goods and the degree of home bias. Corsetti *et al.* (2004) show that, under incomplete markets, a high degree home-bias and low import price elasticity are key to make the real exchange rate volatile and to obtain a negative correlation with relative consumption. Given the import price elasticity of substitution at the consumer level, ρ, distribution services reduce the price elasticity of tradable goods of the producers' level, which is equal to

$$\rho \left(1 - \eta \frac{P_N}{\bar{P}_H}\right)$$

where P_N and $\bar{P}_H$ are set at their steady state values.

All these features, which are present in the model we estimate, contribute to generating volatility and persistence in the real exchange rate. The estimation of the model will suggest which of these modeling assumptions is more important in matching the stilised facts of the real exchange rate.

4 The empirical analysis

Our analysis is based on the estimation of three models. We compare the complete model - whose setup has been described in the previous sections - with two downsized versions: one without distribution services (international price discrimination being the result of only local currency pricing) and the other in which the PCP holds and pass-through is complete.

4.1 Model solution

Since a closed form solution is not possible, the model is solved by taking a loglinear approximation of the equations in the neighborhood of a deterministic steady state. In this steady state the shocks are set to their mean values, 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 and 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.

4.2 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. From their joint probability distribution $P(Y, \Theta)$ one can derive the fundamental relationship between their marginal and conditional distributions known as Bayes theorem:

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

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.

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.[14] 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.[15]

4.2.1 The data

The home country is the euro-area and the foreign country are the US. Estimation 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 US) and the euro-dollar real exchange rate.

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

[15] 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).

Figure 1 shows all the used data. 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.

4.2.2 Prior distributions and calibrated parameters

A very small number of parameters are calibrated. They are reported in Table 1A. 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 1B. All prior distributions are assumed to be independently distributed.

The mean of the prior distribution of the share of tradables in the consumption basket, a_T, is set equal to 0.45 while the standard deviation is set to 0.1 .[16] The prior mean of the share of the home produced goods in the home tradable composite good, a_H, is set is set equal to 0.8 and the standard deviation to 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 elasticity of marginal utility with respect to consumption σ_C has a mean value equal to 2 and a standard deviation of 0.2.

The priors on the coefficients in the monetary policy reaction functions are standard: the persistence coefficient mean is set to 0.8 (standard deviation equal to 0.1) the response to inflation has a mean of 1.5 (standard deviation equal to 0.1) in order to avoid indeterminacy when solving the model. The mean of the response to output and the changes in the nominal exchange rate are set to, respectively, 0.1 and 0.

All the parameters measuring the costs for adjusting prices have the same mean value, equal to 5.6, with standard deviation equal to 10. Those measuring the degree of wage stickiness have a mean value equal to 63, with standard deviation equal to 40. These mean values are taken from Corsetti, Dedola and Leduc (2006).

The autoregressive parameters of the shocks have a beta distribution with mean values set to 0.9 and standard deviations of 0.05. Finally, the standard errors of the innovations to the shock processes have non informative distributions.

[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.

5 Estimation results

In this Section we report the results of the estimation of the benchmark model and we compare them to those obtained for the LCP and PCP models. First, we analyze the posterior distribution of some key parameters. We then proceed to assessing the ability of the different models in replicating some selected stylised facts concerning the real exchange rate and to decomposing its dynamics using equation. Finally the role of the different shocks in driving the fluctuations of the main variables of the model is discussed.

5.1 Posterior distributions of the parameters

The summary statistics for the marginal posterior distributions of the structural parameters of the complete model are reported in Table 2. Those of the LCP and PCP models are reported in Tables 3 and 4. All the tables report the 2.5, 50 and 97.5 percentiles of the marginal posterior distributions as well as the mean and the standard deviation. Table 5 presents a comparison of the medians. The median values are pretty stable across models with the exception of the parameters measuring the degree of nominal prices and wages rigidities and the degree of home bias, which tends to be larger in the models without distribution services (LCP and PCP).

The means of the degree of home-bias are large ranging from 0.9 in the complete model to 0.97 in the PCP model. These large values are to be expected since they help in matching the volatility of the real exchange. The extremely high value in the case of the PCP model could be possibly interpreted as a sign of mis-specification: the high home-bias substitutes exchange rate pass-through incompleteness as feature for increasing the volatility of the real exchange rate without augmenting that of the economic fundamentals. Previous attempts to estimate or calibrate this parameter ended up with similar values: both Rabanal and Tuesta (2006) and Lubik and Schorfheide (2005) find a value of 0.87, while Chari *et al.* (2004) calibrate this parameter to 0.984 in their analysis. The mean of the share of nontradable goods has a not negligible median weight, $(1 - a_T)$, that ranges from 0.37 (PCP model) to 0.46 (LCP model). The value in the complete model is equal to 0.38.

In all the models the data tend to push the import elasticity of substitution of tradable goods, ρ, only slightly above its prior mean (1.1) to 1.2. The mean of the parameter that measures the weight of distribution services is equal to 1.08 while the 90 percent probability interval ranges from 0.92 and 1.27. 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 US (approximately equal to 50 percent). Given our estimates, the producer price import elasticity of tradables, $\rho\left(1 - \eta\frac{P_N}{P_H}\right)$, is more or less equal to 0.58. This low value contributes to match the high volatility of the real exchange rate in the complete model.

Data are also informative about the degree of substitutability between tradable and nontradable goods ϕ: the mean is pushed below the prior mean (1.2) to 0.91 in the complete model and 0.75 in respectively 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 is slightly higher than 2 in all three models. This value is lower than that used by Chari *et al.* (2004) to reproduce the exchange rate volatility. Lubik and Schorfheide (2005) estimate a posterior mean value of σ slightly below 4.0.

Posterior estimates of the price-adjustment cost parameters for exporting firms (κ_H^* for euro-area exporters and κ_F for US exporters in Table 2) in the complete model suggests that US import prices at the border change on average once every two quarters, 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 Choudri *et al.* (2004) in a vector autoregressive analysis report an average duration of import prices of around three quarters. Nontradable prices are, as expected, more rigid than tradable ones in both countries The estimates of import price rigidities are lower than those usually found in the literature on empirical NOEM models. These contributions, however, consider only tradable goods and disregard nontradability and distribution services. The results we get for import price stickiness suggest that the lack of these features may severely distort the importance of nominal frictions for import prices.

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. 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 US monetary policy to inflation and output.

The means of the persistence parameters of the structural shocks are rather large 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).

5.2 Evaluating the alternative models

In this Section we first compare the models in terms of their ability of fitting the data by computing their marginal densities and then we evaluate them by using a more standard analysis of the second moments.[17]

Table 6 reports the marginal densities of the model. The complete model has the highest marginal density, followed by the PCP model and LCP model. According to

[17]In computing the marginal densities we use Geweke's (1999) harmonic mean estimator.

Jeffreys' (1961) rule, the evidence is clearly in favour of one alternative if the difference in the marginal densities is of order 100, that is 4.6 in log terms (see also Fernández-Villaverde and Rubio-Ramírez, 2004). This rule suggests only weak support for the LCP model compared with the PCP one. On the other hand, the model with distribution services seems to be favoured by the data against the LCP and PCP alternative models.

The results of the analysis of the second moments of the real exchange rate are reported in Table 7. We compute them using respectively, the 2.5, 50 and 97.5 percentiles of the marginal posterior distribution of the parameters and for each of these staistics we simulated 10,000 time series of length equal to that of the data. This strategy allows to save on time compared to the one in which we use all the draws from the posterior distribution of each of the parameters.

The estimated models are able to replicate the main stylized facts of the real exchange. The relatively high volatility of the real exchange rate is always matched as well as its persistence. In the latter case, however, the value in the data lies at the very end of the posterior distribution of the persistence of the exchange rate. The models are also able to match the negative correlation between the real exchange rate and consumption differentials. All the models are relatively uncertain on the sign of the correlations between the real exchange rate and the different inflation rates as they can be either positive or negative depending on the precise percentiles used in computing the statistics. variables. This is expected, given that the shocks are not cross-correlated. We also considered the model without the shock to the UIP condition. This is able to replicate the volatility of the real exchange rate but at the cost of inducing higher volatility in the fundamentals.

Since we considered a model with a relatively large set of structural shocks, it is interesting to understand their role in driving the dynamics of the real exchange rate and its correlation with relative consumptions. To this end we computed the second moments for the real exchange rate shutting down some of the structural shocks. In particular, we simulated the model assuming no shocks to the UIP condition, no preference shocks, only monetary policy shocks and finally only technology shocks. The results are reported in Table 8A and 8B. Chari *et al.* (2004) showed that a two country model with only tradable goods is able to replicate the volatility and persistence of the exchange rate with only monetary shocks only when the coefficient of risk aversion is relatively large. As far as the volatility of the exchange rate is concerned, Table 8A suggests that shocks to the UIP condition are necessary to obtain a high volatility while preference shocks do not play a significant role. On the other hand, assuming only monetary policy or technology shocks is not enough to achieve a real exchange rate as volatile as in the data. Its persistence is similar to the data in all the cases with the only exception when monetary shocks are the only driving forces in the model. Finally, concerning the Backus-Smith correlation (Table 8B), when only technology and monetary shocks are assumed to be driving the model, we are not able to generate a negative correlation just as in Chari *et al.* (2004). In order to match it, the model must include either shocks to the UIP condition or shocks to the utility function, as it is clear by staring at equation (11).

5.3 The dynamics of the real exchange rate

In order to quantify the relevance of international price discrimination, non tradeable goods and home bias for the dynamics of the real exchange rate, we first decompose its variance using equation 9 and the estimates of the home bias a_H and the weight of tradables goods in the consumer price index a_T. The variances and covariances are obtained by simulation the model. The main results reported in Table 9 are that the component of the variance of the real exchange rate that is due to international price discrimination explains around 56 per cent of the whole variance. The contribution of the home bias is also not negligible, 7.5 per cent. The covariance between the home-bias and international price discrimination terms also explains a large fraction of the variance. The contribution of the internal real exchange rate is negligible as shown by its variance and the covariance terms it is involved. These results are in line with Chari *et al.* (2004) but in our case the importance of nontradable goods is also related to international price discrimination via price setting decisions in tradables sector.

Figure 2 reports graphically the decomposition of the real exchange rate between the euro-area and the US. based on the estimated parameters and equation (7). The graph confirms the results based on the variance decomposition of the real exchange rate that price discirmination and, to a smaller extent home bias, play a crucial role in shaping the dynamics of the real exchange rate as these two components track pretty well its time series.

Given the importance of international price discrimination, we compute the responses of different prices to a one percent change in the nominal exchange rate using the shock to the uncovered interest parity condition to see how this feature affects the transmission of shocks into prices (see Figure 3). 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 exchange rate shock.

5.4 The role of the different shocks in driving fluctuations

One result of the above analysis is the importance of international price discrimination for the dynamics of the real exchange rate. In this Section we quantify the contribution of each of the shocks we considered in the model to fluctuations in the main variables of the model. To this end we compute the asymptotic forecast error variance decomposition in the complete model. The results are reported in Table 10.

As far as the exchange rate is concerned, its main driving force is the shock to the uncovered interest parity condition which accounts for more than three quarters of its variance. The residual variance is accounted for by preference shocks. In a well-known paper, Meese and Rogoff (1983) showed that a range of macroeconomic models were unable to beat a random walk in forecasting the nominal exchange rate; along the same lines, Flood and Rose (1999) recommend abandoning the attempt of explaining exchange rates in terms of macroeconomic variables. The importance of the UIP shock is in line with these empirical findings. The estimated model suggests the existence of strong deviations from the uncovered interest parity condition and may be also indicating that the assumed structure for international financial markets is not able to capture well portfolio shifts, which might be affecting the exchange rate. The results on the role of shocks to preference and to the UIP condition for the real exchange rate may suggest that the data contain nonlinearities involving marginal utilities and risk premiums that are omitted from the linear approximation of the model.

Technology and monetary policy shocks are not relevant for the real exchange rate Similar results are obtained by Rabanal and Tuesta (2006). In their analysis both demand and technology shocks are important for the volatility of the real exchange rate. Fluctuations in consumption and the nominal interest rate are mainly driven by domestic preference shocks, while inflation rates by domestic technology shocks, in particular by the domestic technology shock in the tradable sector. Shocks to the mark-up in the labour market are not important at all, while monetary policy shocks are, to some extent, only relevant for the domestic interest rate. In the model without the UIP shock, the preference shock is the mainly determinant of the dynamics of the real exchange rate dynamics, a result that is not surprising given what equation (11) suggests.

6 Concluding remarks

We have estimated four two-country NOEM models using euro-area and US data to replicate the high volatility and persistence of the real exchange rate. The models differ for assumption on degree of exchange rate pass-through into import prices and for the presence of an UIP shock. We find that the model that better fits the data is the one having LCP and incomplete pass–through. The models with the worst fit are the one in which the assumption of complete pass-through holds and that without the UIP shock. Hence, incomplete pass-through and UIP shock can be thought as crucial features to reproduce the high exchange rate volatility without any implications for the volatility of other macroeconomic aggregates. The relevance of the UIP shock for the real exchange rate fluctuation is confirmed by the forecast error variance decomposition. We also find that all the models are able to replicate the persistence of the real exchange rate thanks to staggered prices and wages and monetary policy conducted in an inertial way.

The empirical relevance of the two estimated features suggests that the switching effect of changes in the nominal exchange rate is relatively low for consumer prices. However, the size of the effect can be higher at the border, for import prices.

These results stimulate further work. In this paper, we have focused on the role of pass-through for the real exchange rate volatility and persistence. However, the capability of a model to replicate the persistence of real exchange rate could be improved by introducing physical capital. This feature should also improve the matching of the negative correlation between relative consumption and real exchange rate (the Backus Smith puzzle). More general preferences could be introduced to increase persistence. For example, translog preferences, or habit in consumption and in labor.

Finally, the empirical estimates could be used as a starting point for a microfounded two-country welfare analysis. Incomplete pass-through, in fact, modify the relative strength of substitution and wealth effect of a given change in the nominal exchange rate. The spillovers and the related welfare-improving policy measures could be not obvious.

INCOMPLETE

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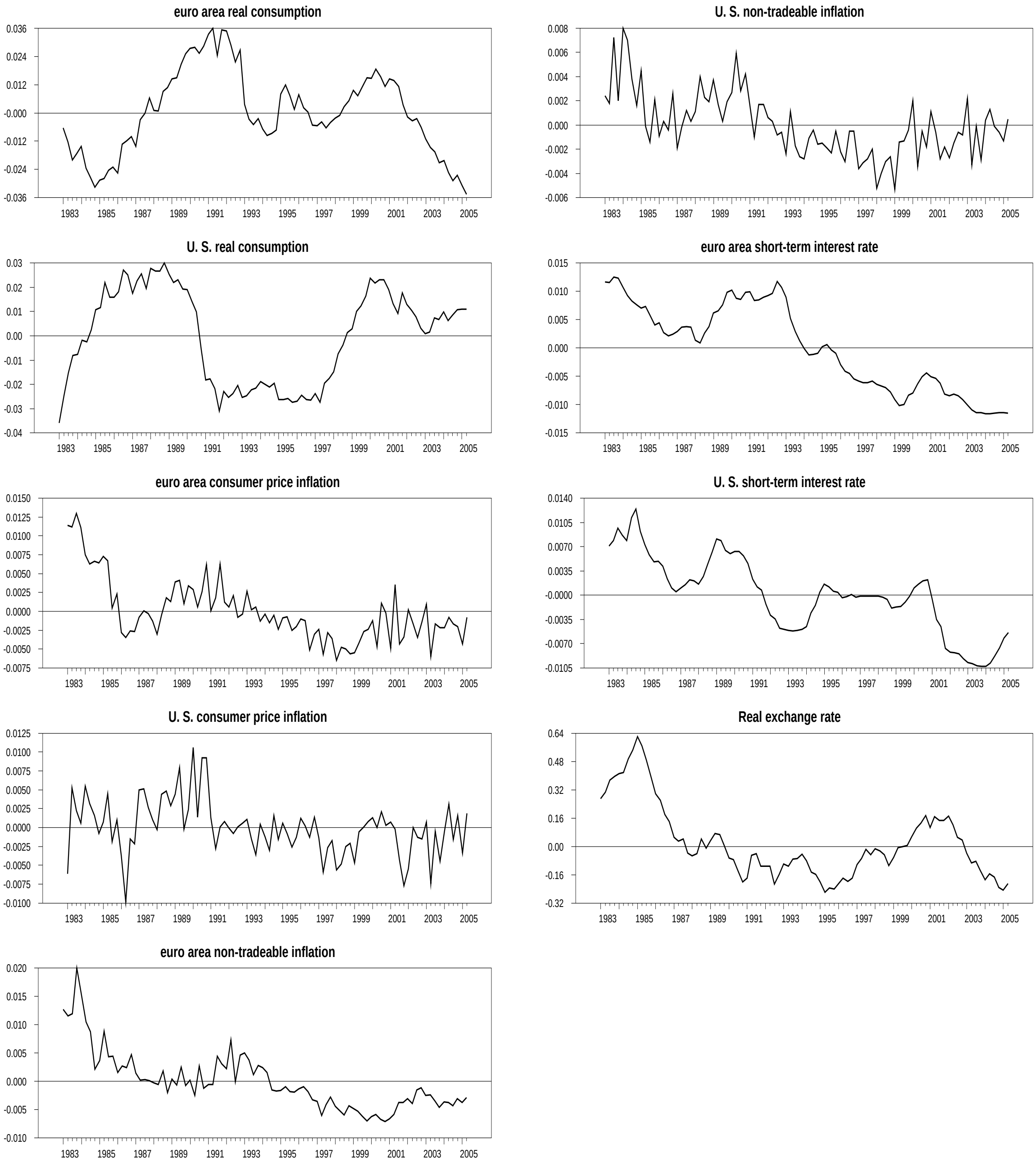

Figure 1. Data

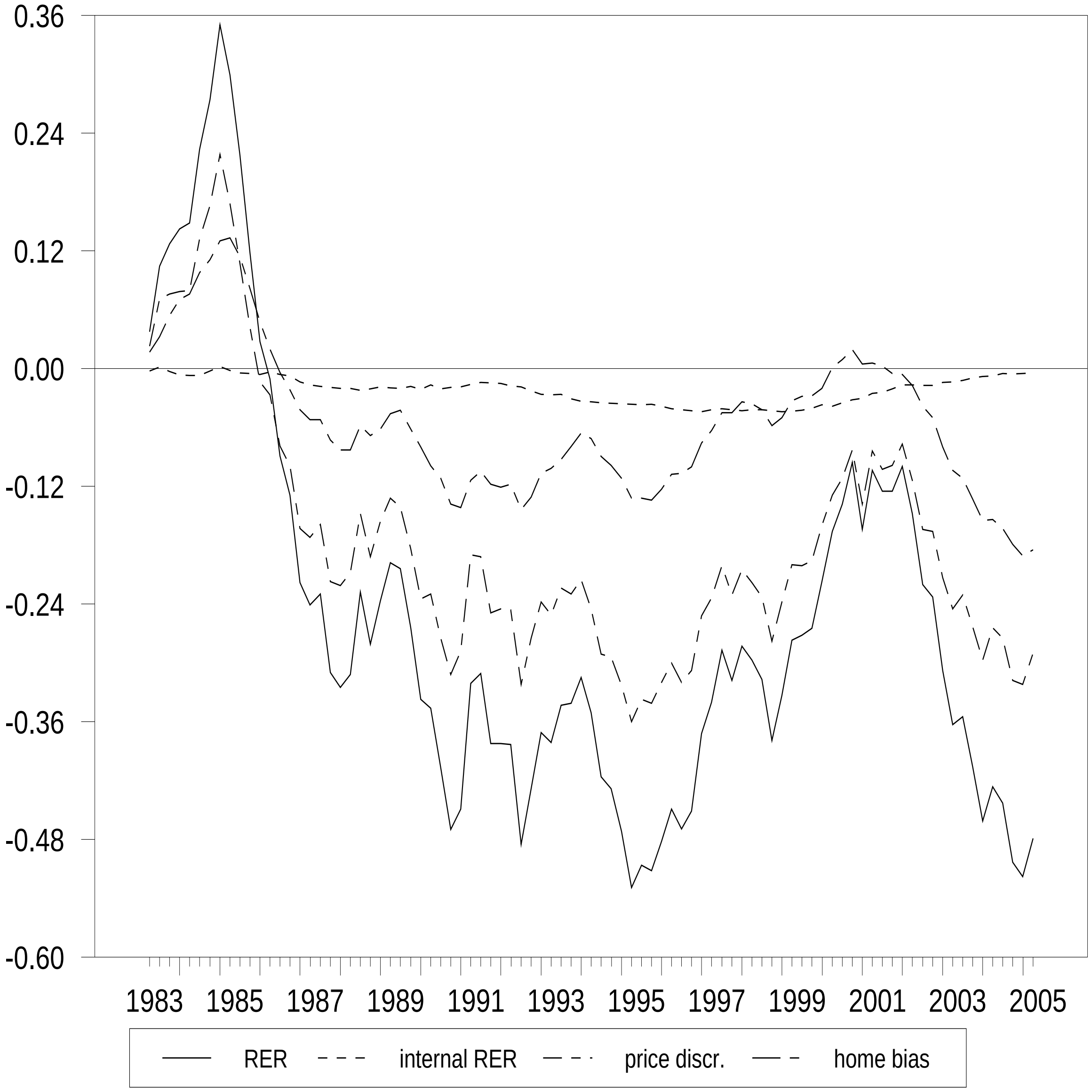

Figure 2. Decomposition of the real exchange rate between the euro-area and the US: Complete model

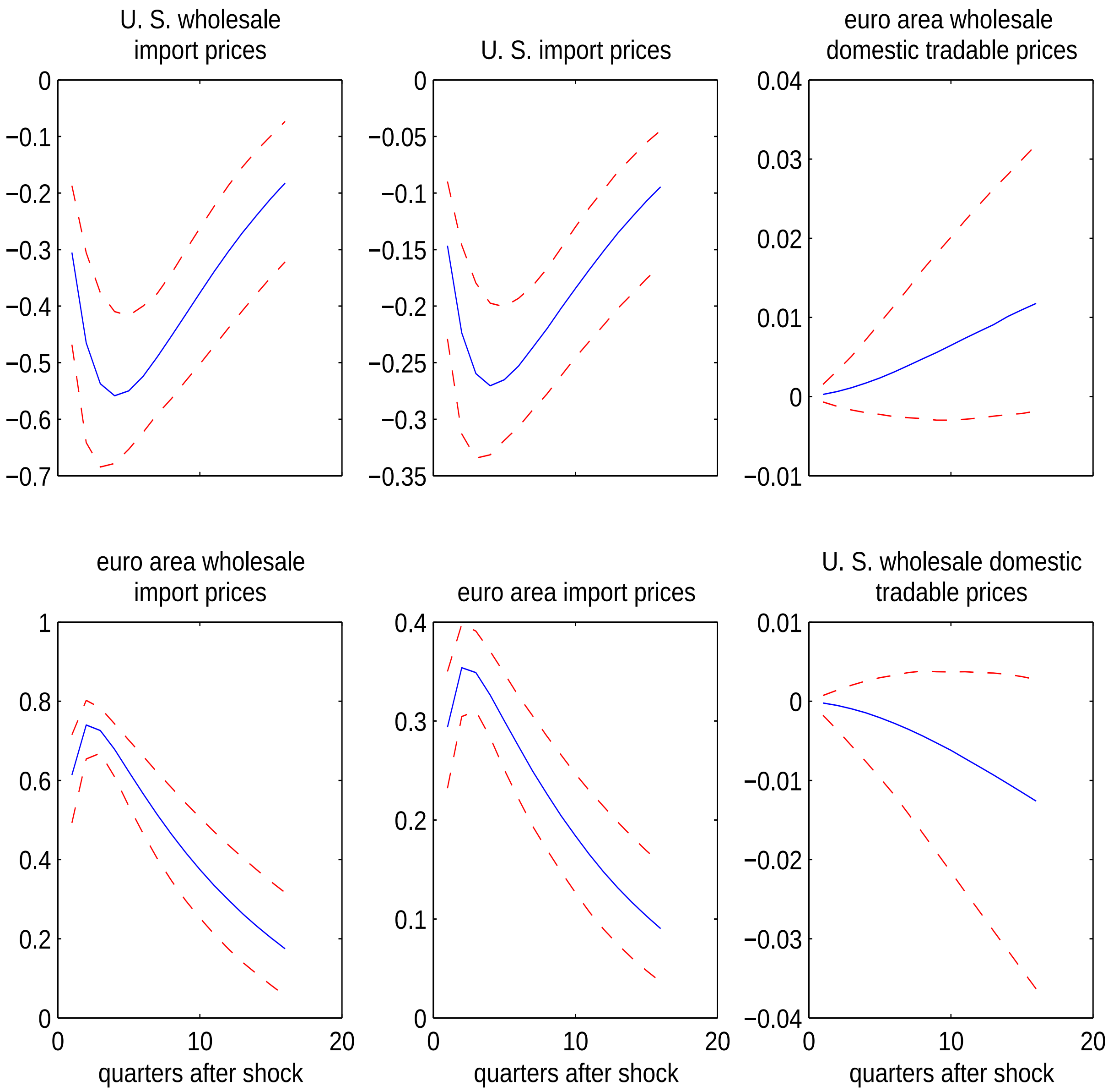

Figure 3. Exchange rate pass-through: Shock to the UIP condition

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_p	Beta	0.90	0.05
ρ	Gamma	1.14	0.10	ρ_p^*	Beta	0.90	0.05
ϕ	Gamma	0.74	0.10	ρ_u	Beta	0.90	0.05
σ	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_p	Uniform[0,10]	5	0.29
ρ_R^*	Beta	0.80	0.10	σ_p^*	Uniform[0,10]	5	0.29
ρ_π^*	Gamma	1.50	0.10	σ_u	Uniform[0,10]	5	0.29
ρ_Y^*	Normal	0.0	0.10	σ_R^*	Uniform[0,10]	5	0.29
ρ_S^*	Normal	0.0	0.10	σ_R^*	Uniform[0,10]	5	0.29
κ_H	Gamma	5.6	10.0	σ_T^*	Uniform[0,10]	5	0.29
κ_F	Gamma	5.6	10.0	σ_N^*	Uniform[0,10]	5	0.29
κ_N	Gamma	5.6	10.0	σ_T^*	Uniform[0,10]	5	0.29
κ_H^*	Gamma	5.6	10.0	σ_N^*	Uniform[0,10]	5	0.29
κ_F^*	Gamma	5.6	10.0	σ_W	Uniform[0,10]	5	0.29
κ_N^*	Gamma	5.6	10.0	σ_W^*	Uniform[0,10]	5	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. Statistics for the posterior distribution: Complete model

	posterior					prior	
parameter	2.5	50	97.5	mean	st. dev.	mean	st. dev.
κ_0	0.0045	0.0100	0.0184	0.0105	0.0041	0.01	0.005
ρ	1.0487	1.2247	1.4125	1.2265	0.0919	1.14	0.10
ϕ	0.6932	0.9130	1.1687	0.9176	0.1226	0.74	0.10
σ	1.9910	2.3470	2.7513	2.3529	0.1929	2.00	0.20
ρ_R	0.8324	0.8685	0.8997	0.8678	0.0172	0.80	0.10
ρ_π	1.4670	1.6678	1.8816	1.6700	0.1065	1.50	0.10
ρ_Y	0.1037	0.1952	0.2892	0.1954	0.0470	0.10	0.10
ρ_S	-0.0506	-0.0174	0.0201	-0.0169	0.0179	-0.0	0.10
ρ_R^*	0.8621	0.8992	0.9326	0.8987	0.0180	0.80	0.10
ρ_π^*	1.3337	1.5184	1.7165	1.5203	0.0976	1.50	0.10
ρ_Y^*	-0.1033	0.0991	0.2974	0.0986	0.1018	0.10	0.10
ρ_S^*	-0.0623	-0.0168	0.0345	-0.0160	0.0243	-0.0	0.10
κ_H	3.3856	10.1310	27.1556	11.4883	6.1898	5.6	10.0
κ_F	1.6086	3.2680	6.9822	3.5346	1.4088	5.6	10.0
κ_N	22.5164	53.6298	113.5779	57.3492	23.6343	5.6	10.0
κ_H^*	7.9886	22.6502	60.4401	25.7234	13.6383	5.6	10.0
κ_F^*	1.9055	2.8267	4.4724	2.9305	0.6874	5.6	10.0
κ_N^*	8.4375	26.7870	73.6306	30.6272	17.2781	5.6	10.0
κ_W	162.1143	283.8806	491.3413	295.8850	84.5535	63.0	40.0
κ_W^*	197.6208	348.9554	550.3467	355.6547	90.6009	63.0	40.0
ρ_p^*	0.8883	0.9231	0.9525	0.9224	0.0164	0.9	0.05
ρ_p	0.8888	0.9253	0.9561	0.9245	0.0172	0.9	0.05
ρ_u	0.8998	0.9311	0.9569	0.9304	0.0147	0.9	0.05
ρ_T^*	0.8499	0.9169	0.9614	0.9137	0.0289	0.9	0.05
ρ_N^*	0.8588	0.9183	0.9611	0.9161	0.0266	0.9	0.05
ρ_T^*	0.8387	0.8918	0.9345	0.8904	0.0244	0.9	0.05
ρ_N^*	0.8958	0.9426	0.9715	0.9402	0.0195	0.9	0.05
σ_p	0.0229	0.0286	0.0378	0.0291	0.0039	5.0	8.33
σ_p^*	0.0186	0.0240	0.0334	0.0245	0.0039	5.0	8.33
σ_u	0.0031	0.0044	0.0062	0.0045	0.0008	5.0	8.33
σ_R^*	0.0009	0.0010	0.0012	0.0011	0.0001	5.0	8.33
σ_R^*	0.0009	0.0011	0.0013	0.0011	0.0001	5.0	8.33
σ_T^*	0.0144	0.0216	0.0358	0.0226	0.0056	5.0	8.33
σ_N^*	0.0054	0.0088	0.0152	0.0092	0.0026	5.0	8.33
σ_T^*	0.0135	0.0167	0.0213	0.0169	0.0020	5.0	8.33
σ_N^*	0.0031	0.0054	0.0096	0.0056	0.0017	5.0	8.33
σ_W	0.0938	0.4609	1.1555	0.5035	0.2785	5.0	8.33
σ_W^*	0.0749	0.4130	1.0963	0.4583	0.2687	5.0	8.33
η	0.9167	1.0816	1.2659	1.0840	0.0882	1.2	0.10
a_H	0.8616	0.8960	0.9298	0.8959	0.0174	0.8	0.10
a_T	0.5406	0.6149	0.6925	0.6153	0.0389	0.45	0.10

Table 3. Statistics for the posterior distribution: LCP model

	posterior					prior	
parameter	2.5	50	97.5	mean	st. dev.	mean	st. dev.
κ_0	0.0046	0.0082	0.0108	0.0079	0.0041	0.01	0.005
ρ	0.9868	1.1715	1.3789	1.1745	0.0919	1.14	0.10
ϕ	0.5680	0.7510	0.9663	0.7553	0.1226	0.74	0.10
σ	1.9170	2.2697	2.6612	2.2747	0.1929	2.00	0.20
ρ_R	0.8261	0.8631	0.8968	0.8627	0.0172	0.80	0.10
ρ_π	1.5466	1.7478	2.0115	1.7572	0.1065	1.50	0.10
ρ_Y	-0.0801	0.0090	0.2342	0.0452	0.0470	0.10	0.10
ρ_S	-0.0402	-0.0050	0.0362	-0.0041	0.0179	-0.0	0.10
ρ_R^*	0.8254	0.8670	0.9113	0.8678	0.0180	0.80	0.10
ρ_π^*	1.4156	1.5959	1.7884	1.5973	0.0976	1.50	0.10
ρ_Y^*	-0.1078	0.0926	0.2859	0.0918	0.1018	0.10	0.10
ρ_S^*	-0.0416	-0.0076	0.0320	-0.0068	0.0243	-0.0	0.10
κ_H	5.5124	9.0060	18.3046	10.0090	3.1898	5.6	10.0
κ_F	3.5825	5.3245	7.9986	5.3561	1.4088	5.6	10.0
κ_N	41.1119	71.1131	115.6039	72.9456	19.6343	5.6	10.0
κ_H^*	1.7534	3.2481	9.2988	4.2385	2.6383	5.6	10.0
κ_F^*	3.2755	5.3095	8.9819	5.5538	1.6874	5.6	10.0
κ_N^*	24.5311	61.3477	121.0752	63.7559	27.2781	5.6	10.0
κ_W	25.4238	74.0857	407.9212	139.8955	122.5535	63.0	40.0
κ_W^*	23.7123	56.0477	189.3272	78.5536	50.6009	63.0	40.0
ρ_p^*	0.9013	0.9413	0.9762	0.9415	0.0164	0.9	0.05
ρ_p	0.8805	0.9261	0.9647	0.9253	0.0172	0.9	0.05
ρ_u	0.9373	0.9539	0.9666	0.9534	0.0147	0.9	0.05
ρ_T^*	0.9126	0.9622	0.9827	0.9580	0.0289	0.9	0.05
ρ_N^*	0.8986	0.9693	0.9884	0.9580	0.0266	0.9	0.05
ρ_T^*	0.8782	0.9463	0.9768	0.9418	0.0244	0.9	0.05
ρ_N^*	0.8999	0.9402	0.9683	0.9386	0.0195	0.9	0.05
σ_p	0.0193	0.0269	0.0370	0.0273	0.0039	5.0	8.33
σ_p^*	0.0148	0.0195	0.0269	0.0198	0.0039	5.0	8.33
σ_u	0.0026	0.0035	0.0047	0.0035	0.0008	5.0	8.33
σ_R^*	0.0009	0.0012	0.0015	0.0012	0.0001	5.0	8.33
σ_R^*	0.0010	0.0011	0.0014	0.0011	0.0001	5.0	8.33
σ_T^*	0.0050	0.0095	0.0184	0.0100	0.0056	5.0	8.33
σ_N^*	0.0075	0.0103	0.0133	0.0103	0.0026	5.0	8.33
σ_T^*	0.0061	0.0091	0.0150	0.0095	0.0020	5.0	8.33
σ_N^*	0.0055	0.0091	0.0132	0.0090	0.0017	5.0	8.33
σ_W	0.0108	0.0828	0.2140	0.0876	0.2785	5.0	8.33
σ_W^*	0.0045	0.0448	0.1443	0.0518	0.2687	5.0	8.33
η	...	...	...	...	...	...	...
a_H	0.9146	0.9470	0.9709	0.9461	0.0174	0.8	0.10
a_T	0.3457	0.5383	0.7438	0.5401	0.0389	0.45	0.10

Table 4. Statistics for the posterior distribution: PCP model

	posterior					prior	
parameter	2.5	50	97.5	mean	st. dev.	mean	st. dev.
κ_0	0.0033	0.0054	0.0099	0.0058	0.0018	0.01	0.005
ρ	1.0443	1.2241	1.4237	1.2261	0.0972	1.14	0.10
ϕ	0.5627	0.7426	0.9585	0.7471	0.1006	0.74	0.10
σ	1.8347	2.1661	2.5411	2.1725	0.1799	2.00	0.20
ρ_R	0.8267	0.8640	0.8962	0.8633	0.0177	0.80	0.10
ρ_π	1.4533	1.6522	1.8535	1.6516	0.1029	1.50	0.10
ρ_Y	0.1467	0.2250	0.3189	0.2268	0.0439	0.10	0.10
ρ_S	-0.0537	-0.0212	0.0133	-0.0209	0.0169	-0.0	0.10
ρ_R^*	0.8697	0.9100	0.9462	0.9095	0.0196	0.80	0.10
ρ_π^*	1.2981	1.4856	1.6867	1.4876	0.0992	1.50	0.10
ρ_Y^*	-0.0933	0.0998	0.2971	0.1005	0.0994	0.10	0.10
ρ_S^*	-0.0608	-0.0095	0.0499	-0.0083	0.0277	-0.0	0.10
κ_H	2.2296	3.5239	5.0725	3.5505	0.7812	5.6	10.0
κ_F	...	...	...	...	...	...	...
κ_N	10.9219	19.6154	43.4611	21.5959	8.3378	5.6	10.0
κ_H^*	...	...	...	...	...	...	...
κ_F^*	1.6033	3.3061	6.5133	3.4854	1.271	5.6	10.0
κ_N^*	0.7014	5.6455	24.7722	7.4513	6.6511	5.6	10.0
κ_W	210.2401	342.2764	519.6272	348.1872	79.475	63.0	40.0
κ_W^*	252.8069	366.3486	507.3019	370.0352	65.4145	63.0	40.0
ρ_p^*	0.8815	0.9134	0.9382	0.9125	0.0145	0.9	0.05
ρ_p	0.8705	0.9079	0.9384	0.9069	0.0173	0.9	0.05
ρ_u	0.9267	0.9463	0.9635	0.9460	0.0094	0.9	0.05
ρ_T^*	0.9209	0.9627	0.9805	0.9590	0.0159	0.9	0.05
ρ_N^*	0.9188	0.9498	0.9720	0.9486	0.0136	0.9	0.05
ρ_T^*	0.8601	0.9048	0.9362	0.9031	0.0195	0.9	0.05
ρ_N^*	0.9372	0.9718	0.9854	0.9692	0.0122	0.9	0.05
σ_p	0.0221	0.0270	0.0336	0.0273	0.0029	5.0	8.33
σ_p^*	0.0176	0.0227	0.0307	0.0231	0.0033	5.0	8.33
σ_u	0.0028	0.0038	0.0052	0.0038	0.0006	5.0	8.33
σ_R^*	0.0009	0.0010	0.0012	0.0010	0.0001	5.0	8.33
σ_R^*	0.0010	0.0011	0.0014	0.0011	0.0001	5.0	8.33
σ_T^*	0.0040	0.0052	0.0071	0.0053	0.0008	5.0	8.33
σ_N^*	0.0041	0.0053	0.0074	0.0054	0.0009	5.0	8.33
σ_T^*	0.0050	0.0066	0.0094	0.0067	0.0011	5.0	8.33
σ_N^*	0.0018	0.0028	0.0053	0.0030	0.0009	5.0	8.33
σ_W	0.1792	0.2771	0.3785	0.2744	0.0546	5.0	8.33
σ_W^*	0.1094	0.2223	0.3743	0.2249	0.0724	5.0	8.33
η	...	...	...	...	...	...	...
a_H	0.9635	0.9738	0.9817	0.9735	0.0046	0.8	0.10
a_T	0.5039	0.6336	0.7151	0.6268	0.0551	0.45	0.10

Table 5. Comparison of median values of parameters

parameter	Complete	LCP	PCP
κ_0	0.0100	0.0082	0.0054
ρ	1.2247	1.1715	1.2241
ϕ	0.9130	0.7510	0.7426
σ	2.3470	2.2697	2.1661
ρ_R	0.8685	0.8631	0.8640
ρ_π	1.6678	1.7478	1.6522
ρ_Y	0.1952	0.0090	0.2250
ρ_S	-0.0174	-0.0050	-0.0212
ρ_R^*	0.8992	0.8670	0.9100
ρ_π^*	1.5184	1.5959	1.4856
ρ_Y^*	0.0991	0.0926	0.0998
ρ_S^*	-0.0168	-0.0076	-0.0095
κ_H	10.1310	9.0060	3.5239
κ_F	3.2680	5.3245	...
κ_N	53.6298	71.1131	19.6154
κ_H^*	22.6502	3.2481	...
κ_F^*	2.8267	5.3095	3.3061
κ_N^*	26.7870	61.3477	5.6455
κ_W	283.8806	74.0857	342.2764
κ_W^*	348.9554	56.0477	366.3486
ρ_p^*	0.9231	0.9413	0.9134
ρ_p	0.9253	0.9261	0.9079
ρ_u	0.9311	0.9539	0.9463
ρ_T^*	0.9169	0.9622	0.9627
ρ_N^*	0.9183	0.9693	0.9498
ρ_T^*	0.8918	0.9463	0.9048
ρ_N^*	0.9426	0.9402	0.9718
σ_p	0.0286	0.0269	0.0270
σ_p^*	0.0240	0.0195	0.0227
σ_u	0.0044	0.0035	0.0038
σ_R^*	0.0010	0.0012	0.0010
σ_R^*	0.0011	0.0011	0.0011
σ_T^*	0.0216	0.0095	0.0052
σ_N^*	0.0088	0.0103	0.0053
σ_T^*	0.0167	0.0091	0.0066
σ_N^*	0.0054	0.0091	0.0028
σ_W	0.4609	0.0828	0.2771
σ_W^*	0.4130	0.0448	0.2223
η	1.0816	...	...
a_H	0.8960	0.9470	0.9738
a_T	0.6149	0.5383	0.6336

Table 6. Marginal densities

Model	**Marginal density**
Complete	2977
LCP	2970
PCP	2974

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

Table 7. Selected second moments of the real exchange rate

Moment	**Data**	**Complete**			**LCP**			**PCP**		
percentiles		2.5	50	97.5	2.5	50	97.5	2.5	50	97.5
$\sigma\left(RS_t\right)$	20.74	7.41	14.32	33.01	8.57	14.10	23.09	7.94	14.46	26.73
$\rho\left(RS_t\right)$	0.97	0.92	0.92	0.94	0.91	0.93	0.94	0.91	0.93	0.94
$\rho\left(RS_t, \frac{C_t}{C_t^*}\right)$	-0.48	-0.32	-0.39	-0.37	-0.29	-0.28	-0.29	-0.39	-0.51	-0.63

Notes: Each figure is computed using the percentiles of the marginal posterior distribution of the parameters reported in in the first row ('percentiles') and simulating 10,000 time series the variables of the model of length equal to that of the data and dropping the first 1000 observations.

Table 8A. Selected second moments of the observable variables: Complete model

		σ					ρ				
	Data	All	$\sigma_u=0$	$\sigma_p=0$	$\sigma_R\neq 0$	$\sigma_Z\neq 0$	All	$\sigma_u=0$	$\sigma_p=0$	$\sigma_R\neq 0$	$\sigma_Z\neq 0$
RS	0.97	14.32	6.12	13.37	1.30	2.56	0.92	0.96	0.92	0.78	0.96
π_c	0.75	0.50	0.49	0.46	0.05	0.44	0.64	0.65	0.59	0.68	0.60
π_c^*	0.40	0.45	0.44	0.42	0.06	0.41	0.48	0.47	0.42	0.80	0.40
π_n	0.85	0.42	0.42	0.37	0.04	0.36	0.79	0.78	0.75	0.86	0.75
π_n^*	0.57	0.35	0.34	0.31	0.06	0.30	0.74	0.74	0.71	0.86	0.70
R	0.98	0.48	0.48	0.32	0.14	0.28	0.95	0.95	0.91	0.75	0.95
R^*	0.97	0.35	0.35	0.24	0.16	0.17	0.93	0.92	0.87	0.78	0.93
C	0.49	1.35	1.32	0.79	0.33	0.67	0.84	0.84	0.91	0.75	0.94
C^*	0.96	1.15	1.13	0.66	0.44	0.42	0.84	0.83	0.87	0.78	0.94

Notes: Each figure in the table is computed using the median of the marginal posterior distribution of the parameters and simulating 10,000 time series the variables of the model of length equal to that of the data and dropping the first 1000 observations.

Table 8B. Selected second moments of the observable variables: Complete model

	All	$\sigma_u = 0$	$\sigma_p = 0$	$\sigma_R \neq 0$	$\sigma_Z \neq 0$
$\rho\left(RS_t, \frac{C_t}{C_t^*}\right)$	-0.39	-0.29	-0.35	1.00	0.85

Notes: Each figure in the table is computed using the median of the marginal posterior distribution of the parameters and simulating 10,000 time series the variables of the model of length equal to that of the data and dropping the first 1000 observations.

Table 9. Real exchange rate fluctuations: Economic decomposition

(Percentage of variance of the real exchange rate)

	Complete			**LCP**			**PCP**		
component	2.5	50	97.5	2.5	50	97.5	2.5	50	97.5
σ(Internal Rexc)	0.86	0.24	0.06	1.87	0.67	0.22	0.85	0.24	0.13
σ(Home bias)	12.17	7.55	4.87	36.24	35.68	32.03	93.91	96.60	98.08
σ(IPD)	45.71	55.71	65.35	18.19	25.06	32.63	0.00	0.00	0.00
σ(Int. Rexc, home bias)	-1.07	-0.08	-0.00	7.31	1.78	-0.29	5.28	3.16	1.82
σ(Int. Rexc, IPD)	4.39	2.34	0.96	4.85	1.91	0.62	0.00	0.00	0.00
σ(Home bias, IPD)	37.94	34.22	28.74	31.47	34.83	34.73	0.00	0.00	0.00

Notes: Each figure in the table is computed using the median, the 2.5 and the 97.5 percentiles of the marginal posterior distribution of the parameters and simulating 10,000 time series the variables of the model of length equal to that of the data and dropping the first 1000 observations.

Table 10. Decomposition of the asymptotic forecast error variance: Complete model

Variable	z_H	z_F^*	z_N	z_N^*	z_R	z_R^*	z_U	z_U^*	z_U	z_W	z_W^*	Total
euro-area												
C	10.2	0.3	13.3	0.0	5.4	0.0	63.9	0.7	5.9	0.3	0.0	100
π_c	47.8	0.4	29.3	0.0	0.7	0.1	15.5	0.2	4.8	1.1	0.0	100
π_{nt}	14.8	0.0	59.7	0.0	0.8	0.0	21.6	0.2	1.7	1.2	0.0	100
R	16.7	0.1	16.2	0.0	8.4	0.0	56.2	0.2	1.8	0.4	0.0	100
re	1.5	0.6	0.5	0.3	0.2	0.3	11.1	8.0	77.5	0.0	0.0	100
US												
C	0.8	3.8	0.0	8.3	0.0	13.1	1.4	64.2	8.2	0.0	0.2	100
π_c	0.4	53.0	0.0	28.0	0.0	1.7	0.7	10.4	4.4	0.0	1.4	100
π_{nt}	0.1	8.2	0.0	64.2	0.0	2.4	1.1	17.2	5.2	0.0	1.7	100
R	0.1	7.6	0.0	14.2	0.0	18.2	1.1	53.1	5.4	0.0	0.3	100

Notes: Each figure in the table is computed using the median of the marginal posterior distribution of the parameters.