Supply shocks and real exchange rates*

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Abstract

Previous studies of the sources of real exchange rate fluctuations have concluded that real demand shocks account for the bulk of the movements in real exchange rates. In this paper, bilateral real exchange rates between the US, the UK, Germany and Japan are investigated using a statistical approach that allows for long-run equilibrium relationships between real exchange rates and the fundamental variables. The results differ from previous findings in that most long run movements in real exchange rates are due to supply shocks. This can be interpreted as empirical support for the Balassa (1964) and Samuelson (1964) relative productivity approach to real exchange rate determination.

1 Introduction

Purchasing power parity (PPP) implies that real exchange rates fluctuate stationarily around a constant equilibrium level. More often than not, PPP is rejected in empirical tests. Hence, equilibrium real exchange rates appear to be changing over time. Different models of real exchange rate determination emphasize different factors as sources of these movements. According to the Balassa (1964) and Samuelson (1964) approach, the

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development of equilibrium real exchange rates is determined by relative productivity in the tradable and non-tradable sectors. Sachs and Wyplosz (1984), and Frenkel and Razin (1986), among others, argue that real exchange rates are instead driven by real demand factors such as government spending. A third class of models follow Dornbush (1976) and focus on how real exchange rates respond to monetary shocks given that nominal prices are sticky in the short-run.

Information about the sources of real exchange rate fluctuations is useful for evaluating the empirical relevance of different classes of models of real exchange rate determination. For instance, the finding that most long-run movements in real exchange rates are due to relative productivity shocks can be interpreted as empirical support for the Balassa (1964) and Samuelson (1964) model. If most fluctuations in the short- to medium-run are caused by monetary shocks, the behavior of real exchange rates at reasonable forecasting horizons is broadly consistent with sticky price models á la Dornbush.

Knowing what causes movements in real exchange rates is also important for policy decisions about exchange rate arrangements and monetary policy in general. The more important monetary shocks and other transitory shocks are, the more suitable is a fixed exchange rate arrangement that insulates the economy from this short-run real exchange rate volatility.

Previous studies of the sources of real exchange rate fluctuations have concluded that real demand shocks account for most of the variance of real exchange rates, in the short-run as well as in the long-run (Clarida and Gali, 1994; Weber, 1997; Chadha and Prasad, 1997). Diverging results are presented by Rogers (1999) and Eichenbaum and Evans (1995), who document a larger relative influence of monetary shocks. Interestingly, these studies invariably conclude that supply shocks have only a negligible impact on real exchange rates. This is surprising in light of the related literature on long-run real exchange rate determination, where versions of the Balassa-Samuelson model dominate and exchange rates are modelled primarily (or exclusively) as functions of relative productivity (Canzoneri et al., 1999, Chinn and Johnston, 1996).

Another notable feature of the variance decomposition literature is that virtually all studies model only *changes* in the real exchange rates and the fundamental variables. The presence of long-run relationships between the levels of the variables is either rejected (as in Clarida and Gali, 1994; and Rogers, 1999) or not investigated (as in Weber, 1997).[1] Again, there is a gap between this empirical literature and related studies of long-run real exchange rate determination. Most papers in the latter field do find long-run equilibrium relationships between real exchange rates and various fundamental variables. There is ample documentation of cointegration between levels of real exchange rates and, for instance, relative productivity (see MacDonald, 1998, for a survey).

Hence, previous studies of the causes of fluctuations in real exchange rates (i) invariably conclude that supply shocks have a negligible impact on long-run real exchange rates and (ii) do not find cointegration between the levels of the variables (or do not investigate whether they are cointegrated). This paper provides evidence of long-run equilibrium relationships between real exchange rates and the fundamental variables. Furthermore, when cointegration is taken into account, supply shocks dominate the long-run variance decompositions of real exchange rates. This result is robust across a number of alternative empirical specifications. It can be interpreted as empirical support for the Balassa (1964) and Samuelson (1964) model that emphasizes relative productivity developments as source of long-run movements in real exchange rates.

2 Statistical methods

Macroeconomists have used long-run restrictions on VAR models to identify structural shocks since the 1980s. This approach has only recently been applied to real exchange rates. The first paper to investigate what structural shocks that have caused the movements in real exchange rates is Clarida and Gali (1994). They impose long-run identifying restrictions a'la Blanchard and Quah (1989) on a VAR model containing the first differences of relative output, relative prices and real exchange rates. Their main result is

[1] Actually, Clarida and Gali (1994) find cointegration for one of the four countries studied, but they ignore this in the subsequent empirical analysis. In Rogers (1999), the null hypothesis of cointegration would not be rejected if the 90 percent critical values of the Johansen (1988) tests were used instead of the 95 percent critical values.

that real demand shocks account for the bulk of the fluctuations of real exchange rates in the long-run as well as in the short-run. The influence of supply shocks is insignificantly different from zero at all horizons for all the countries. Subsequent research has essentially confirmed the findings of Clarida and Gali (Chadha and Prasad, 1997; Weber, 1997). The largest influence of supply shocks is reported by Weber (1997), who conclude that they account for about a third of the long-run variance of the bilateral real exchange rates between Japan on one hand and the United States and Germany on the other.

The statistical approach in this paper differs from previous studies in that long-run equilibrium relationships between the levels of the variables are taken into account. If the real exchange rates are cointegrated with the fundamental variables, models using only differenced data are misspecified and the information contained in the levels of the data is not utilized. The absence of cointegration implies that it is not possible to model an equilibrium level of the real exchange rate as function of the included fundamental variables. This result is at odds with the literature on long-run real exchange rate determination, where real exchange rates are frequently found to be cointegrated with various fundamental variables, see McDonald (1998) for a survey. A study that incorporates long-run equilibrium relationships between real exchange rates and the other variables is Alexius (2000). Focusing on the real exchange rates between the four Nordic countries and Germany, she finds that supply shocks dominate the long-run variance decompositions for these small open economies.[2]

The traditional Blanchard and Quah (1989) approach used by Clarida and Gali (1994), Rogers (1999), Weber (1997), and others, utilizes data on changes in the variables. There are however also similar methods designed to handle long-run equilibrium relationships between the levels of the variables. The common trends approach discussed by King, Plosser, Stock and Watson (1991) and Warne (1993) imposes long-run restrictions on a

[2] In Alexius (2000), real demand shocks and monetary shocks are aggregated into a single category. This is questionable since higher government spending presumably leads to a real exchange rate appreciation, while an expansionary monetary policy leads to a depreciation. As shown by Faust and Leeper (1997), aggregating different shocks into a single category is only appropriate if they have the same effect on the dependent variables. The total effect of demand shocks on real exchange rates could be much larger than documented by Alexius (1999) since the effects of the real and nominal demand shocks may offset each other.

cointegrated VAR to identify structural shocks. We start with the following n-dimensional VAR model:

$$\Delta x_t = \mu + \Pi x_{t-1} + \sum_{i=1}^{P} \Gamma_i \Delta x_{t-i} + \varepsilon_{t+1}. \tag{1}$$

The cointegrated VAR model in (1) can be re-written as a common trends model (see e.g. Stock and Watson, 1993):

$$x_t = x_0 + A\tau_t + \phi(L) v_t. \tag{2}$$

where

$$\tau_t = \mu + \tau_{t-1} + \varphi_t \tag{3}$$

$A\tau_t$ is the permanent component of x_t and $\phi(L) v_t$ is the transitory component. The number of cointegrating vectors r in (1) determines the number of independent stochastic trends k in the common trends model (2) as $k = n - r$ or the number of variables in the system minus the number of cointegrating vectors. τ_t are the k stochastic trends with the drifts μ and the innovations φ_t. The loading matrix A determines how the variables in x_t are affected by the stochastic trends in the long run. The permanent shocks in φ_t are allowed to enter into the transitory shocks v_t, whereby shocks to the stochastic trends also affect the "cycles" or short-run dynamics of x_t. In order to identify the structural shocks, restrictions can be imposed on the long-run impact matrix A. $k(k-1)/2$ restrictions are needed for exact identification.[3] Forecast error variance decompositions can be used to study how much of the variance of real exchange rates that is due to the different structural shocks.

Although the purpose of the variance decomposition literature is empirical, several

[3] With n variables, r cointegrating vectors and k common trends, there are nk parameters in the A-matrix. The cointegrating restrictions identify rk parameters. Rewriting A as $A_0\pi$ and applying a Cholesky decomposition to π yields another $k(k-1)/2$ parameters, hence leaving $k(k-1)/2$ free parameters to be identified. As pointed out by Warne (1993), this does not imply a recursive structure of the influence of τ_t on x_t. See Warne (1993) for a more detailed discussion of the number of restrictions needed for exact identification.

studies also contain theoretical models. For instance, Clarida and Gali (1994) and Weber (1997) develop versions of the two country, rational expectations open macro model of Obstfeld (1985). Other studies, such as Rogers (1999), refrain from presenting a theoretical model. The identifying assumptions imposed on the VAR models are however very similar irrespective of what theoretical model that is used. For instance, monetary shocks are identified using the long-run neutrality of money, which is a characteristic common to most (if not all) open economy macro models. As pointed out by Stockman (1994) in his comment to the Clarida and Gali paper, this standard assumption implies that temporary supply shocks and temporary real demand shocks are classified as monetary shocks. Theoretical foundations for the present empirical strategy are found in Clarida and Gali (1994) or Weber (1997). Here, attention is instead devoted to investigating the robustness of the empirical results with respect to changes in the identifying assumptions and the included variables.

3 Empirical results

The data are collected from the OECD data base Main Economic Indicators. Bilateral real exchange rates between the United States, the United Kingdom, Germany and Japan are constructed from nominal exchange rates (units of domestic currency per unit of foreign currency) and CPIs. Corresponding data on relative real GDP, y_t, relative government consumption as share of output, g_t, and the relative price level (CPI), p_t, are defined as the domestic variable minus the foreign variable.[4] All variables are in logarithms of the levels of the time series. The sample period is 1960Q1 to 1998Q4. As in previous studies, the ADF unit root test indicate that the time-series are I(1).

We want to estimate the common trends model in (1) to (3) for each bilateral real exchange rate and the corresponding time-series on relative real GDP, relative government spending and relative price levels. The first step when estimating a common trends model is to determine the cointegrating rank r of the system. As discussed above, pre-

[4] The real GDP data consist of the volume indices series from Main Economic Indicators.

vious studies within the variance decomposition literature have concluded (or assumed) that real exchange rates are integrated of order one but not cointegrated with the other fundamental variables. In contrast, numerous empirical studies of long-run real exchange rate determination have found cointegration between real exchange rates and relative productivity, relative government consumption and/or terms of trade.

The economic interpretation of the presence of cointegration is that there exists a time-varying equilibrium real exchange rate as function of the included fundamental variables. Since it is controversial whether real exchange rates are cointegrated with other fundamental variables, several different tests are used to investigate whether the presence of cointegration is a robust finding for this data set.

The Johansen (1988) cointegration tests indicate that there is one cointegrating vector in all cases. Neither the trace test nor the λ-max test reject the null hypothesis of cointegration, see Table A1. There is more evidence of additional cointegrating vectors than of no cointegration as two of the second largest trace statistics are significant using the 90-percent critical values from Osterwald and Lenum.[5]

Stock and Watson (1988) propose a test for the null hypothesis that the data are not cointegrated. Alternatively, there are r_a covariance stationary linear combination of the time series. There will then be r_a eigenvalues that are smaller than one, which is their alternative hypothesis.[6] Here, the null hypothesis of no cointegration is rejected for five of the six bilateral systems, see Table A2. The exception is the GBP/USD real exchange rate. Park's (1992) canonical cointegration test also indicates that there is cointegration in four of the six systems, see Table A2. Since at least two of the three tests indicate that there is cointegration in each system, and the few cases where this is rejected differ between the tests, we conclude that the real exchange rates are cointegrated with the fundamental variables in this data set.

The cointegrating vectors reflect long-run equilibrium relationships between real ex-

[5]If 95-percent critical values are used, as in Rogers (1999), the trace statistics still indicate a single cointegrating vector in all cases but the λ-max statistics reject the null hypothesis of cointegration.

[6] Focusing on a VAR(1) for simplicity, Johansen (1988) test for the rank of in ($\Delta x_t = \Pi x_{t-1} + \Gamma_1 \Delta x_{t-1} + \varepsilon_{t+1}$), Stock and Watson focus on the number of eigenvalues of the estimated $\widehat{\Phi}$ in ($x_t = \Phi x_{t-1} + \varepsilon_t$) that are smaller than unity.

change rates, relative output, relative government consumption and relative price levels. From a Balassa-Samuelson relationship between the real exchange rate and relative productivity, higher (relative) domestic output appreciates the real exchange rate in the long-run.[7] The magnitude of the effect of relative productivity on equilibrium exchange rates is usually found to be slightly less than one to one, see for instance MacDonald (1998) or Alexius and Nilsson (2000) for discussions of the empirical evidence. Higher (relative) government consumption is also expected to appreciate the real exchange rate since it implies a higher demand for non-tradable goods.

The relative price level is a special case. It would obviously be a violation of long-run monetary neutrality if it were cointegrated with real exchange rates. However, excluding the monetary variable from the cointegrating relationship implies that monetary shocks cannot affect the real exchange rate in the long-run. While this may well be a reasonable assumption, several previous studies have allowed monetary shocks to have real effects on real exchange rates in the long-run. For comparison with the literature, long-run effects of monetary shocks are allowed. It turns out that these effects are small, but given that relative prices are allowed into the cointegrating relationship, this is an empirical result and not an assumption.

Numerous procedures for estimating cointegrating vectors are available. All estimators based on the levels of the time series, such as OLS (as suggested by Engle and Granger, 1987), DOLS (Stock and Watson, 1993), FMOLS (Phillips and Hansen, 1990) or Park (1992), produce very similar parameter estimates of the expected signs and magnitudes. In contrast, the point estimates of the cointegrating vectors from the Johansen (1988) procedure have the expected signs only in half of the cases. Many of the point estimates are also implausibly large, two to four (even up to 20) in absolute values compared to expected magnitudes in the range of $0.5 - 1$. The Park (1992) estimates of the cointegrating vectors are shown in Table A3 and the Johansen estimates are shown in

[7] The Balassa-Samuelson model actually predicts a positive relationship between relative productivity in the tradable-nontradable sectors and real exchange rates. To the extent that (i) long-run trends in output are driven by productivity and (ii) non-tradable productivity is similar across the countries, this translates into a relationship between long-run trends in output and real exchange rates.

Table A4.

A possible reason for the differing behavior of the Johansen estimates is that they are based on the error-correction representation, which may be poorly estimated in the case of real exchange rate if they do not return to long-run equilibrium with a fixed proportion of last period's deviation from equilibrium as assumed in the Johansen approach.[8] The other estimates of the cointegrating vectors are similar to each other but very different from the Johansen estimates. We use the Phillips and Hansen (1990) fully modified OLS estimates shown in Table 1 because they are most consistent with expected signs and magnitudes given previous empirical results as well as theory. The main results in terms of variance decompositions are robust between the OLS, FMOLS, DOLS and Park (1992) estimates of the cointegrating vectors.

The cointegrating vectors in Table 1 imply that higher relative productivity is associated with a stronger real exchange rate in the long-run as all the coefficients on relative output are positive. The magnitude of the effect varies between 0.64 and 1.14. The USD/DEM is an exception as one percent increase in relative productivity is only associated with a real exchange rate appreciation of 0.41 percent. Relative productivity appears to be more important to the Japanese real exchange rate as the three largest point estimates are found for DEM/JPY (1.14), USD/JPY (1.01), and GBP/JPY (0.77). Japan has experienced a much faster economic growth over the sample period than the other countries.

Higher relative government consumption is also associated with stronger real exchange rates as expected since it implies a higher relative demand for non-tradables. The estimated effects of changes in government consumption are of the same magnitudes as the effects of relative productivity, 0.67-1.16. An outlier here is the GBP/USD real exchange rate, where one percent higher government spending only appreciates the real exchange rate by 0.315. As expected from long-run monetary neutrality, the coefficients on relative

[8] For another application of the Johansen procedure to real exchange rates where the estimates of β are implausibly large and of apparently random signs while other estimates based on the levels of the time series have the expected signs and magnitudes, see Alexius and Nilsson, 2000. Here, the common trends model shows various signs of miss-specification if the apparently non-stationary Johansen cointegrating relationships are imputed.

prices are small in absolute values (0.08-0.36) and of different signs.

The structural shocks are identified by imposing restrictions on their long-run effects. Given one cointegrating vector and four I(1) variables, there are three stochastic trends, identified as a relative productivity trend, a real demand trend and a monetary trend. All three shocks are allowed to affect the real exchange rate and the relative price levels in the long-run. Monetary shocks are identified by the assumption that they do not affect relative output or government spending in the long-run. They are however allowed (but not forced) to affect real exchange rates in the long-run. There will also be a transitory shock which presumably captures noise in the foreign exchange markets.

One additional restriction is needed for exact identification. Government spending shocks can be assumed not to affect output in the long run, or productivity shocks can be assumed not to affect government spending in the long run. As often, it is possible to find arguments both for and against both restrictions. For instance, a fiscal policy reaction function implying that government consumption (as fraction of GDP) increases as the country gets richer implies that government spending is affected by productivity shocks. In the baseline model, following Rogers (1999), government spending shocks are allowed to affect output but productivity is assumed not to affect government spending in the long-run. In Section 4, we check whether the results are robust to changes in this assumption.

Given the cointegrating vectors and the identifying restrictions, the common trends model in (2) and (3) can be estimated. The number of lags in the VAR model is set sufficiently high to remove residual autocorrelation. Impulse response functions show how the variables react to the different structural shocks.[9] A simple check of the validity of the identifying assumptions is whether these effects have the expected signs. A positive supply shock should increase output and decrease prices in the short-run as well as in the long-run. In contrast, a demand shock should increase both output and prices in the short-run. All the empirical models are reasonable in the sense that the short-run responses of output and prices to supply and demand shocks have the expected signs.

[9] The short-run impulse response functions show how the four variables respond to the four different shocks in the six bilateral systems. These 48 graphs are available from the author on request.

Many of the short-run impulse responses are however not significantly different from zero.

All the real exchange rates appreciate significantly in response to increases in (relative) productivity in the short run as well as in the long run. This is consistent with the Balassa (1964) and Samuelson (1964) approach but not with the Obstfeld (1985) model or other models without a distinction between tradable and non-tradable goods. If each country produces a single good, higher productivity increases relative supply of the good, thereby lowering its relative price and hence depreciating the real exchange rate. Clarida and Gali (1994), and others, whose empirical specification is derived from a version of the Obstfeld (1985) model, also find that real exchange rates appreciate in response to increased in productivity.

Variance decompositions show how much of the fluctuations in the real exchange rate that are due to each type of structural shock at different horizons. Three of the six real exchange rates behave roughly as expected: DEM/JPY, USD/JPY and GBP/DEM. Table 2 shows the variance decompositions for these real exchange rates as the forecasting horizon is increased from one to 40 quarters.

Transitory shocks dominate at the very short horizons. They account for 65, 37, and 52 percent of the variance at the one quarter horizon for the DEM/JPY, USD/JPY and GBP/DEM, respectively. The relative influence of the transitory shocks then declines as the forecasting horizon is increased. At ten years, only 15, 16 and 20 percent of the variance is due to transitory noise. This implies that most of the ten-year fluctuations in these real exchange rates can be explained by the included fundamental variables.

Monetary shocks account for 20-40 percent of the variance at horizons between one and 40 quarters for the DEM/JPY USD/JPY and GBP/DEM real exchange rates. This implies that monetary shocks are somewhat more important than what has typically been found. The share of the variance due to monetary shocks tends to peak slightly at business cycles frequencies, 8 to 20 quarters, and decline thereafter.

Government spending shocks could well have both a cyclical pattern and be important in the long-run as the countries have experienced different long-run developments in government spending relative to GDP. For the DEM/JPY, USD/JPY and GBP/DEM, real demand shocks are however equally unimportant at all horizons. They generally account for less than five percent of the variance (9.4 percent at 40 quarters for the USD/JPY).

The influence of supply shocks for the DEM/JPY, USD/JPY and GBP/DEM is shown in the third column of Table 2. It increases continuously with the horizon, from 14, 21 and 17 percent of the forecast error variance in the first quarter to 57, 45 and 48 percent at the ten-year horizon. This is an interesting finding since previous studies have invariably concluded that fluctuations in real exchange rates are mainly due to real demand shocks. Here, relative supply shocks explain the bulk of the movements at ten-year horizons. This can be interpreted as empirical support for the Balassa (1964) and Samuelson (1964) relative productivity approach to real exchange rate determination. The identifying assumptions used to label the structural shocks can always be questioned, but it remains true that the shocks causing the long-run movements in relative output also cause most of the movements in real exchange rates. Interpreting the long-run trends in real output as long-run productivity trends is one of the least controversial identifying restrictions that can be used in this framework..

Table 3 shows the forecast error variance decompositions for the GBP/USD, USD/DEM and GBP/JPY for horizons of one to 40 quarters. The main difference between these real exchange rates and the three discussed above is that transitory shocks dominate the variance decompositions even at forecast horizons of ten years for the GBP/USD, USD/DEM and GBP/JPY. This is not an ideal situation given that the empirical model identifies the structural shocks using restrictions on their long-run effects. However, the variance decompositions still contain interesting information.

The USD/DEM real exchange rate is special in that the share of the variance due to transitory shocks actually *increases* with the forecasting horizon. The large share of the variance due to transitory shocks at ten years (82 percent) can be interpreted as the common trends model's way of indicating that the USD/DEM real exchange rate is close to stationary over the sample period. PPP is formally rejected for all the real exchange rates, but it is difficult to capture long-run phenomena like PPP even in data sets covering several decades. The real exchange rates are shown in Figures 1 and 2. The USD/DEM is not distinctly trended over the sample period and eye-ball econometrics would not necessarily reject PPP.

Transitory shocks cause more than half (52 percent) of the fluctuations at the ten-year horizons also for the GBP/USD real exchange rate, which also displays a very moderate trend (see Figure 2). For the GBP/JPY, 48 percent of the variance is still due to transitory shocks at ten years. Judging from Figure 2, this real exchange rate appears to contain substantial long-run movements over the sample period, but there are also transitory fluctuations that are larger and more persistent than for the three real exchange rate shown in Figure 1.

Another notable feature of the variance decompositions in Table 3 is that while the influence of supply shocks increases with the horizon, they are much less important here than for the three real exchange rates discussed above. Supply shocks cause less than 25 percent of the movements in the GBP/USD and GBP/JPY real exchange rates also at the ten-year horizon. For the USD/DEM real exchange rate, supply shocks never account for more than 7.4 percent of the variance. This is consistent with previous findings; it is the large influence of supply shocks for the DEM/JPY, USD/JPY and GBP/DEM real exchange rate that is atypical.

Monetary shocks are unimportant to the GBP/JPY real exchange rate as they account for less than nine percent of the variance at all horizons. For the GBP/USD and USD/DEM real exchange rates, about 20 percent of the variance at the short forecast horizons is due to monetary shocks. Their influence falls to ten percent as the horizons is increased. Real demand shocks are more important to the GBP/JPY real exchange rate than to the other real exchange rates studied here as they account for 20-30 percent of the variance at forecasting horizons of one to 40 quarters.

The most interesting observations from studying the short- to medium-run variance decompositions can be summarized as follows. (i) Supply shocks explain about half of the ten-year fluctuation of the DEM/JPY, USD/JPY and GBP/DEM real exchange rates. (ii) 80 percent of the ten-year fluctuations in these three real exchange rates can be explained by movements in the included fundamental variables. (iii) The GBP/USD, USD/DEM and DEM/JPY real exchange rate contain a lot of transitory fluctuations that are not captured by the fundamental variables included in this study. Half or more of the forecast error variance decompositions are due to transitory shocks even at ten-year horizons.

The long-run forecast error variance decompositions (shown in Table 4) reveal what structural shocks have caused the long-run movements of the real exchange rates. The long-run forecast error variance decompositions can be thought of as the continuation of Table 2 and 3 as the forecasting horizon approaches infinity. Transitory shocks do not affect the real exchange rates in the long-run by construction. The other identifying assumptions have the following interpretations: All shocks that have permanent effects on output are classified as supply shocks. Shocks that only affect relative price levels in the long-run are classified as monetary shocks. Real demand shocks affect government spending and price levels.

The second column of Table 4 shows the share of the long-run variance of the real exchange rates due to supply shocks. Supply shocks account for a much larger share of the long-run variance of real exchange rates here, 63 to 90 percent for all the real exchange rates except the GBP/USD (26 percent). These results contrast blatantly with the typical finding that supply shocks only account for a minuscule portion of the movements in real exchange rates. The largest share of the variance due to supply shocks previously documented is found in Weber (1997), where it amounts to a third of the long-run variance. The only empirical results comparable to those in Table 4 are found in Alexius (1999), where a common trends model that does not contain real demand shocks is estimated for the bilateral real exchange rates between Sweden, Norway, Finland and Denmark on one hand and Germany on the other.

Monetary shocks are unimportant to the long-run movements in the real exchange rates except for the GBP/USD, where they account for 19 percent of the variance. As discussed above, the shocks have a transitory as well as a permanent component. Monetary shocks can in principle be important to the real exchange rates at business cycle frequencies while still have a negligible long-run effect. Real demand shocks typically account for 20-30 percent of the long-run movements. They are more important to the GBP/USD (55 percent) and less important to the GBP/JPY (4 percent). Previous studies have concluded that 60-90 percent of the variance of real exchange rates is due to real demand shocks at all horizons.

Figures 1 and 2 show the six bilateral real exchange rates (in logarithms and normalized to zero in 1960:1). Two observations can be made in light of Tables 2 to 4. First, the two real exchange rates where transitory shocks explain more than half of the variance even at forecast horizons of ten years are the two real exchange rates where the presence of stochastic trends is less distinct (GBP/USD and USD/DEM). Second, there is a tendency for supply shocks to be more important to the real exchange rates that contain more pronounced stochastic trends (USD/JPY, GBP/JPY and GBP/DEM). A possible interpretation is that differences in productivity developments between countries can produce substantial trends in real exchange rates and hence cause large deviations from long-run purchasing power parity.

4 Robustness of the results

The results from VAR models where the structural shocks are identified using restrictions on their long-run effects may vary considerably with the exact formulation of the empirical model. It is therefore important to study the robustness of the results with respect to changes in the identifying assumptions and the included variables. Here, five alternative empirical models are estimated. Three of them incorporate long-run equilibrium relationships between the real exchange rates and the fundamental variables. First, the model in this paper is reestimated using relative money supply instead of relative price levels to capture monetary shocks (model A).[10] Second, the identifying assumption that productivity shocks do not affect government spending is replaced by the alternative assumption that government spending does not affect output in the long-run (model B).

[10] Data on money supply (M2) are taken from the OECD data base Main Economic Indicators.

This implies full crowding out of government spending in the long-run and a possible feed-back from real output to government spending. For instance, richer countries may have higher government spending relative to GDP.

In model C, the government spending variable is excluded to leave us with the three variables studied by Clarida and Gali: Real exchange rates, relative output and relative prices. In contrast to Clarida and Gali, cointegration between the levels of the variables is taken into account. Since there is one cointegrating vector in each of these three-variable systems, there are only two stochastic trends interpreted as a relative supply trend and a relative demand trend. The single identifying assumption is then that demand shocks do not affect real output in the long-run. This is the same empirical model as Alexius (2000) applies to the bilateral real exchange rates between Denmark, Finland, Norway and Sweden on one hand and Germany on the other.

The final two models ignore the presence of long-run equilibrium relationships between the variables. Model D is the original Clarida and Gali model using only first differences of real exchange rates, relative output and relative prices is applied. Model E is the empirical model of this paper estimated under the assumption of no cointegration, i.e. a four variable VAR containing the first differences of the real exchange rate, relative output, relative prices and relative government expenditure.

Table 5 shows the shares of the long-run variances due to supply shocks in the five alternative empirical models. In models A to C, cointegrating relationships between the variables are taken into account. In almost every case, supply shocks account for a much larger share of the long-run variance than what has been found in previous studies. The exceptions is the GBP/USD real exchange rate, where the share of the long-run variance due to supply shocks is below 30 percent in models B and C. It is however also clear that the identifying assumptions matter as the results vary considerably between the empirical specifications. The influence of supply shocks is smallest in case B, when productivity shocks are allowed to affect government spending in the long-run. The identifying assumptions can always be questioned, but it remains true that when long-run equilibrium relationships between the variables are allowed for, the shocks that drive relative real GDP in the long-run also constitute the main driving force of the long-run real exchange rates.

The fifth column shows the share of supply shocks from applying the Clarida and Gali model in first differences to the present data set. Similarly, the final column stems from a VAR in first differences containing the four variables included in the present study. This exercise produces the same negligible influence of supply shocks as in Clarida and Gali (1994) and others. Here, the bulk of the real exchange rate fluctuation are caused by real demand shocks, as is typically found when only changes in the variables are modelled.

Rogers (1999) also estimates a number of alternative empirical models. Supply shocks typically account for less than ten percent of the long-run variance of real exchange rates in his study. The largest share of the long-run variance due to supply shocks is 25.2 percent. However, the alternative of cointegration between real exchange rates and the fundamental variables is not included among his nine empirical models, even though the reported cointegration tests are significant using 90-percent critical values.[11]

Table 5 demonstrates that the treatment of possible long-run equilibrium relationships between real exchange rates and fundamental variables is essential for the results in terms of variance decompositions. If there exist long-run equilibrium relationships between levels of real exchange rates and other variables such as relative productivity, as has been shown in numerous empirical studies of long-run real exchange rate determination, it is important to include them explicitly in the empirical analysis. In particular, the shocks causing long-run movements in relative output levels appear to cause most long-run movements also in real exchange rates once cointegration is allowed.

5 Conclusions

The bulk of the empirical literature on real exchange rates focuses on long-run purchasing power parity. Since PPP is usually rejected in empirical tests, equilibrium real exchange

[11] Rogers (1999) runs the Johansen cointegration tests for 2, 5, and 8 lags in the VAR. The λ-max statistics for the null hypothesis of no cointegration are 29.4, 26.5 and 24.7 and the trace statistics are 50.5, 49.1, and 47.9. The 90-percent critical values in Osterwald and Lenum (1992) are 24.7 and 43.9.

rates appear to vary over time. The question is what causes changes in equilibrium real exchange rates. By studying the sources of movements in real exchange rates, new answers to old questions about real exchange rate determination can be obtained. Evidence that either type of structural shock is quantitatively more important can be interpreted as empirical support for a particular class of models of real exchange rate determination. Nuances can also be added to the all-or-nothing PPP hypothesis. For instance, as 82 percent of the ten-year forecast error variance of the GBP/USD real exchange rate is due to transitory shocks, it can be argued that PPP holds for all practical purposes for this real exchange rate even though the hypothesis is rejected by the formal tests.

Previous studies have found that most real exchange rate fluctuations are due to demand shocks, and that the influence of supply shocks is negligible. This is a surprising result given that the relative productivity approach of Balassa (1964) and Samuelson (1964) dominates the related literature on long-run real exchange rate determination. Also, the statistical approach used in previous studies implies that there are no long-run equilibrium relationships between real exchange rates and fundamental variables. This also contrasts to the literature on long-run-real exchange rates, where there is ample evidence of cointegrating relationships between real exchange rates and relative productivity, government spending and/or terms of trade (see for instance Chinn and Johnston, 1996, or Canzoneri, Cumby and Diba, 1999).

In this paper, the sources of fluctuations in real exchange rates are investigated using the common trends approach, where long-run equilibrium relationships between real exchange rates and fundamental variables are explicitly taken into account. Contrary to previous studies, relative productivity shocks are found to be the dominating source of long-run movements in real exchange rates. $60 - 90$ percent of the long-run forecast error variance of the USD/DEM, USD/JPY, DEM/JPY, GBP/JPY and GBP/DEM real exchange rates is due to supply shocks. The GBP/USD real exchange rate is an exception as supply shocks only account for 26 percent of its long-run variance.

To check the robustness of the results, several alternative empirical models using other identifying assumptions and/or variables are estimated as well. The exact formulation of the empirical model matters as the share of the long-run variance decomposition due to supply shocks varies considerably between the different models. However, productivity shocks remain much more important source of movmements in real exchange rates than what has been documented in previous studies in the models where cointegration between the levels of the real exchange rates and the fundamental variables is included. The results can be interpreted as empirical support for the relative productivity approach of Balassa (1964) and Samuelson (1964).

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Tables

Table 1: Point estimates of the cointegrating vectors using FMOLS[a]

Real exchange rate	q_t	y_t	g_t	p_t
USD/DEM	1.00	0.410	1.165	0.311
USD/JPY	1.00	1.014	1.020	-0.335
GBP/USD	1.00	0.717	0.315	0.357
DEM/JPY	1.00	1.144	0.783	-0.201
JPY/GBP	1.00	0.766	0.666	0.140
GBP/DEM	1.00	0.644	0.998	0.085

[a] This is the Phillips and Hansen (1990) fully modified OLS procedure.

Table 2: Forecast error variance decompositions at different horizons

Countries	Horizon	Supply	Real demand	Monetary	Transitory
DEM/JPY	1	14.31	1.70	18.84	65.15
	4	29.48	2.22	30.21	38.09
	8	38.00	2.26	30.78	29.95
	12	42.64	2.74	29.57	25.05
	20	48.55	3.80	26.93	20.72
	40	56.82	5.77	22.19	15.21
USD/JPY	1	21.23	0.20	41.54	37.21
	4	17.34	0.67	44.78	37.20
	8	21.97	0.40	44.59	33.04
	12	26.89	0.82	43.28	29.01
	20	34.11	3.81	38.39	23.67
	40	45.27	9.41	29.07	16.25
GBP/DEM	1	17.36	2.85	27.88	51.92
	4	25.70	1.81	31.21	41.28
	8	36.49	0.99	33.29	29.23
	12	38.21	1.05	34.18	26.55
	20	40.56	2.65	32.40	24.39
	40	48.47	3.88	27.17	20.48

Table 3: Forecast error variance decompositions for different horizons

Countries	Horizon	Supply	Real demand	Monetary	Transitory
GBP/USD	1	3.67	0.13	20.59	75.60
	4	9.38	0.45	11.20	78.98
	8	13.55	1.43	9.36	75.66
	12	17.62	2.11	9.44	70.82
	20	21.48	2.83	9.15	66.54
	40	23.37	12.71	10.74	53.29
USD/DEM	1	2.87	18.68	22.79	55.66
	4	1.96	10.51	20.16	67.38
	8	4.74	7.91	16.46	70.90
	12	6.34	6.67	13.2	73.79
	20	7.39	5.01	9.81	77.80
	40	6.24	3.99	7.51	82.25
GBP/JPY	1	7.50	30.13	2.22	60.15
	4	6.25	27.81	8.12	57.82
	8	4.72	27.25	6.41	61.67
	12	3.80	27.32	5.46	63.42
	20	3.77	28.02	5.77	62.43
	40	23.9	23.24	4.61	48.21

Table 4: Long run variance decomposition for the levels

Real exchange rate	Supply	Government consumption	Monetary
USD/DEM	63.7	30.3	6.0
USD/JPY	72.2	20.0	7.8
GBP/USD	26.3	54.9	18.9
DEM/JPY	80.1	11.7	8.2
GBP/JPY	76.4	22.2	1.2
GBP/DEM	90.6	4.1	5.0

Table 5: The share of the long run variance due to supply shocks in alternative empirical models

Real exchange rate	Model A	Model B	Model C	Model D	Model E
USD/DEM	50.1	67.5	39.6	16.04	13.81
USD/JPY	36.8	33.6	74.3	9.63	9.34
GBP/USD	43.5	26.9	14.5	4.95	6.10
DEM/JPY	99.9	49.4	91.7	2.42	4.69
GBP/JPY	71.5	92.9	91.3	17.68	15.72
GBP/DEM	73.0	29.6	99.7	6.86	4.18

Model A is the original model with money supply instead of price levels
Model B is the original model with a different distinction between supply shocks and real demand shocks
Model C is the three-variable model including the levels of q_t, $p_t - p_t^*$, and $y_t - y_t^*$.
Model D is the Clarida and Gali model using only the first differences: $[\Delta q_t, \Delta(p_t - p_t^*)$, and $\Delta(y_t - y_t^*)]$.
Model E is the model of this paper without cointegration, i.e $[\Delta q_t, \Delta y_t, \Delta g_t, \Delta p_t\ ]$.

Appendix: Additional Tables

Table A1: The Johansen (1988) tests for cointegration tests

Real exchange rate	$\lambda(1)$	$\lambda(2)$	$\lambda(3)$	$\lambda(4)$	$tr(1)$	$tr(2)$	$tr(3)$	$tr(4)$	# lags
USD/DEM	28.57	13.40	865	1.48	52.10	23.52	10.13	1.48	6
USD/JPY	31.70	12.48	8.80	2.97	55.94	24.24	11.76	2.97	6
GBP/USD	24.93	14.92	10.21	1.02	49.09	26.16	11.23	1.02	3
DEM/JPY	30.81	11.03	9.30	4.28	55.42	24.62	13.59	4.28	3
GBP/JPY	41.01	15.54	8.94	3.92	69.41	28.40	12.86	3.92	5
GBP/DEM	31.82	17.11	6.84	5.32	61.09	29.27	12.16	5.32	5
Critical values	24.73	18.60	12.07	2.69	43.95	26.79	13.33	2.69	

90-percent critical values are taken from Osterwals and Lenum (1992)
While the information criteria indicate that one to three lags are appropriate, three to six lags are required to remove residual autocorrelation.

Table A2: Park (1992) and Stock and Watson (1988) cointegration tests.

Real exchange rate	Park	Stock and Watson
USD/DEM	9.140 (0.010)	-60.288
USD/JPY	11.026 (0.004)	-80.672
GBP/USD	2.801 (0.246)	-35.074
DEM/JPY	3.173 (0.205)	-83.453
GBP/JPY	4.263 (0.119)	-68.661
GBP/DEM	5.661 (0.059)	-75.109

[a]This is Park's (1992) canoical cointegrating regression (CCR) test including a deterministic time trend. The test statistics has a χ^2 (1) distribution. At the five percent level, the null hypothesis of cointegration is rejected for test statistics above 5.99.
[b] This is the Stock and Watson (1988) common trends statistics. The null hypothesis of no cointegration is rejected for test statistics smaller than the five percent critical value -46.072.

Table A3: Park's (1992) estimates of the cointegrating vectors

Real exchange rate	q_t	y_t	g_t	p_t
USD/DEM	1.0	0.747	1.158	2.122
USD/JPY	1.0	0.866	1.078	-0.204
GBP/USD	1.0	1.172	-1.062	1.030
DEM/JPY	1.0	1.129	1.607	0.053
GBP/JPY	1.0	0.661	1.282	-0.592
GBP/DEM	1.0	1.419	1.815	-1.750

Table A4: The Johansen estimates of the cointegrating vectors

Real exchange rate	q_t	y_t	g_t	p_t
USD/DEM	1.0	2.204	0.729	0.498
USD/JPY	1.0	0.847	2.910	-0.629
GBP/USD	1.0	-0.551	2.242	1.186
DEM/JPY	1.0	-0.046	3.741	0.194
GBP/JPY	1.0	6.226	20.819	-0.710
GBP/DEM	1.0	-1.468	-3.071	-0.020

Figure 1: The USD/JPY, GBP/DEM and DEM/JPY real exchange rates

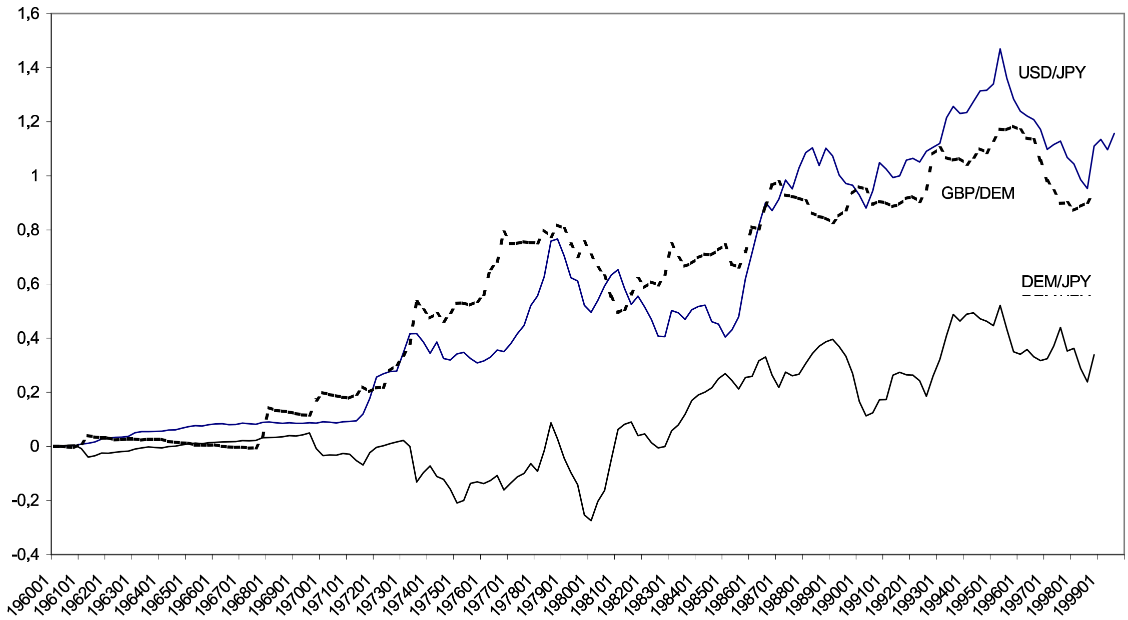

Figure 2: The GBP/JPY, USD/DEM and GBP/USD real exchange rates