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Measuring the Euro-Dollar Permanent Equilibrium Exchange Rate using the Unobserved Components Model¹

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Abstract

This paper employs an unobserved component model that incorporates a set of economic fundamentals to obtain the Euro-Dollar permanent equilibrium exchange rates (PEER) for the period 1975Q1 to 2008Q4. The results show that for most of the sample period, the Euro-Dollar exchange rate closely followed the values implied by the PEER. The only significant deviations from the PEER occurred in the years immediately before and after the introduction of the single European currency. The forecasting exercise shows that incorporating economic fundamentals provides a better long-run exchange rate forecasting performance than a random walk process.

JEL Classifications: F31; F47

Key words: Permanent Equilibrium Exchange Rate; Unobserved Components Model; Exchange rate forecasting.

1. Introduction

The Euro-dollar exchange rate has become the pivotal exchange rate in the international monetary system, much as the German mark–US dollar rate was prior to the formation of the euro. Since its launch in 1999, the Euro-Dollar exchange rate has experienced large fluctuations. As Figure 1 shows, it depreciated steadily from 1999 to 2002 before steadily rising until 2008. This behaviour has puzzled many commentators because it did not seem to be warranted by the traditional set of economic fundamentals (see, for example, Belloc and Federici (2010)). Indeed, at the inception of the Euro the perceived wisdom was that it would stay at parity with the US dollar. The study of such anomalous behaviour has given rise to a growing literature that investigates the relationship between the Euro-Dollar exchange rate and economic fundamentals. They include the productivity differential between Europe and the US (Corsetti and Pesenti, 1999, Alquist and Chinn, 2002, Schnatz et al, 2004, Miller 2008); the growth rate, inflation differentials, current account patterns (De Grauwe, 2000, De Grauwe and Grimaldi, 2005); interest rate differentials and relative rates of return in the US and euro area (Bailey et al., 2001, Heimonen, 2009). Others have focused on non-fundamental factors, such as order flows (Dunne et al. 2010); different quoting activity of investors in response to announcements (Omrane and Heinen, 2009) and the existence of chaotic dynamics in the Euro-Dollar exchange rate when investors have heterogeneous beliefs (Federici and Gandolfo 2012).

Despite the large body of research in this area, the depreciation of the Euro against the dollar remains a puzzle. Understanding movements of the Euro-Dollar exchange rates also remains an important issue for both academics and policy makers. In this paper, we study the equilibrium values of the Euro-Dollar exchange rate as, in

theory, a currency's value should gravitate in the direction of its long-run equilibrium over time.

There are a large variety of methods available for calculating a country's equilibrium exchange rate, from the internal-external balance approach, to the behavioural and permanent equilibrium approaches (BEER and PEER), through to the new open economy macroeconomic (NOEM) approach (see MacDonald (2000) and Driver and Westaway (2004) for a survey of the literature). All of these approaches have their own advantages and disadvantages.⁴ This is perhaps why end users (such as central banks and practitioners) use a range of estimating techniques in coming to a view as to whether an exchange rate is misaligned.

In this paper we focus on an extension to the so-called PEER approach. In summary, this approach relies on decomposing an actual real exchange rate into its permanent and transitory components, and then using the permanent component as a measure of the equilibrium exchange rate. A variety of time series methods have been used to extract the permanent component including the Beveridge-Nelson (1981) decompositions (Huizinga, 1986; Cumby and Huizinga, 1990), structural vector autoregression (Clarida and Gali, 1994), cointegration-based methods (Clark and MacDonald, 2004), and the unobserved components (UC) approach (Berger and Kempa, 2011).

This paper estimates the Euro-Dollar PEER using the UC framework. However, in contrast to the UC model specification in Berger and Kempa (2011),

4. The equilibrium exchange rate determined under the internal-external balance framework requires that any current account imbalance must be sustainable. However, this approach contains a normative element in defining what is meant by sustainability and internal balance. In contrast, the BEER approach is not normative. The exchange rate relationship determined under the BEER approach is subject to statistical testing. However, the BEER is consistent with the observed economic fundamentals. Therefore, business cycle factors may contribute heavily to the measure of equilibrium exchange rates. Finally, the NOEM models assume the optimizing behaviour of consumers that has implications for the current account and exchange rates. However, the NOEM models cannot produce a trend appreciation of real exchange rates such as these observed for the Central and Eastern Europe economies (Égert et al. 2006).

which is based on a small open economy model, our UC model incorporates a set of economic fundamentals that are most frequently applied when using the BEER approach (See Clark and MacDonald, 1999). We analyse the PEER, instead of a BEER, because there are two major advantages of using the UC model specified in this paper to obtain the PEER. First, compared to the BEER approach, our UC model setup clearly distinguishes between the impact of the long-term and short-term components of an economic fundamental on the real exchange rate. This helps us to separate business cycle factors from the equilibrium exchange rate movements. This addresses the weakness of the BEER approach discussed in Égert et al. (2006). Second, the UC model enables us to obtain true, ex-ante exchange rate forecasts incorporating long-run relationships between the real exchange rate and economic fundamentals. In contrast to the VECM or error correction models used in MacDonald and Taylor (1993), Chinn and Meese (1995) and Cheung et al. (2005), we do not have to impose a pre-estimated cointegration vector or long-run relationship prior to producing exchange rate forecasts. The forecasts of real exchange rates from $t = T + 1$ to $T + l$ are obtained using observations of past exchange rates and fundamentals up to $t = T$. In addition, although we found a cointegration relationship between the Euro-Dollar exchange rate and its economic fundamentals, in the case of exchange rates where cointegration is not identified, our UC model setup is still applicable. Failure to find cointegration between the real exchange rate and the economic fundamentals can occur because the BEER approach is not based on any specific exchange rate model and in that sense may be regarded as a very general approach to modelling equilibrium exchange rates. The rejection of cointegration may be due, for example, to omitted variables from the cointegration relationship. In this case, standard regression and cointegration analysis cannot obtain robust estimates of a long-run

relationship. However, as demonstrated by Everaert (2010), the UC model can overcome this issue.

The remainder of this paper is structured as follows. In the next section we outline our unobserved component models of the PEER. In section 3 we discuss the data used. Section 4 contains our estimates of the unobserved component models, while Section 5 contains the out-of-sample forecasting results. Section 6 concludes.

2. The model

2.1 Permanent and transitory decomposition of the real exchange rates

This paper implements the UC model to obtain the Euro-Dollar PEER and estimate the subsequent misalignment from 1975Q1 to 2008Q4.⁵ The UC model decomposes observed time series into their unobserved elements, such as its permanent (trend) and transitory (cycles) components. The permanent component represents the long-term development of a time series, while the transitory component represents the business cycle movements. Each unobserved component is formulated as a stochastic process. The decomposition of an observed time series into its unobserved components provides a better understanding of the dynamics of the series. It also enables us to forecast future observations in the series (Harvey, 2006). Using the UC framework to obtain the PEER and misalignment is not completely new. For example, Berger and Kempa (2011) implement a UC model based on a small open economy model to estimate the Canadian-US PEER. Our UC model specification differs from this approach as it incorporates a set of economic fundamentals suggested by Clark and

⁵ We have chosen to end the sample period in 2008 to avoid the effects of financial crisis and the ‘great recession’ which we believe would dominate the data set and prevent our UC based estimates being comparable to other estimates.

MacDonald (1999), which relate the real exchange rate movements to the economic fundamentals, such that

$$q_t = \beta' Z_t + \varepsilon_t \quad (1)$$

Where q_t is the real exchange rate, Z_t contains a set of economic fundamentals. ε_t is a random disturbance and β is a vector of coefficients. In this paper, we assume that $Z_t = (tot_t, pd_t, gov_t, rid_t)'$, and tot_t , pd_t , gov_t and rid_t denote the terms of trade differential, the productivity differential, the relative government expenditure to GDP ratio and the real interest rate differential between the euro area and the US, respectively.⁶ The real exchange rate can be affected by these economic fundamentals. For example, the terms of trade is the ratio of export prices to import prices and is related to a country's current account and balance of payments. If the price of a country's exports rises by more than its imports, its terms of trade will improve. This, in turn, results in rising demand for that country's currency and an appreciation of its real exchange rate. In addition, a country's fiscal balance can be a key determinant of its exchange rate. A permanent increase in government expenditure to GDP ratio may lead to monetisation of government debt. A large debt burden may prove worrisome to foreign investors if they believe the country risks defaulting on its obligations. Therefore, they may become less willing to own securities denominated in that currency and this will lead to a depreciation of the real exchange rate. Conversely, a

⁶ The relation between the real exchange rates and real macroeconomic fundamentals is discussed in Faruquee (1994), MacDonald (1997) and Fell (1996). Although there is a strong theoretical case for including net foreign assets in an equilibrium exchange rate relationship, net foreign assets typically do not prove to be significant in the kind of specification used here, largely because our determinants will ultimately be the drivers of the evolution of net foreign assets and there will be collinearity issues. The NFA term seems to work better in simpler models, such as that of Lane and Milesi-Ferretti (2002) where it is a (the) key driver of the equilibrium exchange rate.

fiscal tightening that permanently improves the net foreign assets position of a country will lead to a real exchange rate appreciation (Frenkel and Mussa 1988). Furthermore, real interest rate differentials are frequently introduced as a determinant of the real exchange rate via the uncovered interest rate parity condition. Higher interest rates in a country relative to other countries will attract foreign capital and cause its exchange rate to rise. Although economic theory suggests that the interest rate differential should tend to equalise across countries in the long run, in the short to medium term it will impact on the real exchange rate. Finally, the impact of productivity differentials on the real exchange rate is illustrated by Balassa-Samuelson theory, which states that the relatively larger increases in productivity in the traded goods sector are associated with a real appreciation of a country's currency.

In the UC framework, the real exchange rate can be directly related to the permanent and transitory components of the above four fundamentals, such that

$$q_t = \left(\theta_1 \overline{tot}_t + \theta_2 \overline{pd}_t + \theta_3 \overline{gov}_t \right) + \left(\vartheta_1 \widehat{tot}_t + \vartheta_2 \widehat{pd}_t + \vartheta_3 \widehat{gov}_t + \vartheta_4 \widehat{rid}_t \right) + \mu_t, \quad (2)$$

where \overline{tot}_t , \overline{pd}_t and \overline{gov}_t are the permanent components of the fundamentals, often modelled as random walk processes, whilst \widehat{tot}_t , \widehat{pd}_t , \widehat{gov}_t and \widehat{rid}_t are the transitory components. As with most of the existing literature, we find that rid_t is a stationary variable, and thus does not have a permanent component.⁷ We allow the permanent and transitory components of each fundamental to have different coefficients in equation (2). This is motivated by the idea that the permanent and

⁷ Unit root test statistics presented in Appendix B suggest that rid_t is a stationary variable, and is therefore a sum of an AR process and irregular term.

transitory components of the fundamentals may not have a uniform impact on real exchange rate movements.⁸

However, if the real exchange rate does not constitute a cointegrating relationship with the permanent components of a set of selected fundamentals, μ_t will be an $I(1)$ error term in equation (2). Failure to find cointegration should be taken as evidence against the existence of a stable long-run equilibrium relationship between the real exchange rate and the permanent components of selected fundamentals. However, Everaert (2010) demonstrates using a Monte Carlo experiment that there may still be long-run relationships between integrated but non-cointegrated variables. Following Everaert (2010), we specify μ_t as the sum of an irregular term, ε_{1t} , and a random walk component, v_t :

$$\mu_t = v_t + \varepsilon_{1t}, \quad \varepsilon_{1t} \sim NID(0, \sigma_{\varepsilon 1}) \quad (3)$$

$$v_t = v_{t-1} + \eta_{1t}, \quad \eta_{1t} \sim NID(0, \sigma_{\eta 1}) \quad (4)$$

where v_t represents any $I(1)$ omitted variables from the cointegration relation. Studies which use the UC models to account for omitted variables from the cointegration relationship, include Harvey et al. (1986), Sarantis and Stewart (2001) and Berger and Everaert (2010).⁹ The long-run relationship between non-cointegrated

⁸ For example, according to Frenkel and Mussa (1988), the permanent component of the relative government expenditure to GDP ratio may be negatively related to the real exchange movements, as permanent increases in government expenditure may lead to monetisation of government debt and pressure on currency depreciation in the long-run. However, in the short to medium-run, the real exchange rate can be positively affected by a rise in government spending as it may likely to increase net domestic demand.

⁹ Harvey et al. (1986) implement a UC model to account for an underlying productivity trend in the employment-output relation. Sarantis and Stewart (2001) use an UC model to capture the omitted variables such as wealth from the consumption-income relation. Berger and Everaert (2010) implement a panel UC model to count for labour market institution in the unemployment and labour tax rates.

variables can be estimated consistently with maximum likelihood (ML) using the Kalman filter and the significance of the long-run relationship between non-cointegrated variables can be tested using standard Wald or a likelihood ratio (LR) tests (Chang et al., 2009 and Everaert, 2010). Moreover, the UC model can easily accommodate a cointegration analysis using the methods proposed by Nyblom and Harvey (2000); if $\sigma_{\eta_1} = 0$ in equation (4), v_t reduces to a constant, and cointegration is found between real exchange rate and the permanent components of economic fundamentals in equation (2).

Clark and MacDonald (1999) define the PEER as the elements of the real exchange rate driven by the permanent components of the economic fundamentals. Therefore, their PEER is measured by $\theta_1 \overline{tot}_t + \theta_2 \overline{pd}_t + \theta_3 \overline{gov}_t + v_t$, where v_t is interpreted as the permanent components of any omitted fundamentals from the cointegration relationship. The total misalignment is then defined as the difference between the real exchange rate and the PEER, $\vartheta_1 \widehat{tot}_t + \vartheta_2 \widehat{pd}_t + \vartheta_3 \widehat{gov}_t + \vartheta_4 \widehat{rid}_t + \varepsilon_{1t}$.

2.2 Permanent and transitory decomposition of economic fundamentals

The terms of trade differential, the productivity differential (Balassa-Samuelson effect) and the relative government expenditure to GDP ratio are the non-stationary variables, and are considered to have a long-term effect on the real exchange rate movements. Therefore, the three fundamentals are decomposed into the permanent, transitory and irregular components as follows:

$$Y_t = \overline{Y}_t + \widehat{Y}_t + \varepsilon_{Yt} \quad (5)$$

To save space, \bar{Y}_t represents the permanent components (i.e. \overline{tot}_t , \overline{pd}_t and \overline{gov}_t) and \hat{Y}_t denotes the transitory components (i.e. \widehat{tot}_t , \widehat{pd}_t and \widehat{gov}_t). The permanent component, \bar{Y}_t , is referred to as the permanent (equilibrium) value of the fundamentals. The transitory component, \hat{Y}_t , measures the extent to which the actual fundamental deviate from its equilibrium level. \bar{Y}_t and \hat{Y}_t are modelled as follows,

$$\bar{Y}_t = \bar{Y}_{t-1} + \beta_{\bar{Y}} + \eta_{\bar{Y}}, \quad \eta_{\bar{Y}} \sim \text{NID}(0, \sigma_{\eta Y}^2), \quad (6)$$

$$\hat{Y}_t = \phi_{\hat{Y}}(L) \hat{Y}_{t-1} + \kappa_{\hat{Y}}, \quad \kappa_{\hat{Y}} \sim \text{NID}(0, \sigma_{\kappa Y}^2). \quad (7)$$

In contrast to the above three fundamentals, the real interest rate differential is a stationary variable, and is considered to have a short to medium term effect on real exchange rate movements. Therefore, the real interest rate differential is modelled as the sum of a transitory component and an irregular term.

Finally, the above UC model, consisting of equations (2)-(7), can be recast into state-space form for estimation. The state-space model is presented in Appendix A. The hyperparameters in the UC model can be estimated by maximum likelihood using the prediction error decomposition produced by the Kalman filter. Since non-stationary variables, such as \overline{tot}_t , \overline{pd}_t , \overline{gov}_t and v_t , appear in the state vector, the Kalman filter requires a diffuse initialisation, and we use the initialisation method developed by Koopman and Durbin (2003). Estimating the multivariate UC model,

we can obtain the unobserved permanent and transitory components and the coefficients on the real exchange rate equation simultaneously.¹⁰

3. Data

Our empirical analysis is based on the Euro-Dollar real exchange rate, and the four fundamentals: the terms of trade differential, the productivity differential, the relative government expenditure to GDP ratio and the real interest rate differential of euro area relative to the US. The synthetic euro area data is constructed by aggregating country-specific variables of the member countries. The series are taken from the IMF International Financial Statistics (IFS), and from the OECD Labour productivity growth dataset. Appendix B sets out in more detail how the data was constructed. All variables, with the exception of the real interest rate differential, are transformed into logarithms for the estimation.

4. Estimation results

4.1 *The baseline model*

The parameter estimates of the UC model (hereafter, Model 1) outlined in Section 2 are reported in Table 1.¹¹ Table 1 presents the coefficients of the real exchange rate equation (2). In general, these coefficients are consistent with standard predictions in the literature. The coefficient of the permanent component of the terms of trade differential, θ_1 , appears positive and statistically significant indicated by the LR

¹⁰ All the computations were performed using the library of state-space functions in SsfPack 3.0 developed by Koopman et al. (2008) and Ox 5 by Doornik (2006).

¹¹ Inspection of the auxiliary residuals allows us to detect two outliers occurring during 1980Q1 and 2008Q3 for the real interest rate differential and the terms of trade, respectively. Two dummy variables are used for these outliers. The coefficients on both dummy variables are statistically significant.

statistic. This reflects a substitution effect generated by higher prices of exported goods relative to imported goods. Higher export prices will initially lead to higher wages in the tradable sector relative to the non-tradable sector, and eventually raise the overall price level in the domestic country and an appreciation of the domestic currency. The coefficient of the permanent component of the relative government expenditure to GDP ratio, θ_3 , is negative and significant. This is consistent with the argument of Frenkel and Mussa (1985) that a permanent increase in the government expenditure to GDP ratio will lead to monetisation of government debt and real exchange rate depreciation in the long-run. Although the other coefficients in equation (2) are statistically insignificant, they all have the expected signs.¹² Diagnostic test statistics are also presented in Table 1. Both the Ljung-Box statistics for autocorrelation in the one-step-ahead prediction errors and the Jarque-Bera statistics for normality are insignificant. This indicates that Model 1 is appropriately specified.

{Table 1 about here}

4.2 AR(2) specification for the transitory component of the real exchange rate

Estimation results from Model 1 suggest that the real Euro-Dollar exchange rate movements are primarily driven by the permanent components of the terms of trade differential and the relative government expenditure to GDP ratio. None of the transitory components of the economic fundamentals seem to have significant

¹² θ_2 is positive as suggested by the Balassa-Samuelson effect (Balassa, 1964 and Samuelson, 1964): higher productivity in the domestic relative to the foreign economy is expected to result in an appreciation of the domestic currency. In addition, Frenkel and Mussa (1985) suggests that in the short to medium-run, the real exchange rate appreciates if a rise in government spending increases net domestic demand, and thus θ_{20} is expected to be positive. Finally, a country that has higher interest rate yields, will have pressure on its currency to appreciate, and thus θ_{40} is positive.

influence on the real exchange rate. Our result reflects the limitation of using traditional economic fundamentals in explaining exchange rate fluctuations in the short-run. As discussed in Frankel and Rose (1995) and Rogoff (2001) the exchange rate is known to have a low correlation with other economic variables except at low frequencies. The short-run movements of exchange rates are therefore likely to be driven by non-fundamental factors, such as noise trading and irrational behaviour. Therefore, we model the transitory component of the real exchange rate, \hat{q}_t , as an exogenous AR process,

$$\hat{q}_t = \phi_q(L)\hat{q}_{t-1} + \kappa_q,$$

and equation (2) therefore becomes:¹³

$$q_t = (\theta_1 \overline{tot}_t + \theta_2 \overline{pd}_t + \theta_3 \overline{gov}_t) + \hat{q}_t + \mu_t, \quad (8)$$

The parameter estimates of this modified model (Model 2) are reported in Table 2. We observe a moderate increase in the size of θ_1 , θ_2 and θ_3 compared to Model 1. However, the significance of these coefficients does not alter.

{Table 2 about here}

Although Models 1 and 2 can provide a non-spurious long-run relation between the real exchange rate and the permanent components of the fundamentals,

¹³ As the real interest rate differential does not appear in equation (8), when transitory component of the real exchange rate is modelled as an AR process we exclude this variable for Model 2.

regardless whether these variables are cointegrated, we found that the estimates of σ_{η_1} in equation (4) are close to zero for Models 1 and 2. This may indicate the existence of a cointegration relation. We used Nyblom and Harvey (2000) to test the null hypothesis that $\sigma_{\eta_1} = 0$. The test statistics are presented in the upper panel of Table 3. They confirm that the real exchange rate constitutes a cointegration relation with the permanent components of the integrated fundamentals. The null hypothesis that $\sigma_{\eta_1} = 0$ cannot be rejected when the lag length $m \geq 2$.¹⁴ As a robustness check, the trace and maximum eigenvalue statistics obtained from Johansen's cointegration approach are presented in lower panel of Table 3. They also indicate the existence of a cointegration relation between the real exchange rate and the integrated economic fundamentals.

{Table 3 about here}

4.3 The PEER and total misalignment

Figure 1 plots the permanent and transitory components of the real exchange rate and economic fundamentals obtained from Model 1. It shows that the euro was relatively close to its equilibrium values and the total misalignment was modest during the 1970s and 1980s. The period 1975 to 1980, following the advent of floating exchange rates, is characterized by an overvaluation of the euro. The real Euro-dollar exchange rate is above its PEER. However, the dollar strengthened significantly during the second half of the 1980s. In response, to the appreciation of the dollar during this period and the substantial US current account deficit, the

¹⁴ The details of the test are discussed in Nyblom and Harvey (2000).

September 1985 ‘Plaza Accord’ was signed between the US and the G5 to induce a gradual depreciation of the dollar. Our results suggest that the appreciation of the dollar against the euro was primarily due to a shift in the PEER during this period. From mid-1985 the trend of dollar appreciation rapidly reversed. Strong signs that the dollar was undervalued became apparent in 1995-1998. This corresponds to a period of weakness of the dollar against the major European currencies.

Finally, following the launch of the euro in 1999 the Euro-Dollar real exchange rate was considerably undervalued relative to the PEER until 2003. As shown in Figure 2, Models 1 and 2 produce consistent estimates for the PEER and the total misalignment.

Considering the period 1975–2000, our findings are broadly consistent with earlier contributions (Maeso-Fernandez et al. 2002; Detken et al., 2002; Duval 2002). Maeso-Fernandez et al (2002) estimate a BEER and PEER of the euro effective exchange rates using various model specifications. The authors found periods of dollar undervaluation against the euro in the late 1970s and in 1987 in the aftermath of the ‘Louvre Accord’. There are also periods of dollar overvaluation identified during the mid 1980s and 2000, although the magnitude of overvaluation varies depending on the model specifications used. Duval (2002) builds a dynamic model for the Euro-Dollar real equilibrium exchange rate using the NATREX and the BEER approaches. Their findings suggest that the euro was undervalued against the dollar in the mid-1980s and from 1999 onwards. Detken et al. (2002) estimate equilibrium values of the euro effective exchange rates. Their results confirm that the euro was overvalued in the second half of the 1970s until the beginning of the 1980s. They also found two periods of strong undervaluation of the effective Euro exchange rate during the mid-1980s and, from 1998 until the end of their sample in 2000.

In addition to using our UC models, we also use Clark and MacDonald's (2004) cointegration-based PEER approach to estimate the PEER as a robustness check.¹⁵ The PEER and the total misalignment cointegration-based PEER, obtained using the Granger and Gonzalo (GG) (1995) decomposition, are also presented in Figure 2. They appear to be broadly consistent with those estimated from Models 1 and 2, although the results from Models 1 and 2 seem to suggest that the euro is closer to its equilibrium value than implied by the cointegration-based approach. The degree of uncertainty surrounding the estimates of equilibrium exchange rates is also highlighted in Detken et al. (2002) and Maeso-Fernandez et al (2002) when different model specifications and approaches are used. Although our results are generally robust in term of identify periods of over-/undervaluation, we are cautious when interpreting the magnitude of these over-/undervaluation.

{Figures 1 and 2 about here}

5. Out-of-sample forecasting

Using Models 1 and 2 to forecast exchange rates, we do not need to impose the cointegration vector or any long-run relations obtained from a separate estimation procedure prior to exchange rate forecasting, as is the case when VECM or error correction models being used, as in MacDonald and Taylor (1993), Chinn and Meese (1995) and Cheung et al. (2005). This is because the UC model has a natural state-space representation, and the statistic treatment can be based on the Kalman filter. A convenient property of the Kalman filter is that it handles missing observations in a

¹⁵ Estimation result of the VECM model is available upon request.

data set. When the Kalman filter is used for forecasting purposes, it treats the observations in the forecasting period as a set of missing observations, and produces observation forecasts and their forecast error variances (See Commandeur and Koopman, 2007).

A rolling sample approach is used, with the full-sample period first divided into a pre-forecasting period from 1975Q1 to 1995Q4 and a forecasting period from 1996Q1 to 2008Q4.¹⁶ The pre-forecasting sample moves forward quarter-by-quarter and the model's hyperparameters are re-estimated at each step until the end of the sample is reached. In total, 53 one-quarter-ahead forecasts and 42 twelve-quarter-ahead forecasts are calculated. We compare the out-of-sample forecasting ability of Models 1 and 2 with the random walk process of the real exchange rate. To conduct a transparent comparison between the UC models with the random walk process, we first compare the out-of-sample forecasting ability of a univariate UC model of the real exchange rate, where the real exchange rate is decomposed into its permanent and transitory components.¹⁷ If Models 1 and 2 are better than the random walk process in terms of forecasting, but the univariate UC model is not, this suggests that the inclusion of the economic fundamentals do help to predict future real exchange rates.

Table 4 reports the ratios of root-mean-squared errors (RMSE) of both the univariate and multivariate UC models relative to the random walk process. One striking result revealed from Table 4 is that the relative RMSEs of the univariate UC model with respect to the random walk process are very close to one and remain relatively constant across different forecasting horizons. However, for Models 1 and 2, the longer the forecasting horizons, the smaller the RMSE produced by these

¹⁶ The choice of 1996Q1 is ad hoc. However, it provides a sufficiently large sample for initial estimation and for evaluating out-of-sample forecasting performances of the UC models.

¹⁷ As with Berger (2011), we assume that the permanent component of real exchange rate follows a random walk process, and the transitory component is a stationary AR(2).

models relative to the random walk process. We also implement both Diebold and Mariano (DM) (1995) and Harvey, Leybourne and Newbold (HLN) (1997) tests of equal forecast accuracy to determine whether differences in forecasting errors between a UC model and the random walk process are significant. Both the DM and HLN statistics are calculated under the null hypothesis that the UC model is equivalent in forecasting accuracy to the random walk process. The test statistics in Table 4 that are highlighted in bold indicate that the null hypothesis of equivalent forecasting accuracy is rejected. It can be seen that none of the null hypotheses that the univariate UC model is equivalent in forecasting accuracy to the random walk process can be rejected. However, Model 1 is significantly better in terms of forecasting future exchange rates than the random walk process from eight-quarter-ahead forecasting horizons onwards. This indicates that the economic fundamentals help to predict the long-run movement of real exchange rates. Furthermore, Model 2, which allows the transitory component of the real exchange rate to be modelled independently to follow an AR process, improves the short-run forecasting accuracy with respect to Model 1.

{Table 4 about here}

5. Conclusions

This paper employs a UC model incorporating a set of economic fundamentals to estimate the Euro-Dollar PEER from 1975Q1 to 2008Q4. The advantages of using the UC model are two-fold. First, compared to the BEER approach, our UC model setup clearly distinguishes between the impact of the long-term and short-term components of an economic fundamental on the real exchange rate. This helps us to separate business cycle factors from the equilibrium exchange rate movements. Second, the

UC model allows us to obtain true, ex-ante exchange rate forecasts incorporating long-run relationships between the real exchange rate and economic fundamentals. It does not require the long-run relationship to be estimated separately prior to forecasting, as is the case when VECM or error correction models are used. Moreover, although we found a cointegration relationship between the Euro-Dollar exchange rate and its economic fundamentals, our UC model can obtain robust estimates of the long-run relationship regardless of whether or not cointegration is found.

Our estimated PEER suggests that the euro was overvalued during the second half of the 1970s and the first half of the 1990s. These time periods correspond to a period of weakness of the dollar against the major European currencies. Two periods of undervaluation of the euro are also identified during the mid-1980s and in the first three years following the launch of the euro in 1999.

The undervaluation of the euro in the mid-1980s is associated with the period of significant dollar strength prior to the 'Plaza Accord'. However, the appreciation of the dollar against the euro was primarily due to a shift in the PEER and thus the total misalignment was modest during this period. On the contrary, the total misalignment following the euro's launch in 1999 was more severe. The depreciation of the euro during this period was more associated with transitory factors than a downward shift in the PEER. Many arguments have been put forward to explain this phenomenon. However, theories remain incomplete. Our results also suggest that the Euro-Dollar real exchange rate is predominately driven by the permanent components of the terms of trade differential and the relative government to GDP ratio between the euro area and the US. The impact of the transitory components of the economic fundamentals on the real exchange rate appears minimal. This is consistent with the arguments of

Frankel and Rose (1995) and Rogoff (2001) that economic fundamentals are weakly related to exchange rate fluctuations in the short-run.

Finally, our forecasting results suggest that Models 1 and 2, which include the economic fundamentals, provide more accurate exchange rate forecasts over a long-run forecasting horizon than a random walk process. Furthermore, Model 2, which allows for the transitory component of the real exchange rate to be modelled as an AR process, improves the short-run forecasting accuracy in comparison to Model 1. In short, we demonstrate that the method proposed in this paper can be a useful technique for central banks to estimate the equilibrium exchange rate and to predict long-run exchange rate movements.

In future research our approach could usefully be extended to other currencies and also perhaps to effective exchange rates using a multi-country panel framework, for example.

Appendix A. State-space model representation of Model 1

The state-space representation of Model 1 is given by

$$Y_t = \mathbf{Z}\mathbf{a}_t + \mathbf{G}\varepsilon_t$$

$$\mathbf{a}_t = \mathbf{d} + \mathbf{T}\mathbf{a}_{t-1} + \mathbf{H}\eta_t$$

where \mathbf{Z} , \mathbf{T} , \mathbf{d} , \mathbf{G} and \mathbf{H} are time-invariant matrices containing the hyper-parameters of the model:

$$\mathbf{Z} = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ \theta_1 & \theta_2 & \theta_3 & \vartheta_1 & \vartheta_2 & \vartheta_3 & \vartheta_4 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{T} = \begin{bmatrix} \mathbf{I}_3 & \mathbf{0}_{3 \times 4} & \mathbf{0}_{3 \times 4} & \mathbf{0}_{3 \times 1} \\ \mathbf{0}_{4 \times 3} & \mathbf{T}_{\phi 1} & \mathbf{T}_{\phi 2} & \mathbf{0}_{4 \times 1} \\ \mathbf{0}_{4 \times 3} & \mathbf{I}_4 & \mathbf{0}_{4 \times 4} & \mathbf{0}_{4 \times 1} \\ \mathbf{0}_{1 \times 3} & \mathbf{0}_{1 \times 4} & \mathbf{0}_{1 \times 4} & \mathbf{I}_1 \end{bmatrix},$$

$$\mathbf{T}_{\phi 1} = \begin{bmatrix} \phi_{1,tot} & 0 & 0 & 0 \\ 0 & \phi_{1,pd} & 0 & 0 \\ 0 & 0 & \phi_{1,gov} & 0 \\ 0 & 0 & 0 & \phi_{1,rid} \end{bmatrix}, \quad \mathbf{T}_{\phi 2} = \begin{bmatrix} \phi_{2,tot} & 0 & 0 & 0 \\ 0 & \phi_{2,pd} & 0 & 0 \\ 0 & 0 & \phi_{2,gov} & 0 \\ 0 & 0 & 0 & \phi_{2,rid} \end{bmatrix},$$

$$\mathbf{d} = [\beta_{tot}, \beta_{pd}, \beta_{gov}, 0, 0, 0, 0, 0, 0, 0, 0, 0],$$

$$\mathbf{G} = \text{diag}\{\sigma_{\varepsilon,tot}, \sigma_{\varepsilon,pd}, \sigma_{\varepsilon,gov}, \sigma_{\varepsilon,rid}, \sigma_{\varepsilon 1}\} \text{ and}$$

$$\mathbf{H} = \text{diag}\{\sigma_{\eta,tot}, \sigma_{\eta,pd}, \sigma_{\eta,gov}, \sigma_{\kappa,tot}, \sigma_{\kappa,pd}, \sigma_{\kappa,gov}, \sigma_{\kappa,rid}, \mathbf{0}_{4 \times 4}, \sigma_{\eta 1}\}.$$

The observation vector $Y_t = [tot_t, pd_t, gov_t, rid_t, q_t]'$ is known and the state vector

$\mathbf{a}_t = (\overline{tot_t}, \overline{pd_t}, \overline{gov_t}, \widehat{tot_t}, \widehat{pd_t}, \widehat{gov_t}, \widehat{rid_t}, \widehat{tot_{t-1}}, \widehat{pd_{t-1}}, \widehat{gov_{t-1}}, \widehat{rid_{t-1}}, v_t)'$ contains the

unobserved components. Since non-stationary variables $\overline{tot_t}$, $\overline{pd_t}$, $\overline{gov_t}$ and v_t are in

the state vector, the Kalman filter requires a diffuse initialisation and we used the

initialisation method developed by Koopman and Durbin (2003).

Appendix B. Data construction and unit root test

The real Euro-Dollar exchange rate for twelve euro area members prior to 1999 (based on consumer prices) is computed as a weighted geometric average of the bilateral exchange rates of the eleven currencies against the dollar.¹⁸ Therefore, a rise in the Euro-Dollar exchange rate means an appreciation of the Euro against the Dollar. The weights are given by the share of external trade of each euro area country in total euro area trade (taking into account third market effects) for the period 1995-1997.¹⁹ The consumer price indices and bilateral nominal exchange rates were taken from IMF International Financial Statistics (IFS), lines 64 and rf, respectively.

A country's terms of trade is computed as the ratio of its export prices to import prices. The same weights used to construct the synthetic euro-dollar exchange rate prior to 1999 are used to compute the ratio for the euro area. Finally, the terms of trade differential is computed as the ratio of the euro terms of trade relative to the US. Export and import prices for Austria, Finland, Germany and the US were obtained from IFS, lines 76 and 76.x, respectively. Since the data are not available for the remaining countries, export and import unit values taken from IFS, lines 74 and 75, are used.²⁰

In the absence of data on total factor productivity, some previous studies have focussed on 'price measures' of productivity, such as the relative price of non-traded to trade goods prices. In this study we measure the productivity differential as the ratio of real GDP to the number of employed persons in the euro area compared with

¹⁸ Belgium and Luxembourg have a common currency.

¹⁹ Weights used for each currency are 34.49% for Deutsche mark, 17.75% for French franc, 13.99% for Italian lira, 9.16% for Dutch guilder, 7.98% for Belgian and Luxembourg franc, 4.90% for Spanish peseta, 3.76% for Irish pound, 3.27% for Finnish markka, 2.89% for Austrian schilling, 1.07% for Portuguese escudo, 0.74% for Greek drachma.

²⁰ For France, the data series of export and import unit values are available from 1990Q1 onwards, therefore the terms of trade data taken from the OECD database is used before 1990Q1.

the same ratio for the US. Real GDP series were obtained from IFS, line 99bv; Employment data was taken from the OECD Labour productivity growth dataset.

Relative government expenditure to GDP ratio is computed as the ratio of government expenditure to GDP in the euro area relative to the same ratio for the US. For the euro area, the government expenditure to GDP ratio is obtained from the Area Wide Model constructed by Fagan et al. (2001). The corresponding variable for the US is constructed using GDP and government expenditure at current prices taken from IFS, lines 99b and 91f.

Finally, the real interest rate differential is the difference between real interest rates for the euro area and the US. Data on bond yields for the US and a geometric weighted average of long-run interest rates of countries constituting the euro area are used. The expected rate of inflation is proxied by the annual rate of consumer price inflation in the previous year. The nominal long-term interest rates for the euro area countries and the US were taken from IFS lines 61. These refer to yields to maturity of government bonds or other bonds that would indicate longer term rates. The maturity of the interest rates varies between countries ranging from 10 to 15 years.

The stationarity of the constructed data are examined using the ADF test. Test statistics presented in Table B suggest that apart from the real interest rate differential, all the other variables are $I(1)$. The Euro-Dollar real exchange rate being an $I(1)$ process violates the PPP assumption. The persistent nature of the real exchange rate may reflect that it was driven by a set of real fundamentals. In addition, the real interest differential being a stationary variable is consistent with the literature (see Clark and MacDonald, 2004; Hoffmann and MacDonald, 2009).

Table B: Unit root tests (1975Q1-2008Q4)

	<i>Variables in level</i>	<i>Variables in first difference</i>
	<i>Constant +Trend</i>	<i>Constant +Trend</i>
q_t	-2.485	-8.212***
tot_t	-3.019	-8.991***
pd_t	-1.378	-9.946***
gov_t	-1.759	-11.915***
rid_t	-3.809**	-8.362***

Notes: Variables in Table B are constructed as illustrated above. All variables with the exception of rid_t are transformed into logarithms. In addition, the ADF tests use a log length of 4; Significant test statistics are marked using stars with *, ** and *** denoting the 10%, 5% and 1% significance level respectively.

Table 1: Parameter estimates of Model 1

<i>Coefficients on the exchange rate equation</i>							
θ_1	θ_2	θ_3	ϑ_1	ϑ_2	ϑ_3	ϑ_4	
2.565***	0.317	-1.081***	-1.221	-4.729	4.216	1.221	
(0.515)	(0.467)	(0.288)	(1.149)	(3.303)	(5.369)	(1.048)	
<i>AR terms, constant drifts and damping factor</i>							
$\phi_{1,tot}$	$\phi_{2,tot}$	$\phi_{1,pd}$	$\phi_{2,pd}$	$\phi_{1,gov}$	$\phi_{2,gov}$	$\phi_{1,rid}$	$\phi_{2,rid}$
0.944***	-0.259**	1.399***	-0.562**	1.925***	-0.945***	1.633***	-0.680***
(0.132)	(0.105)	(0.285)	(0.272)	(0.049)	(0.046)	(0.122)	(0.118)
<i>Standard deviations of the shocks to permanent and transitory components</i>							
$\sigma_{\eta,tot}$	$\sigma_{\eta,pd}$	$\sigma_{\eta,gov}$	$\sigma_{\kappa,tot}$	$\sigma_{\kappa,pd}$	$\sigma_{\kappa,gov}$	$\sigma_{\kappa,rid}$	$\sigma_{\eta 1}$
1.345	0.713	1.178	0.902	0.289	0.057	0.303	0.011
(0.200)	(0.092)	(0.120)	(0.253)	(0.176)	(0.039)	(0.071)	(0.370)
<i>Dummy variables</i>							
$D80q1$	$D08q3$						
-0.013***	0.040***						
(0.003)	(0.011)						
<i>Likelihood ratio tests</i>							
$H_0: \vartheta_1=0, \text{LogL}^R=1992.86, \chi^2(1)=0.298$				$H_0: \theta_1=0, \text{LogL}^R=1970.48, \chi^2(1)=45.058***$			
$H_0: \vartheta_2=0, \text{LogL}^R=1991.88, \chi^2(1)=2.258$				$H_0: \theta_2=0, \text{LogL}^R=1992.74, \chi^2(1)=0.538$			
$H_0: \vartheta_3=0, \text{LogL}^R=1993.00, \chi^2(1)=0.018$				$H_0: \theta_3=0, \text{LogL}^R=1989.038, \chi^2(1)=7.942**$			
$H_0: \vartheta_4=0, \text{LogL}^R=1992.32, \chi^2(1)=1.378$							
$H_0: \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0, \text{LogL}^R=1989.761, \chi^2(4)=6.496$							
$H_0: \theta_1 = \theta_2 = \theta_3 = 0, \text{LogL}^R=1961.290, \chi^2(3)=63.438***$							
<i>Residual diagnostics</i>							
LogL	$Q(12)_{tot}$	$Q(12)_{pd}$	$Q(12)_{rid}$	$Q(12)_{gov}$	$Q(12)_q$		
1993.009	12.731	15.845	11.315	13.422	10.257		
JB_{tot}	JB_{pd}	JB_{rid}	JB_{gov}	JB_q			
3.498	0.092	2.224	0.933	2.624			

Notes: Numbers in parentheses are standard errors computed using the delta method; The standard deviations of variations of variances parameters are multiplied by 100; *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.

Table 2: Parameter estimates of Model 2

<i>Coefficients on the exchange rate equation</i>							
θ_1	θ_2	θ_3					
3.059***	0.519	-1.263**					
(1.210)	(0.804)	(0.636)					
<i>AR terms, constant drifts and damping factor</i>							
$\phi_{1,tot}$	$\phi_{2,tot}$	$\phi_{1,pd}$	$\phi_{2,pd}$	$\phi_{1,gov}$	$\phi_{2,gov}$	$\phi_{1,q}$	$\phi_{2,q}$
0.994***	-0.271**	1.122***	-0.183**	1.453***	-0.490**	1.348***	-0.435
(0.132)	(0.142)	(0.095)	(0.087)	(0.267)	(0.254)	(0.298)	(0.283)
<i>Standard deviations of the shocks</i>							
$\sigma_{\eta,tot}$	$\sigma_{\eta,pd}$	$\sigma_{\eta,gov}$	$\sigma_{\kappa,tot}$	$\sigma_{\kappa,pd}$	$\sigma_{\kappa,gov}$	$\sigma_{q,\kappa}$	$\sigma_{\eta 1}$
1.101	0.004	0.864	1.164	0.773	0.581	2.144	0.001
(0.226)	(0.627)	(0.285)	(0.248)	(0.050)	(0.272)	(1.440)	(0.116)
<i>Dummy variables</i>							
<i>D08q3</i>							
0.039***							
(0.010)							
<i>Likelihood ratio tests</i>							
$H_0: \theta_1 = 0, \text{LogL}^R = 1446.051, \chi^2(1) = 35.744***$							
$H_0: \theta_2 = 0, \text{LogL}^R = 1463.698, \chi^2(1) = 0.450$							
$H_0: \theta_3 = 0, \text{LogL}^R = 1459.886, \chi^2(1) = 8.074***$							
$H_0: \theta_1 = \theta_2 = \theta_3 = 0, \text{LogL}^R = 1442.003, \chi^2(3) = 43.840***$							
<i>Residual diagnostics</i>							
LogL	$Q(12)_{tot}$	$Q(12)_{pd}$	$Q(12)_{gov}$	$Q(12)_q$			
1463.923	12.821	16.363	10.263	9.661			
JB_{tot}	JB_{pd}	JB_{gov}	JB_q				
3.307	0.045	0.776	2.045				

Notes: Numbers in parentheses are standard errors computed using the delta method; The standard deviations of variations of variances parameters are multiplied by 100; *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.

Table 3: Tests for cointegration

<i>Nyblom and Harvey (2000)</i>					
	<i>m=0</i>	<i>m=1</i>	<i>m=2</i>	<i>m=3</i>	<i>m=4</i>
Model 1	0.397*	0.276	0.221	0.185	0.163
Model 2	0.514**	0.361*	0.291	0.246	0.220
<i>Johansen and Juselius (1990)</i>					
	<i>Trace</i>	<i>5% critical value</i>	<i>Max. Eigenvalue</i>	<i>5% critical value</i>	
<i>None</i>	62.555**	47.856	37.075**	27.584	
<i>At most 1</i>	25.480	29.797	19.332	21.132	

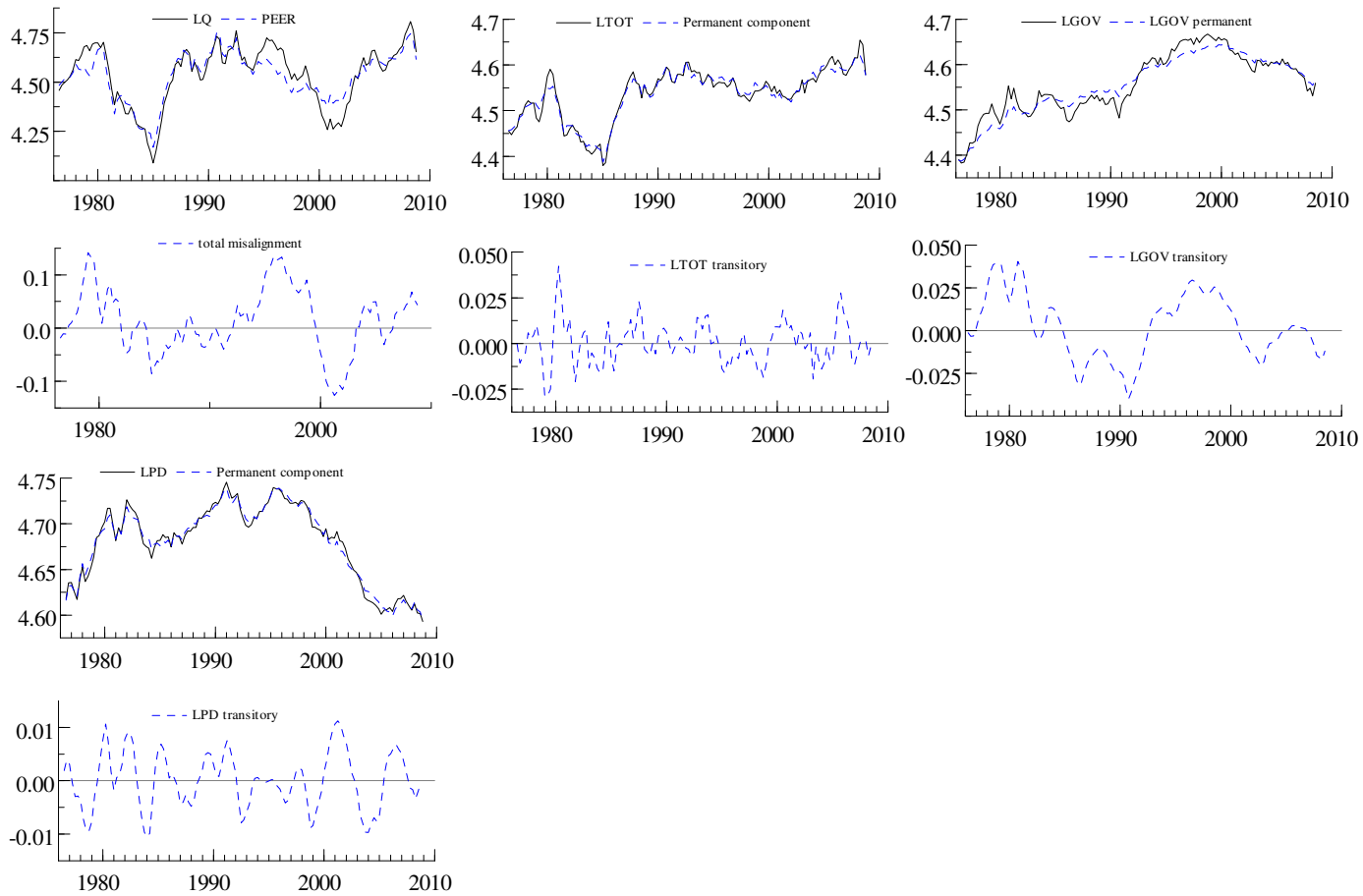
Notes: *m* is lag length selected to modified Nyblom and Harvey's (2000) test statistic to allow for serial correlation. The critical values with 1 degree of freedom at the 10%, 5% and 1% level are 0.347, 0.461 and 0.743, respectively (See Harvey, 2001, Table 1); Significant test statistics are marked using stars with *, ** and *** denoting the 10%, 5% and 1% significance level respectively.

Table 4: Out-of-Sample Forecasts (1996-2008)

<i>Relative Root-Mean-Squared Errors</i>									
	H=1	H=2	H=4	H=6	H=8	H=9	H=10	H=11	H=12
<i>Univariate UC model</i>									
Vs. RW	0.951	0.969	0.931	0.935	0.941	0.934	0.933	0.930	0.919
<i>DM</i>	1.05	0.91	1.02	0.82	0.65	0.62	0.58	0.60	0.66
<i>HLN</i>	1.04	0.88	0.95	0.73	0.54	0.50	0.45	0.45	0.48
<i>Model 1</i>									
Vs. RW	0.956	0.956	1.000	0.933	0.808	0.789	0.780	0.769	0.748
<i>DM</i>	0.60	0.44	0.37	1.15	2.14**	2.43***	2.55***	2.62***	2.75***
<i>HLN</i>	0.59	0.45	0.35	1.02	1.79**	1.97**	2.00**	1.98**	2.00**
<i>Model 2</i>									
Vs. RW	0.932	0.897	0.826	0.760	0.724	0.711	0.706	0.701	0.701
<i>DM</i>	1.58	2.13**	1.88**	2.27**	2.66***	2.76***	2.85***	2.88***	2.90***
<i>HLN</i>	1.57	2.06**	1.75**	2.01**	2.22**	2.24**	2.23**	2.18**	2.11**
<i>Root-Mean-Squared Errors of the random walk process</i>									
<i>RW</i>	0.041	0.064	0.102	0.138	0.169	0.181	0.193	0.201	0.209

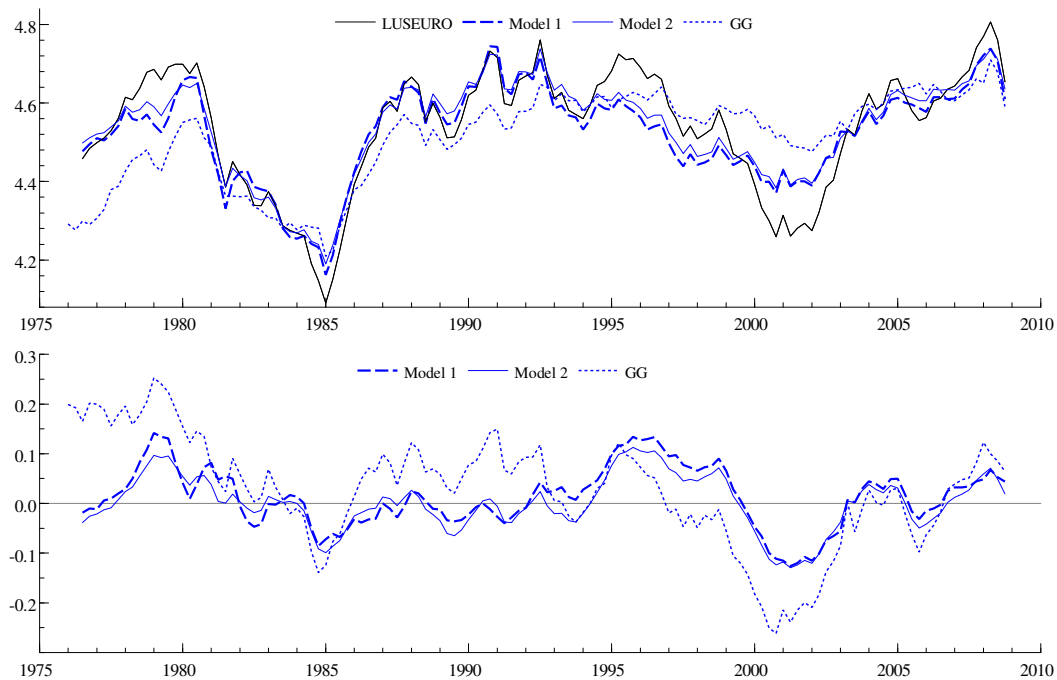
Note: the first row of each model (**Vs. RW**) denotes the relative RMSE of the multivariate model with respect to the RW model; the rows (*DM and HLN*) present the *DM* and *HLN* statistics; ** and *** indicate significance at the 5% and 1% level, respectively.

Figure 1: Unobserved components of the real exchange rate and economic fundamentals obtained from Model 1



Note: The permanent components of the real exchange rate and three integrated economic fundamentals are plotted against their observed time series.

Figure 2: The estimates of PEER and total misalignment obtained from the VECM-based approach and Models 1 and 2



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