*Applied Economics*, 2011, **43**, 1–18

Routledge
Taylor & Francis Group

# The common-trend and transitory dynamics in real exchange rate fluctuations

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This study examines the behaviour of both Common Trend (CT) and transitory components of Real Exchange Rate (RER) fluctuations under the current float. The CT component is in most cases found to be sizeable, albeit its relative importance can vary considerably across major currencies and its estimate can be sensitive to whether or not long-run Purchasing Power Parity (PPP) is imposed on the data. Further analysis suggests that both CT and transitory innovations are linked much more to interest rate changes than to productivity changes. Accordingly, it is interest rate, not productivity, disturbances that drive the highly persistent RER.

## I. Introduction

A longstanding issue in international monetary economics concerns the role of economic fundamentals in explaining Real Exchange Rate (RER) behaviour. Using different statistical approaches, including structural Vector Autoregressive (VAR) analysis and cointegration analysis, a range of studies have examined the sources of RER fluctuations and turned up mixed results. For example, Clarida and Gali (1994) and Eichenbaum and Evans (1995) analyse real dollar-based rates of British pound, German mark and Japanese yen, whereas Rogers (1999) focuses on real dollar–pound rates. These studies suggest that productivity shocks do not have much impact on RERs even at long horizons, while detecting significant effects of monetary shocks. In studying dollar-based RERs for Canada, Germany, Japan and the UK, Mark and Choi (1997) also show that monetary shocks are more important than productivity shocks in explaining RER dynamics at long horizons.

In contrast, there are other studies supporting a significant role of real shocks, especially that of productivity, in driving the permanent component of RER changes.[1] Enders and Lee (1997) suggest that real shocks account for most of the RER changes in Canadian dollar, German mark and Japanese yen. Canzoneri *et al*. (1999) examine a panel of 13 Organization for Economic Cooperation and

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[1] Engel (2000) observes that standard tests for stationarity cannot determine the actual relevance of permanent dynamics in RERs when transitory dynamics are more volatile. Hence, even when finding stationarity in RERs, real shocks may still contribute to the persistence of RERs. Indeed, Rogoff (1996) points out that the empirical rate of RER reversion seems too sluggish to be explained by purely nominal shocks.

*Applied Economics* ISSN 0003–6846 print/ISSN 1466–4283 online © 2011 Taylor & Francis
http://www.informaworld.com
DOI: 10.1080/00036841003742645

Development (OECD) countries and report that relative prices between traded and nontraded goods are cointegrated with relative labour productivity. These results are supportive of the Balassa–Samuelson effect. Under the assumption of nonstationary RERs, Engel and Kim (1999) decompose the dynamics of real dollar–pound rate into transitory and permanent parts using Kalman filter analysis. While transitory dynamics can be linked to monetary factors, permanent dynamics are found to be cointegrated with productivity measures. This accords with the classical dichotomy that real shocks generate permanent effects, whereas the monetary shocks produce purely temporary effects. Based on a cointegrated VAR model for nonstationary RERs, Alexius (2005) analyses their long-run relationships with corresponding fundamental variables for Germany, Japan, the UK and the US. It is shown that productivity shocks are responsible for most of the RER changes at long horizons. In their decomposition analysis with a structural VAR model, Lee and Chinn (2006) examine trade-weighted RERs for the G7 countries and find RER fluctuations to be attributable largely to permanent shocks.

Seeking deeper insights into the sources of RER dynamics, this study examines the empirical importance of various fundamental factors using an empirical approach different from those applied previously. Taking a disaggregate approach to studying RER behaviour, we analyse the joint dynamics of nominal exchange rates and relative prices with a Vector Error Correction (VEC) model. Even if the exchange rate and the relative price converge to an equilibrium relationship in the long run, the two variables can exhibit rather different short-term behaviour. The bivariate model may thus capture richer adjustment dynamics than a univariate model of the RER itself.[2] Moreover, we decompose the joint dynamics into a Common-Trend (CT) and a transitory component. This enables us to evaluate the different parts of RER dynamics separately and to identify their individual linkages to fundamental factors. Also, unlike other decomposition methods, our approach can be applied whether or not long-run Purchasing Power Parity (PPP) holds. We will compare results with and without the PPP condition imposed on the data.

This study shows that the relative importance of CT and transitory dynamics in RER changes can vary a lot across currencies and that their relative contribution can also be sensitive to whether or not long-run PPP is imposed. Moreover, when examining the individual sources of CT and transitory dynamics, our analysis finds mixed results and suggests a contributing role of only a few macro fundamental factors. The results also reveal great heterogeneity across currencies. Amidst the mixed results, some interesting patterns still emerge. Interest rate changes (and to a lesser extent money supply changes) are in most cases found to contribute significantly to CT and transitory dynamics, while productivity changes show no systematic impact on either type of dynamics. Some evidence of productivity effects can be obtained but the results depend on whether the long-run PPP restriction is imposed. In finding only limited relevance of productivity effects, our study provides an interesting contrast to those other empirical studies that stress the importance of productivity shocks in RERs (e.g. Canzoneri *et al.*, 1999; Engel and Kim, 1999; Alexius, 2005). On the other hand, our findings are consistent with some recent open-economy models that highlight the effects of monetary changes on RERs (Chari *et al.*, 2002; Benigno, 2004; Hairault and Sopraseuth, 2005). These models illustrate that monetary disturbances can generate highly persistent RER dynamics.

In light of the PPP puzzle raised by Rogoff (1996), we also investigate if our decomposition analysis can yield alternative insights that may help resolve the puzzle. While transitory dynamics are less persistent than CT dynamics, the estimated half-life of transitory dynamics (which falls between 2.2 and 4.4 years) remains not much faster than Rogoff's (1996) consensus half-life estimate of 3–5 years. To the extent that it is monetary changes rather than productivity changes that contribute significantly to transitory dynamics, our findings do not support the view that productivity changes can largely account for the observed high persistence of RERs.

## II. The Statistical Framework

The joint behaviour of the logarithm of the nominal exchange rate ($e_t$) and the logarithm of relative price levels ($p_t$) is modelled to be a bivariate VEC system as follows:

$$\Delta X_t = \mu + \sum_{j=1}^{k} \Gamma_j \Delta X_{t-j} + \Pi X_{t-k} + \varepsilon_t \tag{1}$$

[2] A popular approach used in previous studies of RER dynamics is the structural VAR method (see, e.g. Clarida and Gali, 1994; Eichenbaum and Evans, 1995; Rogers, 1999). This approach studies the determinants of the RER itself. It does not investigate the possibly different determinants of the CT and transitory components for the RER.

where $X_t = [e_t \quad p_t]'$, $\Pi = -\alpha\beta'$ with $\alpha = [\alpha_1 \quad \alpha_2]'$ containing adjustment coefficients, rank$[\Pi] = 1$, $\beta$ is the cointegration vector and $\varepsilon_t$ is independent and identically distributed (i.i.d.) with mean zero and covariance matrix, $\Omega$. Under cointegration, the system dynamics can be decomposed into a common permanent component and a transitory component. If the PPP condition, $\beta = [1 \quad -1]'$, is also imposed, the RER (given by $\beta' X_t$) is stationary and then permanent shocks to $e_t$ and $p_t$ will have no long-run impact on the RER.

With $\Delta X_t$ being stationary, the Wold decomposition theorem implies the presence of a Vector Moving Average (VMA) representation

$$\Delta X_t = \delta + C(L)\varepsilon_t \tag{2}$$

where $L$ is the lag operator, $C(L) = I + \Sigma_{k=1}^{\infty} C_k L^k$, $I$ is an identity matrix and $\beta' C(1) = 0$. Equations 1 and 2 allow us to study the short- and long-run interactions between $e_t$ and $p_t$ and to analyse their impulse responses to variable-specific shocks (Lütkepohl and Reimers, 1992; Pesaran and Shin, 1998). An alternative to the VMA model is Stock and Watson's (1988) CT model

$$X_t = X_0 + \delta t + C(1)\sum_{i=1}^{t} \varepsilon_i + C^*(L)\varepsilon_t \tag{3}$$

for $C(L) = C(1) + (1 - L)C^*(L)$. Consider a structural CT model as follows:

$$X_t = \mu_0 + \Phi\eta_t + Q^*(L)w_t \tag{4}$$

where $\eta_t = \rho + \eta_{t-1} + \varphi_t$; $Q^*(L)$ is a stationary lag polynomial; and $w_t = [\varphi_t \quad \psi_t]'$ with $\varphi_t$ being the shock to the CT component and $\psi_t$ being the shock to the transitory component. The common stochastic trend, $\eta_t$, determines the trending behaviour of the system variables through the loading matrix, $\Phi$. The transitory dynamics of the system are governed by $Q^*(L)w_t$. With $Q(L)$ equal to $Q(1) + (1 - L)Q^*(L)$, the structural CT model can be linked to the VMA system as follows:

$$\Delta X_t = \delta + C(L)\varepsilon_t = \delta + C(L)F^{-1}F\varepsilon_t = \delta + Q(L)w_t \tag{5}$$

The innovations in $\varepsilon_t$ are thus linked to the structural shocks in $w_t$ via the transformation matrix, $F$, such that $w_t = F\varepsilon_t$. If $F = [F_\varphi \quad F_\psi]'$ can be explicitly determined, individual shocks to the CT and transitory components of the system dynamics can also be constructed.

To determine $F$, we derive $C(L)$ and then find the CT representation of the VMA model (King *et al.*, 1991; Mellander *et al.*, 1992; Bergman, 1996). Following Campbell and Shiller (1988), let

$$M = \begin{bmatrix} 1 & 0 \\ 1 & -1 \end{bmatrix} \tag{6}$$

Let $\Gamma(L) = I - \sum_{j=1}^{p-1} \Gamma_j$ as well. Premultiplying both sides of the VEC model in Equation 1 yields

$$M\Gamma(L)\Delta X_t = M\mu - M\Pi X_{t-p} + M\varepsilon_t \tag{7}$$

Define a variable $y_t = \mathrm{D}_\perp(L)MX_t$, where $\mathrm{D}_\perp(L)$ is a diagonal matrix with its diagonal elements $\mathrm{D}_\perp(L)_{11} = 1 - L$ and $\mathrm{D}_\perp(L)_{22} = 1$. We can then write $B(L)y_t = M\mu + M\varepsilon_t$. Moreover, $\alpha_1 = B(1)_{12}$ and $\alpha_2 = B(1)_{12} - B(1)_{22}$ will give the adjustment coefficients. From Equations 3 and 4, we can also derive that

$$\varphi_t = \det(B(1))^{-1}[-\alpha_2 \quad \alpha_1]\varepsilon_t = F_\varphi \varepsilon_t \tag{8}$$

$$\psi_t = (\alpha'\Omega^{-1}\alpha)^{-1/2}\alpha'\Omega^{-1}\varepsilon_t = F_\Psi \varepsilon_t \tag{9}$$

The transitory innovation, $\psi_t$, generates solely temporary effects on $e_t$ and $p_t$, hence no permanent effects on the RER. The CT innovation, $\varphi_t$, generates long-lasting effects on $e_t$ and $p_t$, but these effects may offset one another in the long run, leaving no permanent effects on the RER when the condition of $\beta = [1 \quad -1]'$ holds.[3] The impulse responses of $e_t$ and $p_t$ to the individual innovations are given by $C(L)F^{-1}$ and those of the RER are given by $\beta' C(L)F^{-1}$.

Some remarks on our empirical methodology should be noted. Instead of analysing the RER as a univariate process, we model its two constituting parts (i.e. the nominal exchange rate and the relative price) jointly as a bivariate process. The bivariate framework can incorporate richer RER adjustment dynamics by allowing for counteracting interactions between the exchange rate and the relative price. Modelling the RER as the realization of a bivariate rather than a univariate process also permits a distinctive decomposition of RER fluctuations into two types of dynamics (namely, CT and transitory dynamics), a time series decomposition not explored previously. To gain a better understanding of these different components of RER changes, we will extend the decomposition analysis to identify their individual links to macro fundamental factors. This differs from the usual linkage analysis that makes no distinction between the separate components of RER dynamics.

Another useful feature of our empirical approach is that it requires no specific assumption as to whether or not long-run PPP holds. The decomposition analysis remains valid so long as a cointegrating relationship exists between the nominal exchange rate

[3] If cointegration exists but PPP does not hold, then CT innovations can have long-run effects on the RER.

**Table 1. Results of cointegration and unit-root tests**

| | Bartlett corrected trace test for cointegration | | | | Restriction test of $\beta' = [1 \quad -1]$ | |
|---|---|---|---|---|---|---|
| | $r = 0$ | $p$-value | $r = 1$ | $p$-value | Estimated $\beta'$ | $p$-value |
| Panel A: Cointegration analysis | | | | | | |
| Germany | 26.91** | 0.035 | 3.85 | 0.761 | $[1 \quad -3.03]$ | 0.235 |
| Japan | 15.54** | 0.048 | 0.00 | 0.962 | $[1 \quad -1.02]$ | 0.898 |
| UK | 37.31** | 0.001 | 5.60 | 0.522 | $[1 \quad 40.43]$ | 0.000 |
| | ADF | ADF–GLS | | | | |
| Panel B: Unit-root analysis | | | | | | |
| Germany | −2.244 | −2.216** | | | | |
| Japan | −2.101 | −1.042 | | | | |
| UK | −2.616* | −1.837* | | | | |

*Notes*: The trace test is Johansen's (2000) Barlett-corrected Likelihood Ratio (LR) trace test (for which $r$ indicates the number of cointegration vector being tested under the null) and the estimated normalized cointegration vector (i.e. the $\beta$ estimate) is also reported in each case. The lag order used for the Johansen procedure is determined using the SIC with a maximum of 12 lags allowed. The restriction test for $\beta' = [1 \quad -1]$ examines the null hypothesis that the long-run PPP condition holds. For unit-root tests, ADF is the standard ADF test, whereas ADF–GLS represents the more efficient GLS-based test devised by Elliott *et al.* (1996). The lag parameters for individual unit-root tests are chosen using the SIC with the maximum lag order set to 16.
* and ** denote statistical significance at the 10 and 5% levels, respectively.

and the relative price, a weaker condition than requiring stationarity of the RER. Such general applicability is attractive, given that the validity of long-run PPP is still a contested issue. We will report statistical results with and without the long-run PPP condition imposed.

## III. Preliminary Data Analysis

Our empirical analysis focuses on three major currencies – the German mark, the Japanese yen and the British pound – under the current float. The data consist of monthly series of consumer price indices and dollar-based exchange rates over the sample period April 1973 to December 2005.[4] The price and exchange rate data are obtained from International Monetary Fund's (IMF) International Financial Statistics (IFS) CD-ROM. All the data series are expressed in logarithms.

Prior to the VEC analysis, we test for unit roots using several standard tests. Both the individual exchange rate and relative price series are confirmed to be nonstationary. In no case can the null hypothesis of a unit root be rejected. We have also tested for a unit root in the first difference and found that the null of a unit root is soundly rejected at usual significance levels.

Our empirical approach posits the existence of a cointegrating relation between the nominal exchange rate and the relative price. To verify this, we first determine the lag specification of the VEC model based on the Schwarz Information Criterion (SIC) with a maximum of 12 lags allowed and then we use lag exclusion tests to choose the proper lag length. These tests suggest the use of two lags for the case of Germany, three lags for the case of Japan and three lags for the case of UK.[5] Next, we test for cointegration between the exchange rate and the relative price using Johansen's (1991, 2000) trace test. As recommended by Phillips (1991), Johansen's full-system maximum likelihood procedure enjoys optimal inferential properties in terms of efficiency and median unbiasedness. This procedure is also known to have good finite-sample properties and be robust to nonnormality and heteroscedasticity (Cheung and Lai, 1993a; Gonzalo, 1994).

The results of the Bartlett-corrected trace test for cointegration are reported in Table 1 (Panel A). We can invariably reject the null of no cointegration but not the null of one cointegration vector present in

[4] Exchange rate data for Germany are denominated in euros instead of deutsche marks from January 1999 onwards. Data conversions are made using the official conversion rate of 1.95583 deutsche marks per euro.
[5] In addition to just using the SIC-determined lag order, we also checked and tried out with different lag parameter values, including $k = 1$, 2, 3 and 4. Largely, similar test results were obtained with these different lag specifications.

the system.[6] The test results support the presence of one cointegration vector in all the cases under study. Table 1 (Panel A) also gives the normalized estimated cointegration vector. The German vector and in particular, the Japanese vector are relatively close to $[1 \quad -1]'$, the theoretical vector for long-run PPP. In contrast, the estimated vector for the UK data is very different with a large and incorrectly signed coefficient on the relative price.[7] We test whether the long-run PPP relation holds in the cointegration space using a likelihood ratio restriction test (Johansen, 1991, 2000). The long-run PPP condition is rejected by the UK data, though not by the German and Japanese data. To be sure, the finding that we can find cointegration between exchange rates and relative prices, but reject the PPP condition is not new. Similar findings have been documented by Cheung and Lai (1993b) and MacDonald (1993).

A direct way to test the PPP relationship is to perform unit-root tests on RERs. We perform both the standard Augmented Dickey–Fuller (ADF) test and the ADF–Generalized Least Squares (GLS) test (Elliott *et al.*, 1996) on each RER series. The SIC is used for lag selection. As shown in Table 1 (Panel B), the unit-root test results are mixed. The null of nonstationarity can be rejected in just the UK case based on the ADF test, while it can be rejected in the cases of both Germany and the UK using the more efficient ADF–GLS test. Unlike what the Johansen test has suggested, neither the ADF nor the ADF–GLS test detects stationarity in the Japanese case.

As pointed out earlier, the implementation of our decomposition analysis does not hinge on the validity of long-run PPP. The only assumption needed is that a cointegration vector exists in the economic system, a condition consistently supported by the cointegration test results. In view of the conflicting results from unit-root tests, we will study RER dynamics under alternative conditions, including using the estimated vector as opposed to the theoretical PPP vector.

## IV. The Relative Importance of the CT Component

Given the finding of a cointegration vector, we estimate the structural VMA model in Equation 5 and then construct the CT component of Equation 4. The estimated CT dynamics are displayed in Figs 1 and 2 for individual countries. These CT dynamics (depicted by solid lines) capture the trend behaviour shared between exchange rates and relative prices (indicated by broken lines). Figure 1 shows the CT dynamics estimated with the long-run PPP assumption. In the German case, the CT dynamics generally move in tandem with relative price changes, but only loosely so with real and nominal exchange rate changes. In the Japanese case, the CT dynamics can closely track not only the relative price movement but also the nominal exchange rate movement. In the UK case, the CT dynamics bear little similarity to those of real and nominal exchanges rates, while they very much follow the relative price dynamics. When the PPP restriction is relaxed in the CT estimation, we find qualitatively similar results in the German and Japanese cases but sharply different results in the UK case (Fig. 2). In the latter case, the CT dynamics move totally independent of the relative price dynamics, albeit they follow the real and nominal change rate dynamics very closely. Indeed, for the UK, the CT dynamics almost coincide with that of the RER. The cross-country difference in sensitivity to the PPP assumption is not too surprising, given that the estimated cointegration vector has been found to differ substantially from the theoretical PPP vector in the UK case but not in the other two cases.

We next examine how the system dynamics respond to the different innovations to the CT and transitory components. Figures 3 and 4 present the impulse responses of the nominal exchange rate, the relative price and the RER to a one-SD positive transitory shock. The 95% confidence bands, obtained using bootstrap resampling with 1000 repetitions, are shown by dotted lines. These confidence bands indicate a high level of sampling uncertainty, as discussed in some previous studies (Cheung and Lai, 2000; Murray and Papell, 2002; Choi *et al.*, 2006). In terms of the adjustment patterns of individual variables, the impulse response results look similar between the Japanese case and the German case. The UK case again shows somewhat different adjustment behaviour, especially when the PPP condition is not imposed (Fig. 4).

Figures 5 and 6 display the impulse responses of the different variables to a one-SD positive CT innovation, along with their 95% confidence bands (given by dotted lines). As shown in the various

[6] We allow for a linear trend in the cointegration vector for both the UK and the German cases. In the Japanese case, a linear trend is permitted in the levels.

[7] The notably different estimate of the cointegration vector for the UK data are puzzling. It may suggest the possibility of some structural change in the data. If a structural break exists, it could seriously distort the data and confound the estimation procedure. While the relevance of the structural-break explanation is beyond the scope of this analysis, we may still keep this possible explanation in mind when interpreting the UK results.


**Fig. 1. Different variable series versus the CT estimated with the long-run PPP condition imposed. (a) Germany, (b) Japan and (c) UK**
*Note*: The CT is plotted as a solid line and the economic variable series is shown by a dotted line in each graph.

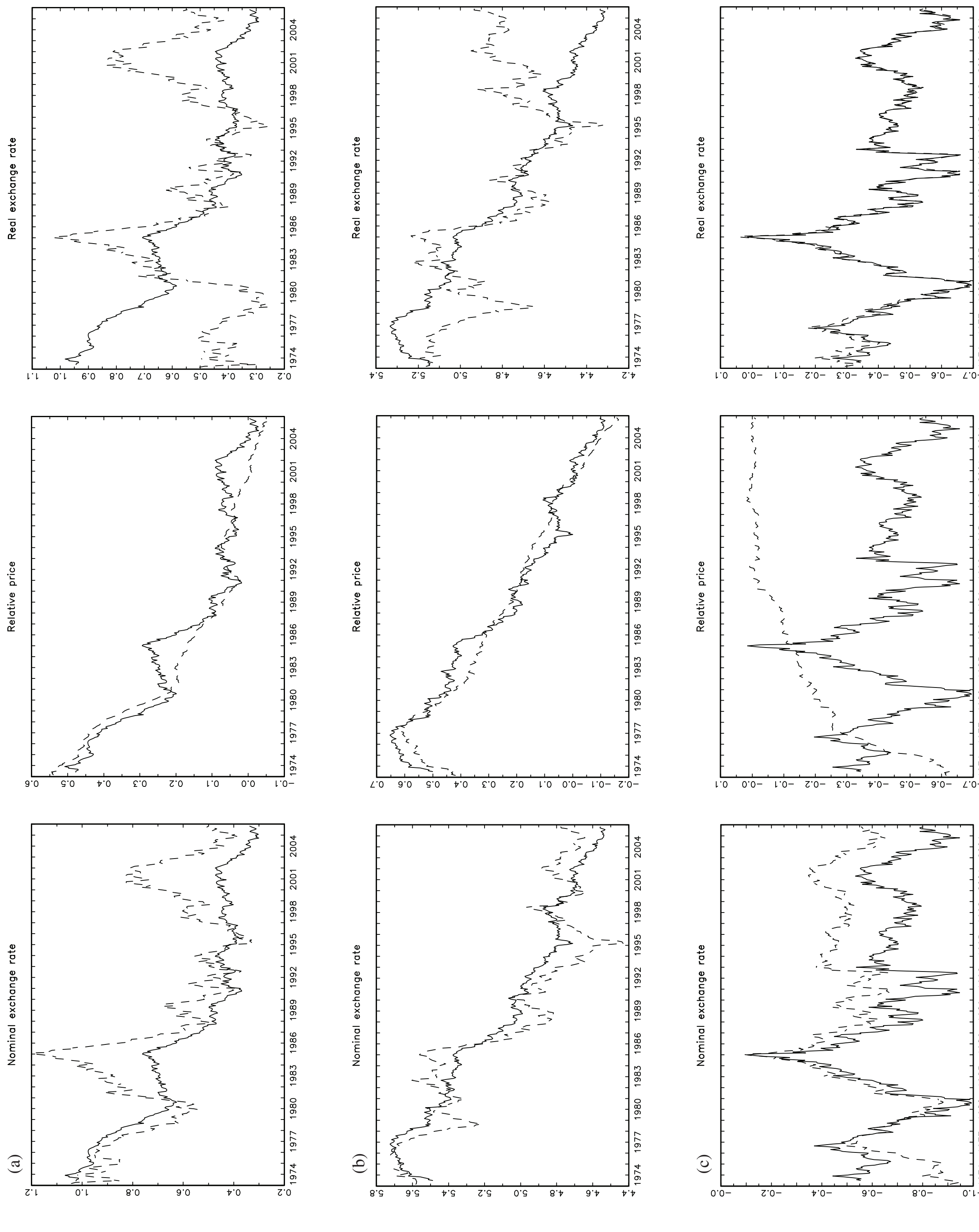


**Fig. 2. Different variable series versus the CT estimated without the long-run PPP condition imposed. (a) Germany, (b) Japan and (c) UK**
*Note:* The CT is plotted as a solid line and the economic variable series is shown by a dotted line in each graph.

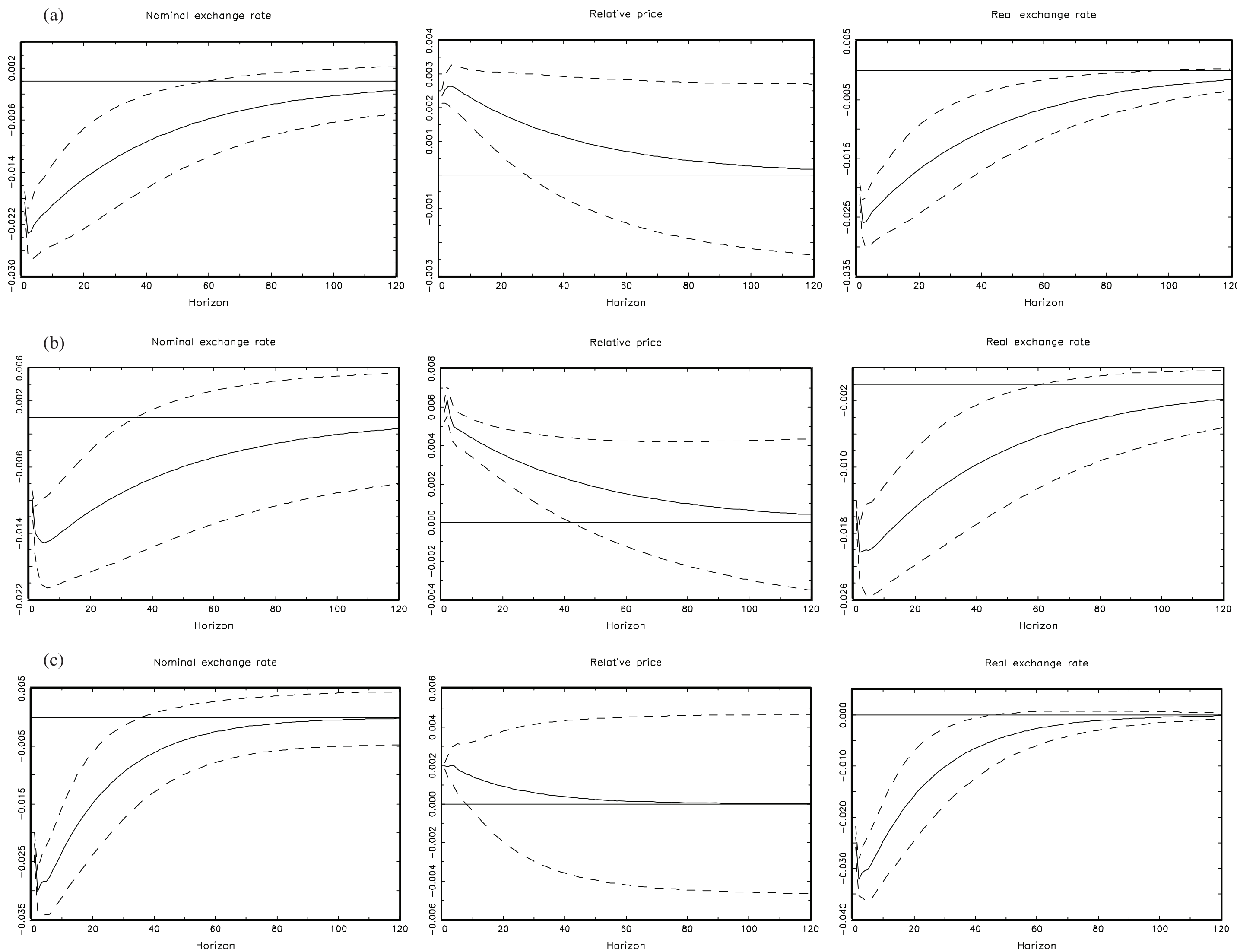


**Fig. 3. Impulse responses of system variables to transitory innovations with the long-run PPP condition imposed. (a) Germany, (b) Japan and (c) UK**
*Note*: The 95% confidence bands for the impulse response estimates are shown by broken lines in each graph.

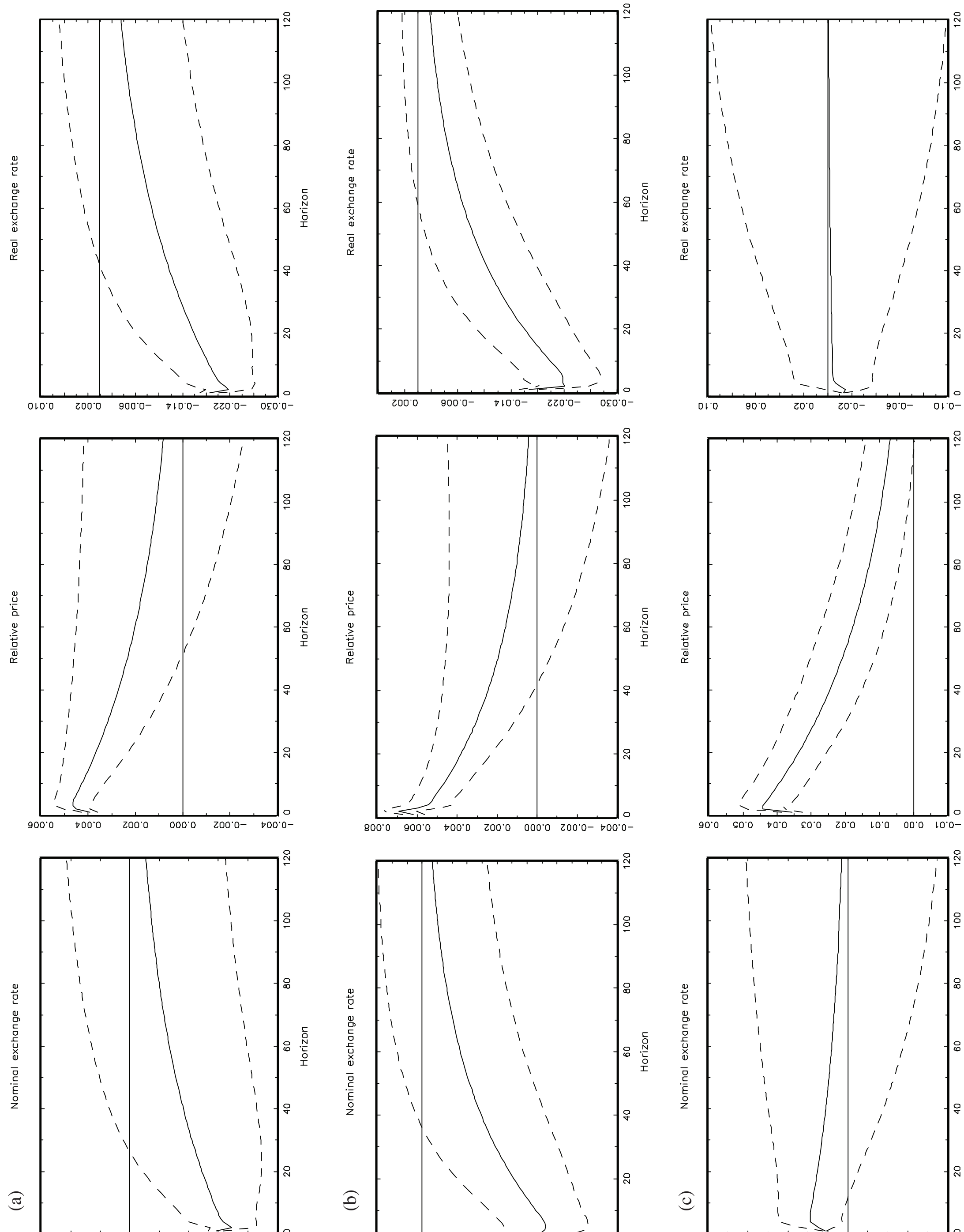


**Fig. 4. Impulse responses of different variables to transitory innovations with no long-run PPP condition imposed. (a) Germany, (b) Japan and (c) UK**
*Note*: The 95% confidence bands for the impulse response estimates are shown by broken lines in each graph.

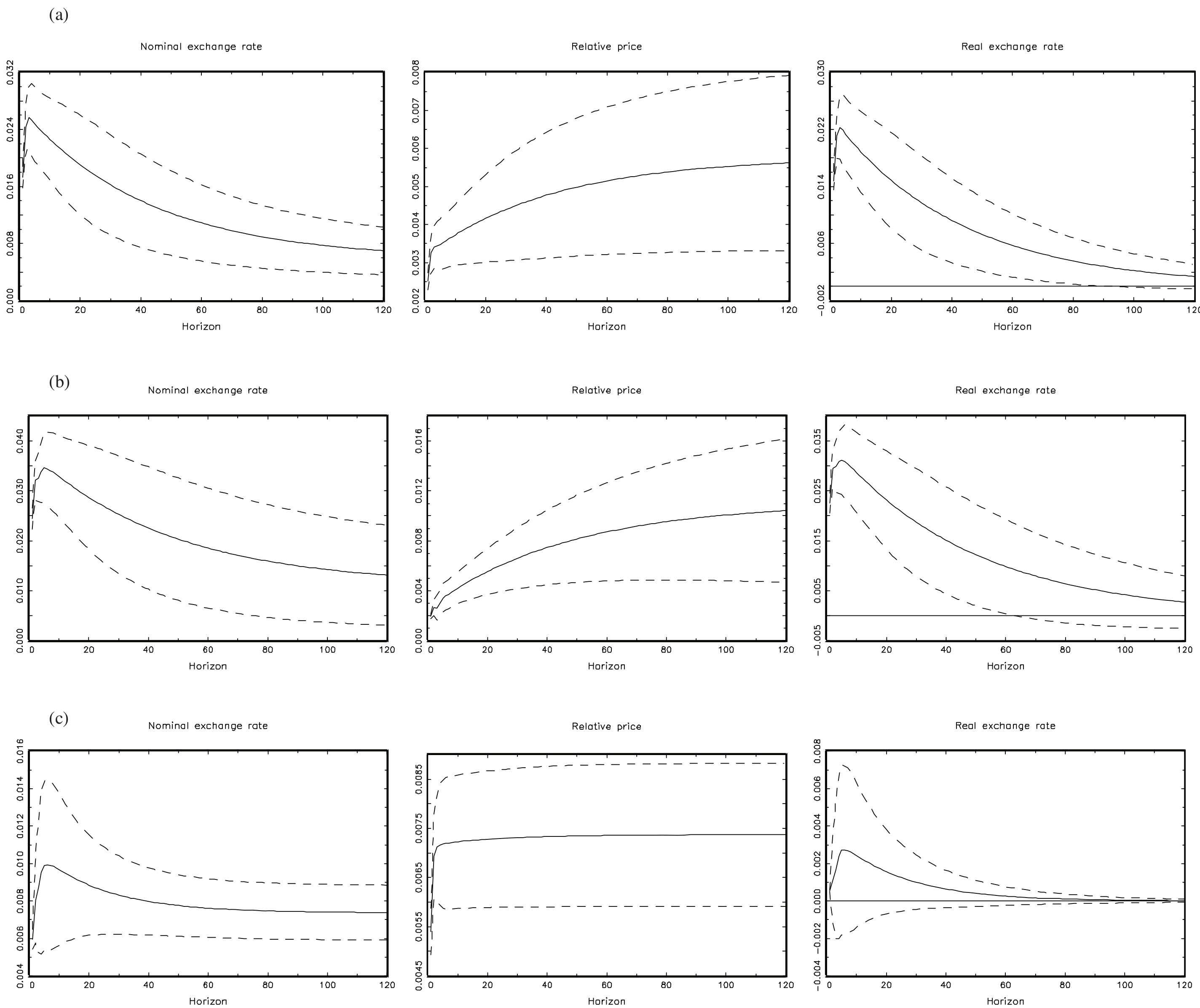


**Fig. 5. Impulse responses of different variables to CT innovations with the long-run PPP condition imposed. (a) Germany, (b) Japan and (c) UK**
*Note*: The 95% confidence bands for the impulse response estimates are shown by broken lines in each graph.

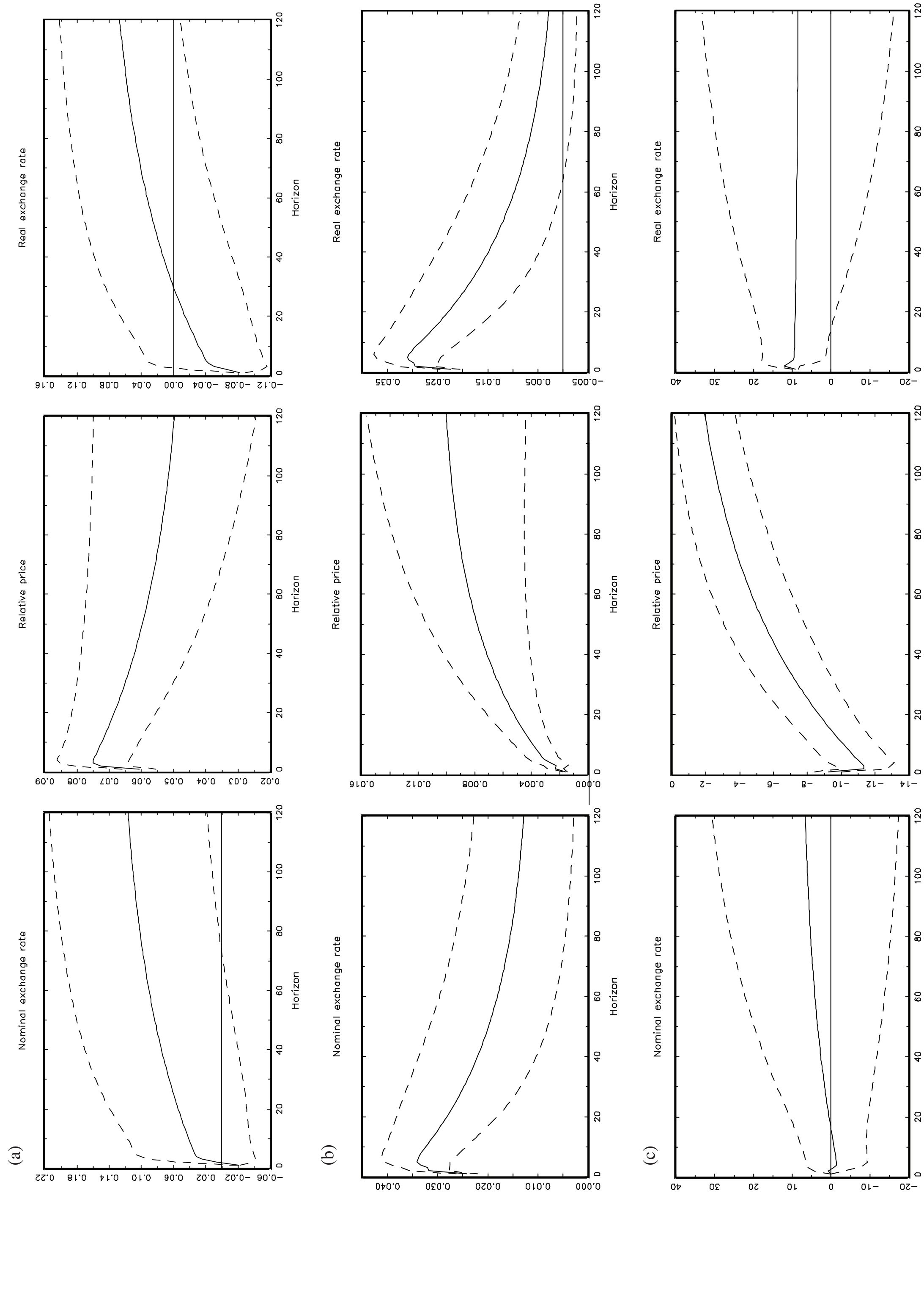


**Fig. 6. Impulse responses of different variables to CT innovations with no long-run PPP condition imposed. (a) Germany, (b) Japan and (c) UK**
*Note:* The 95% confidence bands for the impulse response estimates are shown by broken lines in each graph.

**Table 2. The proportion of the forecast error variance explained by CT innovations**

| | Nominal exchange rate | | | Relative price | | | RER | | |
|---|---|---|---|---|---|---|---|---|---|
| Horizon | Germany | Japan | UK | Germany | Japan | UK | Germany | Japan | UK |
| Panel A: The share of the variance estimated with the long-PPP condition imposed | | | | | | | | | |
| 3 | 52 | 87 | 7 | 60 | 12 | 92 | 40 | 71 | 0 |
| 6 | 55 | 86 | 9 | 62 | 19 | 93 | 42 | 71 | 0 |
| 12 | 56 | 86 | 11 | 67 | 28 | 94 | 43 | 71 | 1 |
| 24 | 58 | 86 | 15 | 75 | 46 | 96 | 43 | 71 | 1 |
| 36 | 60 | 87 | 19 | 81 | 60 | 97 | 43 | 71 | 1 |
| 48 | 61 | 88 | 22 | 85 | 70 | 98 | 43 | 71 | 1 |
| 60 | 62 | 88 | 25 | 88 | 77 | 98 | 43 | 71 | 1 |
| 72 | 63 | 89 | 28 | 90 | 82 | 99 | 43 | 71 | 1 |
| 96 | 64 | 90 | 33 | 93 | 88 | 99 | 43 | 71 | 1 |
| 120 | 66 | 90 | 37 | 94 | 91 | 99 | 43 | 71 | 1 |
| Panel B: The share of the variance estimated without the long-PPP condition imposed | | | | | | | | | |
| 3 | 58 | 81 | 99 | 99 | 10 | 99 | 91 | 64 | 99 |
| 6 | 75 | 81 | 99 | 99 | 16 | 99 | 88 | 66 | 99 |
| 12 | 84 | 82 | 99 | 99 | 27 | 99 | 84 | 66 | 99 |
| 24 | 91 | 83 | 99 | 99 | 45 | 99 | 79 | 67 | 99 |
| 36 | 94 | 83 | 99 | 99 | 59 | 99 | 74 | 67 | 99 |
| 48 | 96 | 84 | 99 | 99 | 69 | 99 | 73 | 67 | 99 |
| 60 | 97 | 85 | 99 | 99 | 76 | 99 | 77 | 67 | 99 |
| 72 | 98 | 86 | 99 | 99 | 81 | 99 | 81 | 67 | 99 |
| 96 | 99 | 87 | 99 | 99 | 87 | 99 | 89 | 67 | 99 |
| 120 | 99 | 88 | 99 | 99 | 91 | 99 | 94 | 67 | 99 |

*Notes*: All the variance decomposition estimates are given in percentage. The share of the forecast error variance (in percentage) attributed to transitory innovations can be computed by subtracting the appropriate number in the table from 100.

graphs, the CT innovation generally has long-lived effects on both the exchange rate and the relative price. When the long-run PPP condition is imposed, the general patterns of adjustment responses are quite similar between the German and the Japanese case, though less so between these two cases and the UK case (Fig. 5). Such similarity across countries in adjustment dynamics disappears, however, with the relaxation of the PPP restriction. As Fig. 6 shows, each country case has its own response patterns that are rather different from those in the other two cases. The differences are particularly evident with regard to RER responses, with CT innovations generally having very persistent effects on the RER.

Through the variance decomposition analysis, the forecast error variance for each of the system variables is divided into portions attributable to specific structural innovations. This enables us to quantify the relative importance of CT and transitory innovations in explaining the fluctuations of a given variable over different horizons. Table 2 (Panels A and B) reports how much CT innovations explain the forecast error variance for the nominal exchange rate, the relative price and the RER (95% confidence interval estimates are not reported here but are available upon request from the corresponding author). At each horizon, the share of the variance attributed to transitory shocks is equal to 100% minus the corresponding share explained by CT innovations.

Let us first inspect the results with the long-run PPP condition imposed. As the percentage estimates in Table 2 (Panel A) indicate, CT innovations are consistently more important than transitory innovations in explaining the exchange rate fluctuations of the mark and the yen, but the opposite is true for the pound. The contribution of CT innovations is especially pronounced in the yen case. Also, for all the three currencies, the share of the variance due to CT innovations grows steadily with the horizon. At the 4-year horizon, CT innovations account for 61% (the mark) and 88% (the yen) of the exchange rate variability. At the 8-year horizon, the explained proportions go up to 64% and 90%, respectively. Regarding the forecasted variance for the relative price, differing results across countries can be seen at short horizons, unlike those for long horizons. For the UK, CT innovations account for most of the relative price variability. A similar finding applies to Germany, though to a lesser extent. For Japan, transitory innovations are the main contributors at horizons of 2 years or less, albeit CT innovations dominate in contribution at longer horizons. In all the country cases, the share of the variance ascribed to the CT innovations rise and the influence of the transitory innovations decline as the horizon extends. At the 4-year (8-year) horizon, CT innovations account for 70–98% (88–99%) of the relative price variability.

Table 2 (Panel A) also provides the decomposition estimates for the RER. Unlike the exchange rate and the relative price, for which CT innovations have burgeoning influences and always dominate at long horizons, the RER has no uniform results across countries. This may reflect the offsetting effects of CT innovations on the exchange rate and the relative price. In general, the contribution of CT innovations remains relatively stable across different horizons. For the real yen rate, CT innovations explain 71% of the RER fluctuations. For the real mark rate, the relative influence of CT innovations declines to about 43%, implying that transitory innovations account for more than half of the variance. For the real pound rate, we obtain very different results, with CT innovations explaining just a minuscule portion (no more than 1%) of the RER variability.

Table 2 (Panel B) reports the variance decomposition results with regard to CT innovations under no PPP assumption. Not surprisingly, the decomposition results for Japan are relatively unaffected by relaxing the PPP condition since its estimated cointegration vector differs not much from the theoretical one. For the other two countries, we obtain very different decomposition results. The unrestricted decomposition estimates suggest that CT shocks can be even more dominant in the RER for the pound and the mark than for the yen. At the 4-year horizon, CT innovations can already explain 96% (99%) of the nominal exchange rate variability, 99% (99%) of the relative price variability and 99% (99%) of the RER variability in the German mark (British pound) case.

On the whole, the variance decomposition results can be sensitive to the PPP assumption. When the PPP condition is maintained, the relative importance of CT and transitory dynamics in RERs is found to vary widely across countries. While transitory dynamics are dominant in the British pound case, CT dynamics are dominant in the Japanese yen case. When dropping the PPP condition, we find broad support for the importance of CT dynamics. Among the three currencies under study, CT dynamics account for 67–99% of the RER variability.

## V. Sources of the CT and Transitory Innovations

While CT and transitory innovations are identified in the decomposition analysis, no attempt has yet been given to examine what the sources of these structural innovations are. A natural question arises as to whether these innovations come from changes in standard macroeconomic factors such as productivity and interest rates. In the analysis below, we are interested in testing whether the changes in economic fundamental variables Granger-cause the innovations to CT and transitory dynamics.

Let $\Delta Z_t$ denote the changes in macroeconomic factors and consider the following equation:

$$w_t = S\Delta Z_t + u_t \tag{10}$$

where $S$ contains the parameters of interest. Running causality tests based on Equation 10 directly, however, would require generated estimates of $w_t$ and lead to an errors-in-variables problem. To avert the problem with generated regressors, we consider an alternative system procedure. The restricted VAR representation that incorporates the cointegration property of the data can be described as follows:

$$B(L)\,y_t = \theta + MF^{-1}w_t \tag{11}$$

Combining this with Equation 10 yields the following system after rewriting

$$B(L)\,y_t = \theta + MF^{-1}S\Delta Z_t + MF^{-1}u_t = \theta + S^{*}\Delta Z_t + v_t \tag{12}$$

where $S = FM^{-1}S^{*}$. Since $F$ and $M$ are nonsingular, $S^{*} = 0$ if and only if $S = 0$. Furthermore, given the matrix $M$ and the matrix $F$ from the CT decomposition, we can back out the estimate for $S$ from $S^{*}$ and then evaluate the significance of macroeconomic factors using a Wald test.

In the actual data analysis, we investigate if the CT and transitory innovations are attributable to the changes in different macro fundamental factors, including the changes in productivity ($\Delta PR_t$), money supply ($\Delta MS_t$), interest rates ($\Delta IR_t$) and oil prices ($\Delta OIL_t$). Productivity is measured as industrial production divided by labour employment (see the Appendix for specific data sources). The oil price is the world crude oil price measured in the US dollars. Without assuming symmetric effects between countries, our analysis allows for possibly different effects from macroeconomic changes overseas (in the US) and those from domestic changes. Tests for causal effects of

**Table 3. Causality tests for the sources of the CT and transitory innovations of RERs**

| | US macro variables | | | Domestic macro variables | | | |
|---|---|---|---|---|---|---|---|
| | $\Delta PR$ | $\Delta MS$ | $\Delta IR$ | $\Delta PR$ | $\Delta MS$ | $\Delta IR$ | $OIL$ |
| Panel A: With the PPP condition imposed | | | | | | | |
| *CT innovations* | | | | | | | |
| Germany | 1.322 | 1.121 | 12.778** | 3.195 | 4.076 | 5.755* | 7.555** |
| | (0.516) | (0.571) | (0.002) | (0.202) | (0.130) | (0.056) | (0.023) |
| Japan | 2.736 | 7.385* | 13.720** | 6.169 | 1.179 | 2.271 | 1.972 |
| | (0.434) | (0.061) | (0.003) | (0.104) | (0.758) | (0.518) | (0.578) |
| UK | 2.393 | 7.967** | 0.474 | 1.184 | 2.358 | 0.136 | 3.557 |
| | (0.495) | (0.047) | (0.924) | (0.757) | (0.502) | (0.987) | (0.313) |
| *Transitory innovations* | | | | | | | |
| Germany | 1.881 | 7.341** | 14.101** | 3.460 | 0.553 | 21.381** | 2.993 |
| | (0.391) | (0.025) | (0.001) | (0.177) | (0.759) | (0.000) | (0.224) |
| Japan | 3.265 | 6.089 | 4.289 | 0.270 | 0.146 | 2.566 | 0.972 |
| | (0.353) | (0.107) | (0.232) | (0.966) | (0.986) | (0.464) | (0.808) |
| UK | 5.345 | 8.330** | 11.553** | 2.371 | 0.041 | 22.549** | 5.488 |
| | (0.148) | (0.040) | (0.009) | (0.499) | (0.998) | (0.000) | (0.139) |
| Panel B: Without the PPP condition imposed | | | | | | | |
| *CT innovations* | | | | | | | |
| Germany | 2.172 | 3.012 | 19.724** | 5.497* | 1.926 | 9.982** | 5.689* |
| | (0.337) | (0.222) | (0.000) | (0.064) | (0.382) | (0.007) | (0.058) |
| Japan | 2.734 | 7.378* | 13.714** | 6.176* | 1.181 | 2.267 | 1.976 |
| | (0.434) | (0.061) | (0.003) | (0.100) | (0.758) | (0.519) | (0.577) |
| UK | 5.252 | 5.193 | 12.613** | 2.271 | 0.045 | 21.204** | 5.382 |
| | (0.154) | (0.158) | (0.006) | (0.518) | (0.998) | (0.000) | (0.146) |
| *Transitory innovations* | | | | | | | |
| Germany | 2.644 | 5.272* | 21.993** | 6.564** | 0.319 | 16.940** | 3.456 |
| | (0.267) | (0.072) | (0.000) | (0.038) | (0.853) | (0.000) | (0.178) |
| Japan | 3.024 | 6.175 | 3.593 | 0.387 | 0.200 | 2.467 | 0.953 |
| | (0.388) | (0.103) | (0.309) | (0.943) | (0.978) | (0.481) | (0.813) |
| UK | 5.764 | 6.515* | 12.495** | 1.712 | 0.122 | 20.551** | 7.266* |
| | (0.124) | (0.089) | (0.006) | (0.634) | (0.989) | (0.000) | (0.064) |

*Notes*: The different macro fundamental variables considered in the causality tests include US and domestic labour productivity ($\Delta PR$), US and domestic money supply ($\Delta MS$), and US and domestic interest rates ($\Delta IR$), and oil prices ($\Delta OIL$). The Wald test statistics presented above examine the null hypothesis of no causal effects from the corresponding variables on the structural shocks to the RER. The numbers in parentheses are $p$-values.
* and ** denote statistical significance at the 10 and 5% levels, respectively.

individual variables are carried out with the following augmented VAR regression

$$y_t = \theta + \sum_{j=1}^{k+1} B_j y_{t-j} + \sum_{j=0}^{k+1} S_j^* \Delta Z_{t-j} + v_t \qquad (13)$$

Both contemporaneous and lagged effects of macroeconomic changes are included. Each macro factor is allowed to contribute to both CT and transitory innovations with no *a priori* restrictions.

Table 3 (Panels A and B) presents the respective results of the causality tests with and without the long-run PPP restriction. Estimated $p$-values are shown in parentheses. We first look at the possible productivity effects. In the cases with long-run PPP imposed, productivity changes are generally found to have a little influence on either CT or transitory innovations. However, a different pattern of results are obtained when long-run PPP is not imposed. In the German mark case, domestic productivity changes contribute to both CT and transitory dynamics. In the Japanese yen case, domestic productivity changes are a significant contributor to CT dynamics but not to transitory dynamics. In the British pound case, productivity changes – be they domestic or US changes – do not have any significant impact at all. Overall, the significance of productivity effects can vary greatly across currencies and is sensitive to whether or not long-run PPP is imposed.

The results on money supply effects show a different pattern from those on productivity effects. Evidently, US money supply changes matter more than those domestic changes. Based on the PPP-imposed test results, US money supply changes contribute significantly to CT dynamics in the Japanese yen and British pound cases and to transitory dynamics in the German mark and British pound cases. In contrast, domestic money supply changes cannot be linked to either CT or transitory dynamics in any of the cases. Without the PPP condition imposed, domestic money supply changes are similarly found to affect neither CT nor transitory dynamics. US money supply changes, on the other hand, can influence transitory dynamics in the German mark and British pound cases. In addition, they contribute to CT dynamics in the Japanese yen case but not in the British pound case anymore. It follows that the relevance of US money supply effects is weakened for the British pound when dropping the PPP assumption.

Compared to money supply changes, interest rate changes seem to have broader relevance, though their significance can still vary a lot across currencies. According to the PPP-imposed test results, domestic interest rate changes can be linked to CT dynamics for the German mark and to transitory dynamics for both the German mark and the British pound. US interest rate changes contribute to CT dynamics for both the German mark and the Japanese yen and to transitory dynamics for both the German mark and the British pound. Like that of money supply effects, the significance of interest rate effects may also change when relaxing the long-run PPP restriction. For both the German mark and the British pound, domestic interest rate changes are now found to influence CT and transitory dynamics alike. The same results hold for US interest rate changes. In the Japanese yen case, domestic interest rate changes continue to have negligible impact on either CT or transitory dynamics. US interest rate changes may matter but they contribute to only CT dynamics and not transitory dynamics in this case. In general, dropping the long-run PPP condition seems to yield broader significance for interest rate effects.

With regard to the effects of oil price changes, the causality test results are also not uniform across countries. Oil price changes may be linked to CT innovations, but only for the German mark and not for the other two currencies. With respect to transitory innovations, the oil price effects are mostly insignificant, except for the British pound when long-run PPP is not imposed.

As a robustness check, we also performed bootstrapping analysis to evaluate the statistical significance of our test results on causal effects. The empirical distribution of each test statistic was constructed from simulating data based on our estimated VEC model through 1000 repetitions. The analysis yielded qualitatively similar findings, reinforcing our main results reported earlier. In particular, the analysis confirmed the heterogeneity in causality test results across currencies as well as the sensitivity of these test results to the imposition of the theoretical PPP condition.[8]

All in all, despite the nonuniform results, some interesting patterns exist. Interest rate changes are, in general, found to be more important than productivity changes in contributing to either CT or transitory dynamics. Money supply changes may also be a contributing source, but their significance is not as broad as interest rate changes, especially when long-run PPP is not imposed. The results also support that US money supply changes tend to be more important than domestic money supply changes in influencing both CT and transitory dynamics. Such asymmetric effects are less evident between US interest rate changes and domestic interest rate changes, on the other hand.

## VI. On the Persistence of Transitory Dynamics

Some remarks concerning the PPP puzzle, as raised by Rogoff (1996), should also be noted. Although the immense short-term volatility of the exchange rate suggests a likely important role of monetary shocks, the observed half-life persistence of RERs seems too high to be generated by monetary disturbances, even allowing for price stickiness. Rogoff (1996) discusses the idea of a middle ground that RERs are buffeted by both monetary and productivity shocks. If this mixed-shocks explanation is valid, PPP reversion should actually be rather fast subsequent to monetary shocks, and the high persistence in the RER would largely be induced by productivity shocks.

Based on our decomposition analysis, we evaluate the RER adjustment speed with respect to the different innovations. For the real mark rate, the estimated half-lives are 4.1 years for CT dynamics and 3.3 years for transitory dynamics. For the real yen rate, the half-lives are measured to be 4.6 and 4.4 years, respectively. In the case of the real pound rate, the half-lives are estimated to be 4.9 years for CT dynamics and 2.2 years for transitory dynamics.

[8] To further examine the robustness of our results with respect to the lag choice, we experimented with alternative lag specifications, different from that suggested by the SIC. These various specifications were found to produce qualitatively similar results to those reported here.

Although our analysis allows for the different effects of monetary changes and productivity changes, the results do not help resolve the PPP puzzle. In view of our half-life estimates, the persistence of the RER with respect to transitory innovations remains too high (with half-lives ranging from 2.2 to 4.4 years). Given that transitory innovations are shown to be linked to monetary changes primarily, productivity changes play a little role in generating such highly persistent dynamics. Indeed, monetary changes are also found to be the principal contributor to CT innovations. It follows that the mixed-shocks explanation does not suffice to account for the PPP puzzle.

Interestingly, a number of recent studies (Chari *et al.*, 2002; Benigno, 2004; Hairault and Sopraseuth, 2005) have highlighted the significant effects of monetary disturbances on RERs in two-country general equilibrium models with nominal stickiness. These open economy models illustrate that monetary changes can generate highly persistent RER dynamics. Our empirical results are in line with the prediction of these models.

## VII. Summary and Concluding Remarks

The relative contribution of CT and transitory dynamics to RER fluctuations has not been investigated in previous empirical studies. Taking a first step, this study applies a statistical decomposition scheme to analyse the two constituting components of RER changes. In general, our decomposition results support the relative importance of CT dynamics for the real rates of the German mark and the Japanese yen. For the real pound rate, the evidence appears less than definitive. We observe that the estimated contribution of the CT dynamics can be quite sensitive to whether or not long-run PPP is imposed.

The decomposition analysis is further extended to examine whether the CT and the transitory dynamics can be linked to changes in specific macroeconomic factors. Our overall results point to a relevant but limited role of macro fundamentals in explaining the CT and transitory dynamics of the RER. Again, the statistical results can vary in significance from one currency to another, and they are also sensitive to the imposition of the theoretical PPP condition. Amidst the less than uniform results, some interesting patterns still emerge. Interest rate changes are, in general, found to be more important than productivity changes in contributing to either CT or transitory dynamics. Money supply changes can also be a contributing source, but their relevance is not as broad as interest rate changes, particularly when long-run PPP is not imposed. Interestingly, US money supply changes are found to be more important than domestic money supply changes in influencing both CT and transitory dynamics. Such asymmetric country effects are much less pronounced for interest rate changes.

Theoretically, monetary and productivity changes can both influence RER dynamics, as illustrated in standard open-economy macroeconomic models (Obstfeld and Rogoff, 1995). In our empirical analysis, productivity changes are found to play little role in explaining either the CT or the transitory dynamics of the RER. Our analysis also finds high persistence in the transitory dynamics. The findings here are in accordance with the recent open-economy models discussed by Chari *et al.* (2002), Benigno (2004) and Hairault and Sopraseuth (2005). These recent studies underscore the importance of monetary changes and demonstrate their ability to generate highly persistent RERs.

Some final remarks on the empirical study of productivity effects are in order. To determine the contributing role of productivity changes in PPP deviations, the commonly used approach is to analyse the RER as a univariate process, estimate its permanent and transitory components and then link them to different economic factors. Presumably because productivity changes are treated as real shocks to relative prices, the conventional view is that productivity factors should be linked to the permanent component, not to the transitory component. The permanent component cannot be identified, however, unless the RER contains a significant nonstationary component. Consequently, previous PPP studies of productivity effects typically accept the existence of a unit root in the RER, although the empirical evidence remains less than conclusive in the literature. In this study, our decomposition analysis can be applied whether or not PPP deviations are stationary. Productivity changes, like monetary changes, are allowed to have persistent effects on relative prices without causing permanent deviations from PPP.

## Acknowledgements

This is a substantially revised version of the discussion paper 'Productivity shocks, monetary shocks and the short- and long-run dynamics of exchange rates and relative prices'. We have received valuable comments from Niels Arne Dam, Søren Johansen, Katarina Juselius, Ronald MacDonald, and seminar participants at the University of Copenhagen and at the 2005 AEA Conference on Exchange Rate Econometrics.

Michael Bergman gratefully acknowledges financial support from the Swedish Research Council.

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## Appendix: Data Sources

| Data variables | Sources |
|---|---|
| Consumer price index | IMF's IFS CD-ROM |
| Nominal exchange rate | IFS CD-ROM |
| Industrial production | OECD main economic indicators |
| | Japan, the UK and the US: Industrial production, manufacturing |
| | Germany: total industrial production |
| Employment | OECD main economic indicators |
| | Germany, Japan and the US: employment in manufacturing |
| | UK: quarterly total employment interpolated to monthly data |
| Money stock | Germany, Japan and the US: M1 taken from IFS CD-ROM |
| | UK: M2 from Bank of England |
| Long-term interest rate | OECD main economic indicators |
| | Germany: 7–15-year public sector bonds |
| | Japan: 10-year benchmark central government bonds |
| | UK: 10-year government bonds |
| | US: Government bonds over 10 years |
| World oil price | Ecowin |