The Convergence of Nominal Exchange Rates and Price Levels to the PPP Equilibrium

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Abstract

A consensus appears to have developed among economists that purchasing power parity (PPP) holds over long periods of time. Recent research has focused on trying to understand why the deviations from PPP are so persistent. Rogoff’s (1986) initial half-life estimates of 3-5 years have been remarkably impervious to refutation. The current study analyzes the response of the individual variables underlying the PPP relationship using a structural VAR where identification of the structural innovations is achieved through restrictions that are testable in the reduced form model, and of course assuming structural error independence. This has several advantages over similar studies using alternative techniques. The empirical results suggest that most of the adjustment back to the PPP equilibrium is done via the nominal exchange rate and, depending on the source of the shock, that adjustment speed can be very slow.
1 Introduction

A consensus appears to have developed among economists that purchasing power parity (PPP) holds over long periods of time. Recent research has focused on trying to understand why the deviations from PPP are so persistent. Rogoff’s (1986) initial half-life estimates of 3-5 years have been remarkably impervious to refutation. The puzzling aspect to this stylized fact is that if PPP deviations have a monetary source, then the half-life of these deviations should be no longer than the time it takes sticky goods prices and wages to adjust to such monetary shocks. A period of time that should be about one year according to Taylor (1999). However, if real shocks are the source of these persistent PPP deviations then the real exchange rate should be much less volatile than the nominal exchange rate, due to the relative infrequency of such innovations. But as Engel (1999) has demonstrated, real exchange rate volatility is essentially as high as that of nominal exchange rates.

The vast majority of studies that examine half-lives of PPP deviations focus on the persistence of the real exchange rate itself rather than on the individual variables that comprise real exchange rates. This implicitly restricts the rate of convergence of the nominal exchange rates and price levels to be the same. Given the differential speeds of adjustment between asset markets, like foreign exchange markets, and goods markets, this restriction appears misplaced. Intuitively we might expect that nominal exchange rates will respond very quickly to PPP deviations while price levels will be slower to change because of their assumed rigidity.

In two recent contributions, Cheung et al. (2002) and Engel and Morley (2001) examine the speed at which nominal exchange rates and price levels individually converge to the PPP equilibrium. Engel and Morley (2001) use an unobserved components model and find that nominal exchange rate deviations from the PPP equilibrium are more persistent than the price level deviations. Cheung et al. (2002) use the generalized impulse response function
of Pesaran and Shin (1996) within a vector error correction model (VECM) of the nominal exchange rate and relative price levels. They find that most of the adjustment to the PPP equilibrium is done by the nominal exchange rate and that the speed of this adjustment is slower than the speed at which the relative price levels adjust, confirming Morley and Engel’s results. While both studies generate the interesting but counter-intuitive result that nominal exchange rates are the primary reason for the persistence in PPP deviations, each has significant drawbacks. The Engel and Morley (2001) study uses restrictions implied by a rational expectations sticky price (RESP) model to identify the structural shocks underlying the PPP system. Such restrictions are dependent on the RESP model’s validity and as such, may be forcing an invalid structure on the data. On the other hand, Cheung et al. (2002) are not able to identify separate shocks at all, using a methodology that can best be described as relying on a composite innovation.

It is well understood that the PPP equilibrium implies a cointegrating relationship between nominal exchange rates and price levels. Engle and Granger (1987) demonstrate the general duality between cointegration and the VECM. While the cointegrating relationship describes the long-run equilibrium of the variables, the VECM describes the short-run dynamics of the variables about their equilibrium. This makes the VECM an ideal tool to examine the speed of convergence of the relevant variables to their PPP equilibrium. I use the VECM that exists between nominal exchange rates and price levels under PPP to draw inferences about the rate at which the various variables converge to the PPP equilibrium. Specifically I use the restrictions implied by the Granger Representation Theorem (GRT) for cointegrated systems to identify a structural dynamic simultaneous equations model of the variables comprising the PPP equilibrium. The identification of the structural model is facilitated by the finding of weak exogeneity of one of the variables for each bilateral system. Unlike most structural VAR studies which require the imposition of ad hoc and/or
intestable restrictions to achieve identification, I am able to identify the structural model using restrictions that can be tested within the VECM model.¹

Employing the data set used by Engel and Morley (2001) I demonstrate that the half-lives of real exchange rate innovations depend on the source of the underlying disturbance. While many of the shocks result in long adjustment periods for the real exchange rate, on the order of 30 months or more, some of the innovations generate a rapid return to the PPP equilibrium by the real exchange rate. This can occur even when the three underlying variables, nominal exchange rate and price levels in each country, take much longer to return to their equilibrium levels. The key is the proportionate response of the three variables. Theoretically an innovation may have no effect on the real exchange rate even though the effect on the underlying variables is quite pronounced as long as the three variables comprising the PPP relationship move in concert. It is the differential speeds of adjustment to their equilibrium levels of the three underlying variables that determines the overall speed of adjustment of the real exchange rate.

In section 2 I demonstrate that the adjustment of the individual underlying variables to the PPP equilibrium is governed to a large degree by the relative size of the error-correction coefficients in the VECM.² This allows me to confirm the main result of Engel and Morley (2001) and Cheung et al. (2002), that the nominal exchange rate is the primary adjuster to PPP disequilibria, by presenting evidence that the size of the error-correction coefficients in the nominal exchange rate equations of the VECM are of an order of magnitude larger than those in the price level equations.

Furthermore, I am able to show that the adjustment of nominal exchange rates to the

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¹I do, however, impose the untested restriction that the structural innovations are orthogonal to each other. This is less a restriction and more the goal of the entire identification process. And while it may be possible to identify a structural model without this particular assumption, it would require an alternative specification of the underlying innovation correlation structure. I will not attempt to argue the merits of assuming an orthogonalized innovation structure over alternatives.

²In the case of a VAR(1) this is definitionally true.
PPP equilibrium is indeed slow. In fact, for many of the innovations, the half-life of the nominal exchange rate is much longer than that of the real exchange rate. But as alluded to earlier, this does not necessarily imply that nominal exchange rates are the primary reason for long real exchange rate half-lives. Even though the price levels play a much smaller role in the adjustment process to the PPP equilibrium, as evidenced by the magnitude of the error-correction coefficients, their half-lives are often much longer than those of the nominal or real exchange rates, depending on the source of the shocks. This implies that the role played by the price levels in explaining real exchange rate half-lives may be larger than is suggested by looking at the magnitude of the error-correction coefficients alone.

I find another important result that demonstrates a weakness of previous studies in this area. Specifically, I find that the U.S. price level is weakly exogenous in four of the six PPP systems analyzed. In the other two systems, the domestic price levels are weakly exogenous. This weak exogeneity result implies that the U.S. price level in four systems and the domestic price levels in the other two systems does no adjusting toward the PPP equilibrium. This means that for all six systems analyzed the rate of adjustment to the PPP equilibrium is different for each of the price levels. Any model that combines the effects of the price levels by examining the relative price level will necessarily be misspecified.

The weak exogeneity results also aid in the orthogonalization of the VECM errors to facilitate the dynamic response analysis. Since there are three variables in the PPP system and one cointegrating or equilibrium relationship, there must be two common (stochastic) trends among the three variables. This implies that among the three innovation sequences in the PPP system two must leave permanent imprints on the variables while having only a transitory effect on the real exchange rate. The third innovation will have only tempo-

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3This does not mean that the weakly exogenous variables will not respond at all to the various innovations. Such responses can occur through the channel of the short-run dynamics among the variables.

4See Stock and Watson (1988), inter alia.
ary effects on all variables, including the real exchange rate. Variables which are weakly exogenous do not adjust to the PPP disequilibrium but will be affected by the short-run cross-equation dynamics. Such variables will only respond in the long run to their own idiosyncratic shocks. The remaining innovations will have no long-run effects on these weakly exogenous variables. This means that in systems in which the U.S. price level is weakly exogenous, one of the two permanent innovations will have no long-run effect on the U.S. price level. This restriction will be enough to just identify the two permanent innovations. A similar restriction holds for the two systems in which the domestic price level is weakly exogenous.

The dynamic response analysis results in several interesting observations. First, in general the pattern of real exchange rate response mimics that of the nominal exchange rate. Cheung et al. (2002) found a similar result. Second, the persistence in the real exchange rate depends upon the source of the shock. Generally speaking the first permanent shock, which can be interpreted as a U.S. price level innovation for four systems and a domestic price level shock in the other two, and the transitory shock result in slower convergence of the real exchange rate than does the second permanent shock. The exceptions to this general observation are also noted. Finally, an historical decomposition of the errors in the VECM demonstrate which innovations were most important for explaining particular real exchange rate episodes.

The rest of the paper is organized as follows. Section 2 discusses the implications for the speed of adjustment of the real exchange rate embedded within the error-correction model. Section 3 presents the data and some preliminary results. Section 4 discusses the procedure used to orthogonalize the VECM errors for use in the impulse response analysis and presents the results obtained from the dynamic innovation analysis. Section 5 concludes with some discussion of the results.

As such weakly exogenous variables are often interpreted as the source of the common trends, e.g. Johansen (1991), King et al. (1991) and Crowder et al. (1999).
The relationship between the parameters of the VECM and the speed at which the real exchange rate converges to its equilibrium can most easily be observed by assuming a simple data generating process (DGP) for the PPP equilibrium system. Let the real exchange rate, $q_t$, be generated by the relationship between (log) nominal exchange rate, $s_t$, and (log) price levels, $p_t$ and $p_t^*$, as in DGP (1).

\[
\begin{align*}
q_t &= s_t - \beta_1 p_t - \beta_2 p_t^*, \\
\omega_t &= a_1 s_t - a_2 p_t - a_3 p_t^*, \\
\nu_t &= b_1 s_t - b_2 p_t - b_3 p_t^*, \\
q_t &= \rho q_{t-1} + \epsilon_{q,t}, \\
\omega_t &= \omega_{t-1} + \epsilon_{\omega,t}, \\
\nu_t &= \nu_{t-1} + \epsilon_{\nu,t},
\end{align*}
\]

(1)

In (1) the equilibrium PPP relationship is given by the first equation with the second equation describing the degree of persistence of the equilibrium error, in this case the real exchange rate. As long as $|\rho|$ is less than one, the real exchange rate reverts to a constant mean and is weakly stationary. The third and fifth equations describe how the common trends are distributed among the three variables. The fourth and sixth equations describe how these trends are generated as pure random walks. I assume that the innovations, $\epsilon_{q,t}$, $\epsilon_{\omega,t}$ and $\epsilon_{\nu,t}$ are uncorrelated.\textsuperscript{6}

\textsuperscript{6}This assumption is not important for the results I derive.
From (1) an error-correction representation exists and is given in (2),

\[
\begin{bmatrix}
\Delta s_t \\
\Delta p_t \\
\Delta p^*_t
\end{bmatrix} =
\begin{bmatrix}
\gamma_1 \\
\gamma_2 \\
\gamma_3
\end{bmatrix}
\begin{bmatrix}
1 \\
-\beta_1 \\
-\beta_2
\end{bmatrix}
\begin{bmatrix}
s_{t-1} \\
p_{t-1} \\
p^*_{t-1}
\end{bmatrix}
+ \begin{bmatrix}
u_{1t} \\
u_{2t} \\
\end{bmatrix}
\]

(2)

where the error-correction coefficients, \(\gamma_i\), and the VECM errors, \(u_i\), are non-linear functions of the parameters from (1). Of particular interest here is the relationship between the persistence parameter of the real exchange rate, \(\rho\), and the error-correction model parameters, \(\beta_i\) and \(\gamma_i\), shown in (3).

\[
\rho = 1 + \gamma_1 - \beta_1 \gamma_2 - \beta_2 \gamma_3
\]

(3)

From (3) one can determine the relative contribution of each of the underlying variables to the overall rate at which the PPP equilibrium adjusts. This is particularly easy in the PPP framework since \(\beta_1 = 1\) and \(\beta_2 = -1\). So the variable that contributes most to the determination of the speed of PPP convergence is that which has the largest (in absolute value) error-correction coefficient parameter.

Several issues should be clarified before proceeding. The relationship given in (3) is a special case that depends on the special structure of (1). In this case the real exchange rate follows a simple AR(1) process so that a VAR(1) completely describes the DGP. There are no lagged differences in (2) and thus no short-run dynamics for the system, only equilibrium adjustment dynamics through the \(\gamma_i\) parameters. In higher order VAR systems, the relationship between \(\rho\) and the \(\gamma_i\)'s will be much more complex, depending on the short-run dynamics parameters, which will themselves be highly non-linear functions of the underlying structural model parameters given by (1). While it may be possible to derive the exact relationship between \(\rho\) and the underlying VECM parameters in higher order VAR systems, it is not practical. These relationships can be inferred by examining the impulse response functions.
(IRF) from the moving average representation (MAR) of the VECM. Still the representation
given in (1) can be useful in determining how the variables in the system contribute to the
overall speed of convergence to equilibrium. I will use this fact later.

The second issue that needs clarification at this point relates to the idea of weak ex-
ogencity of one or more variables in the system. Weak exogeneity refers to the situation
in which the conditional model parameters of interest may be efficiently estimated without
estimating the parameters of the marginal model.⁷ Efficient estimation is not my priority in
this analysis, but weak exogeneity has other implications in the context of the VECM that
I wish to exploit. Specifically, if one of the three PPP variables is weakly exogenous, then
the error-correction term will be absent from the VECM equation in which that variable
is the dependant variable, i.e., \( \gamma_j = 0 \) for \( j = \) the equation in the VECM of the weakly
exogenous variable. For example, let’s assume that \( p_t^* \) is weakly exogenous with respect to
the parameters of interest in (2). This implies that \( \gamma_3 = 0 \) which further implies that either
\( a_1 = a_2 = 0 \) or \( b_1 = b_2 = 0 \) from (1). Two things can now be inferred from this weak
exogeneity restriction; 1) \( p_t^* \) does not respond to the disequilibrium and it will play no role
in the speed of convergence as described by (3), 2) \( p_t^* \) will be the source of the one of the two
common trends in the system, or more correctly the innovation to \( p_t^* \) will be the source of
one of the common trends. Thus the weak exogeneity restriction allows one to identify one
of the common trends. Given that there are two common trends in the PPP system, weak
exogeneity is sufficient to statistically identify one from the other.⁸

The final issue is one of system stability. For the equilibrium in (2) to be a stable one
it should be the case that \( \gamma_1 \leq 0, \gamma_2 \geq 0 \) and \( \gamma_3 \leq 0 \). If, for example, \( \gamma_1 > 0 \), then from
(3) it can be seen that the nominal exchange rate is “adjusting” in such a way as to push

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⁷See Engle et al. (1983) for a formal definition of the concept of weak exogeneity.
⁸To achieve a complete structural identification I will employ the standard assumption of structural error
independence. This assumption combined with cointegration and the weak exogeneity restriction is sufficient
to statistically identify a structural model.
the real exchange rate further from its equilibrium position. An examination of the stability restrictions on the error-correction coefficients implied by the PPP equilibrium will provide another form of evidence on the existence of the PPP relationship itself.

3 Data and Preliminary Results

The data used in this study consist of monthly observations from January 1972 to June 1998 on U.S. dollar exchange rates vis-à-vis the British pound, French franc, German mark, Italian lira, Japanese yen and Canadian dollar and CPI price levels for each country. This is the same data used by Engel and Morley (2001).  

The real exchange rates are defined in the first equation of (1), where the U.S. dollar is treated as the foreign currency, and are plotted in figure 1. For PPP to hold, the real exchange rates should be stationary. Table 1 displays several univariate tests for a unit root. The null hypothesis is that of non-stationarity so that rejection of the null will be consistent with PPP.

Two of the most commonly used unit root tests in the literature are the augmented Dickey-Fuller test (ADF $\tau$-test) of Said and Dickey (1984) and Phillips-Perron test (PP $Z$-test) developed in Phillips and Perron (1988). It is well known that the ADF and PP tests have low power against local stationary alternatives. Elliot, Rothenberg and Stock (1996) (ERS) develop a feasible point optimal test that relies on local GLS detrending to increase the power of the unit root tests. ERS demonstrate that there is no single test that is optimal in all situations. They recommend choosing a test that is tangent to the power envelope at 50% power. Such tests have empirical powers approaching the asymptotic power envelope.

A second serious problem associated with unit root testing is that such tests suffer from
serious size distortions in the presence of negative serial correlation. Schwert (1987, 1989), Phillips and Perron (1988), Pantula (1991), Ng and Perron (1995, 2001) and Perron and Ng (1996) demonstrate that the empirical size of conventional ADF and PP tests approach unity as the sum of the MA parameters in a univariate process approach negative one. Perron and Ng (1996) extend the work of ERS by developing modified versions of the PP tests that have much better size properties than the conventional PP tests but also retain the power of the ERS tests. These unit root tests are based on the local GLS detrending method and in addition use an autoregressive spectral density estimator of the long-run variance. The two tests are labelled the \( MZ_\rho \) and the \( MZ_\tau \) test. The decrease in size and increase in power of the \( M \)-tests are enhanced when one chooses the lag truncation in (8) based on the modified information criteria (MIC) developed in Ng and Perron (2001).\(^{10}\)

### 3.1 Univariate Unit Root Results

The first column of table 1 lists the home currency country in the real exchange rate definition. The second column displays the lag truncation parameter from (8) as determined using the modified AIC (MAIC) of Ng and Perron (2001). Interestingly the MAIC chooses zero lags for all but the Japanese and Canadian real exchange rates. These results are broadly consistent with the DGP given in (1). The next column shows the estimate of \( \rho \) from the GLS-detrended data. The fourth column displays the implied half-lives of shocks to the real exchange rate.\(^{11}\) Consistent with previous findings, these estimates display considerable persistence in real exchange rate deviations with half-lives around three years. The next five columns of table 1 displays the various unit root tests. Consistent with most other studies, there is little evidence of stationary real exchange rate from univariate unit root tests.

\(^{10}\)Appendix A details the procedures used in the univariate unit root analysis.

\(^{11}\)This half-life measure is calculated as \( \frac{\ln(0.5)}{\ln(\rho)} \) and is measured in months.
4 Multivariate Analysis

4.1 Initial VECM Results

Table 2 presents the estimated error-correction coefficients from a VAR(1) model, i.e. that which coincides with DGP (1), for each PPP system. Each VECM is estimated under the maintained cointegrating vector $\beta = [1, -1, 1]'$. Since the errors from the VAR equations are autocorrelated, I use a heteroscedasticity-autocorrelation consistent covariance matrix estimate to calculate standard errors.\textsuperscript{12} While these results are in no way definitive, they do provide initial guidance as to which of the three PPP variables are most important in contributing to the convergence of real exchange rates to their equilibrium. For example, in the U.K., German and French systems, the error-correction coefficient in the exchange rate equation of the VECM is an order of magnitude larger than the coefficients in the price level equations of the VECM. This implies a very strong role for the nominal exchange rate in the adjustment process to the PPP equilibrium. However, in the other three systems the price levels appear to play at least as important a role in the equilibrium adjustment mechanism as the nominal exchange rate. The last column displays the implied half-life estimates from the VECM model. With the exception of Canada, most of these are in line with those presented in table 1.\textsuperscript{13}

4.2 Cointegration Tests of PPP

Kremers et al. (1992) demonstrate that one of the major drawbacks to univariate unit root tests as a test for cointegration is that they impose a common factor restriction that

\textsuperscript{12}I used the Newey-West HAC with a Bartlett correction and 16 lagged autocovariances. The results turn out to be somewhat sensitive to the lag truncation choice suggesting caution should be used when interpreting the standard errors.

\textsuperscript{13}The major difference between the half-life estimates in table 1 and table 2 is that table 1 results are derived from GLS-detrended data while those in table 2 use the raw data.
reduces the power of the tests when the restriction is not valid. They show that when the cointegrating relationships are known tests based on the error-correction model have greater power. Horvath and Watson (1995) extend these results and calculate the distribution of the Wald test for cointegration when some of the cointegrating vectors are known. Column 3 of table 3 presents the calculated Wald statistics under the null hypothesis of zero known cointegrating vectors against the alternative hypothesis of one known and zero unknown cointegrating vectors. These Wald tests were calculated from the VECM with lag truncation, \( k \), determined by minimizing the AIC and given in column 2.\(^{14}\) The evidence in favor of PPP is now much stronger. Only the Canadian system cannot reject the null of zero cointegrating vectors at the 10% level of significance.

Column 4 presents the calculated Johansen (1991) trace test statistics from the unrestricted VECM, where the lag truncation was also that given in column 2, under the null hypothesis of zero cointegrating vectors against the alternative of at least one cointegrating vector. In all six cases the null is easily rejected at standard significance levels.

The last six columns of table 3 present the estimated error-correction coefficients from the VECM when the cointegrating vector is restricted to be \( \beta = [1, -1, 1]' \) and the t-statistics on these coefficients.\(^{15}\) In all six systems the nominal exchange rate is the dominate adjusting variable as evidenced by the magnitude of the error-correction coefficient estimate in each nominal exchange rate equation of the VECM. All are statistically significant at the 11% level or higher and have the appropriate sign for system stability in all six PPP VECMs. In the U.K., German, Japanese and Italian PPP systems the domestic price level also plays a statistically significant role in adjusting to the PPP equilibrium with error-correction terms that are statistically significant and of the appropriate sign. The U.S. price level is weakly

\(^{14}\)Specifically, I allowed a maximum lag in the VECM of eighteen and chose that lag truncation that minimized the AIC.

\(^{15}\)Because the data are monthly there are significant ARCH effects in the residuals from the VECM. The standard errors reported are corrected for such conditional heteroscedasticity using White’s method.
exogenous in these systems implying no role for this variable in PPP equilibrium adjustment. In French and Canadian systems, it is the U.S. price level that plays a statistically significant role in PPP adjustment while the domestic price levels are weakly exogenous.

5 Dynamic Innovation Analysis

The equilibrium defined by PPP implies that $X_t = [s_t, p_t, p_t^*]$ is a cointegrated system with cointegrating rank of one and a cointegrating vector of $\beta = [1, -1, 1]'$. The Granger representation theorem (GRT) establishes that for such a system there exists a vector autoregressive representation (VAR) such that,

$$\Phi(L)X_t = \mu + \varepsilon_t$$

where $X_t$ is a $p \times 1$ vector of time series variables, $\Phi(L)$ is a $k$th-order matrix polynomial in the lag operator with some of its roots on the unit circle and where $\Phi_0 = I$, $\mu$ is the constant and $\varepsilon_t$ is the error vector with covariance matrix $\Omega$, which is, in general, not diagonal.

The response of a particular variable in the VAR in (4) to an unanticipated change in one of the other variables in the VAR is given by the impulse response functions (IRFs). The IRFs can be computed from the moving average representation (MAR) of (4) given by,

$$X_t = \zeta + C(L)\varepsilon_t$$

where $C(L) = \Phi(L)^{-1} = \sum_{i=1}^{\infty} C_i L^i$ and $\zeta = \Phi(L)^{-1}\mu$. From (5) one may determine the effect on $X_{i,t+k}$ from a change in $\varepsilon_{j,t}$ as $C_k(i,j)$, the row $i$, column $j$ element of $C_k$. A problem arises, however, in the interpretation of the impulse, i.e. $\varepsilon_{j,t}$, since the errors are correlated across equations in (4). This can be overcome by appropriately orthogonalizing the errors. In general, such an orthogonalization would require $p^2$ restrictions on (4), $p$ of these can be obtained by arbitrary normalization of each VAR equation. Another $\frac{p(p-1)}{2}$ come
from the relationship between the estimated covariance matrix $\Omega$ and the orthogonalized covariance matrix. That leaves $\frac{p(p-1)}{2}$ extra restrictions needed to achieve an appropriate orthogonalization.

King et al. (1991), Warne (1993) and Crowder et al. (1998) all demonstrate appropriate orthogonalizations when $X_t$ is characterized by cointegration rank $r$. Specifically, cointegration implies another $r(p - r)$ restrictions on (4). These papers all show that an appropriate orthogonalization must impose $\frac{(p-r)(p-r-1)}{2}$ long-run restrictions in order to identify the permanent components and $\frac{r(r-1)}{2}$ short-run restrictions in order to identify the transitory components. In the PPP systems $p = 3$, $r = 1$ and $p - r = 2$ so that one long-run restriction is all that is needed to appropriately orthogonalize the errors. The results from table 3 provide a suitable choice for this restriction. Imposing the weak exogeneity restriction found in each PPP system results in a complete orthogonalization of the VAR errors.

5.1 Half-Life Estimates from Impulse Responses

I follow Kilian and Zha (2002) by defining the half-life of an innovation to the real exchange rate as follows. Let $D_k(j)$ be the response of $q_{t+k}$, the real exchange rate, from a one-unit innovation in $\nu_t(j)$, the $j^{th}$ orthogonalized innovation. Then find the largest $k$ such that $|D_{k-1}(j)| \geq 0.5$ and $|D_{k+i}(j)| < 0.5 \ \forall \ i \geq 0$.

Figures 2 through 7 display the IRFs for each of the PPP VAR systems. An examination of these response patterns yields the conclusion that the real exchange rate responses most closely mimic those of the nominal exchange rate highlighting the important role nominal exchange rates play in the adjustment of real exchange rates to their PPP equilibrium.

\textsuperscript{16}Appendix B provides a more detailed discussion of the procedure used to orthogonalize the errors.
The graphs in the first column of each figure display the IRFs from the first permanent innovation. For the U.K., German, Japanese and Italian PPP systems this represents an innovation to the U.S. price level. In French and Canadian systems the first permanent innovation is a domestic price level shock. Each variable changes permanently, except the real exchange rate, in response to this innovation. The half-lives of the real exchange rate, in response to this shock, vary widely as shown in the last column of table 4. The shortest half-life from the first permanent innovation occurs in the U.S.-U.K. PPP system with an estimated half-life of only 7 months. The longest half-life estimate comes from the U.S.-Canada system where the real exchange rate does not reach its half-life in 240 months, the maximum steps ahead considered in the exercise. The yen-dollar and lira-dollar real exchange rates also exhibit long half-life estimates of 192 and 97 months, respectively.

The relative importance of this particular innovation in explaining the behavior of the real exchange rate can be discerned by examining the forecast error variance decompositions. The variance decompositions give the proportion of the forecast error variance that can be explained by a specific innovation over various forecast horizons. Table 4 presents the estimated real exchange rate variance decompositions for the six PPP systems. From these estimates one can determine that the first permanent innovation is relatively unimportant for the pound-dollar and lira-dollar real exchange rates but is dominant in the Canadian dollar - U.S. dollar real exchange rate, regardless of forecast horizon. This suggests that although the pound-dollar (lira-dollar) real exchange rate has a very short (long) half-life associated with this innovation, the innovation itself is relatively unimportant in determining the overall behavior of the real exchange rate.

The average half-life estimate from the first permanent innovation is 99 months which is,

\[17\] As determined from the weak exogeneity results in table 3.
by far, the longest average half-life of the three innovations considered. But this particular
innovation is rarely important in explaining the behavior of the real exchange rate, the
exception being the CD/$ system in which this innovation, a shock to the Canadian price
level, dominates the behavior of the real exchange rate at medium-to-long horizons.

Tables 5 through 7 display the variance decompositions and estimated half-lives for the
underlying variables in the PPP systems. For the nominal exchange rates, the first perma-
nent innovation plays a dominant role for the Canadian dollar at all forecast horizons. Its
importance in explaining the nominal exchange rate movements at shorter horizons is greater
than that in explaining the price level movements over these same horizons. Combined with
the fact that the nominal exchange rate half-life is significantly longer than the price levels
half-lives associated with this shock leads to the conclusion that the nominal exchange rate
plays a dominant role in explaining the slow real exchange rate convergence.

For the other nominal exchange rates, the first permanent innovation plays a relatively
minor role in explaining their behavior until one looks at the longer horizons. The exception
is the DM/$ nominal exchange rate where the first permanent innovation plays an important,
but not dominant, role. For this system the nominal exchange rate half-life is about three
times longer than the half-lives of the two price levels associated with this shock, and over
three times longer than the half-life of the DM/$ real exchange rate in response to this
particular innovation. Again this suggests an important role for the nominal exchange rate
in explaining the behavior of the real rate in response to this particular innovation.

It is also the case that this innovation dominates all of the price levels behavior at horizons
of 24 months and higher. The half-lives of the price responses to this shock are also, with
Italian and Canadian systems excepted, the shortest of the price level half-lives. What is
perhaps most surprising is that the half-lives of both price levels in response to the first
permanent shock are generally much shorter than the half-lives of the nominal exchange
rate responses to the same innovation. For example, in the £/$ system the half-life of the nominal exchange rate response to the first permanent innovation is 54 months while that of the U.K. and U.S. price levels is 33 months and 24 months, respectively. At first blush this might suggest that the real exchange rate must adjust slowly to this innovation but the £/$ real exchange rate has a half-life of only 7 months! This highlights the importance of the joint adjustment of nominal exchange rates and price levels. Even though all three underlying variables have relatively long half-lives, their adjustments, however slowly, must occur in tandem to result in a rapid adjustment of the real exchange rate itself. Furthermore, while this innovation is important in explaining the behavior of the price levels, especially at longer horizons, it plays a negligible role in the behavior of the real exchange rate.

The response of the ¥/$ system is a particularly interesting case for the first innovation. The half-life of the real exchange rate response to the first permanent innovation is 192 months! The half-life of the nominal exchange rate to the same innovation is 194 months while the half-lives of the two price levels are 62 and 43 months. And this innovation explains a significant proportion of all four variables behavior over the relevant horizon. Clearly the slow adjustment of the real exchange rate to its equilibrium level can be attributable to the slow adjustment of the nominal rate. The DM/$ and CD/$ systems present similar, though less dramatic, examples of the same situation. The innovation is important in explaining the behavior of all four variables and the response half-life of the nominal exchange rate is significantly longer than those of the price levels suggesting the slow adjustment of the real exchange rate can be mostly attributed to the asset market response instead of the goods market response.

The behavior of the FF/$ system is unique in that this innovation makes some contribution to the dynamic behavior of all four variables and all of the half-lives are of similar durations making it difficult to attribute the slow adjustment of the real exchange rate to
any of the three underlying variables specifically. The ITL/$ system is also unique in that the half-lives of the nominal exchange rate and price levels are much shorter than the that of the real exchange rate but the importance of this innovation in explaining the real exchange rate is negligible.

5.1.2 The Second Permanent Innovation

The second column of graphs in figures 2 through 7 display the IRFs from the second innovation. This innovation will have permanent effects on the nominal exchange rate and the domestic (U.S.) price level and transitory effects on the U.S. (domestic) price level and real exchange rate in the U.K., German, Japanese and Italian (French and Canadian) PPP systems.

Examining the variance decompositions in tables 4 through 7 suggests that this innovation has the least importance for the behavior of the DM/$ and CD/$ real exchange rates. This shock has significant effects on the £/$ and ITL/$ real exchange rates. The £/$ real exchange rate has a response half-life of 33 months which is almost twice that of the £/$ nominal exchange rate. While this innovation has essentially no influence on the behavior of the U.S. price level, it does have some marginal impact on the U.K. price level, explaining 37% of the forecast error variance at a one-month horizon down to 13% at 36-month horizon with a response half-life of 44 months. For this particular innovation and PPP system the slow adjustment of the real exchange rate is more attributable to the U.K. price level rather than the nominal exchange rate. The same conclusion can be drawn for the ITL/$ real exchange rate, but now the rapid adjustment of the real exchange rate to this innovation, 3-month half-life, is attributable to the rapid adjustment of the Italian price level, 11-month half-life, rather than the adjustment of the nominal exchange rate, which has a 54-month response half-life as a result of the second permanent innovation.
The FF/$ system is also interesting in that this innovation contributes moderately to the behavior of the real exchange rate, nominal exchange rate and, in the short term, the French price level but the half-life of the real exchange rate response is much less than the half-lives of the responses of the underlying variables. This again suggests that even when the underlying variables are slow to adjust to their new equilibrium values, if they move in a coordinated fashion, the real exchange rate will adjust very rapidly.

5.1.3 The Transitory Innovation

The transitory innovation is relatively important in all six PPP systems in explaining the behavior of the real exchange rate, especially at shorter forecast horizons. The half-lives of the real exchange rate responses lie between a low of 9 months for the FF/$ real exchange rate to a high of 36 months in the CD/$ real exchange rate with an average half-life of about 24 months for the six real exchange rates.

The transitory innovation also plays an important role in the underlying variables for each PPP system, again mainly at shorter forecast horizons. The half-lives of the nominal exchange rate responses to this innovation are much shorter than those of the price levels but still consistent with the half-lives of the real exchange rates. Given that the nominal exchange rate and real exchange rate half-lives are on the order of 9 to 41 months while the half-lives of the price level responses are 54 months or more, it seems reasonable to attribute the real exchange rate adjustment to that of the nominal exchange rates.

5.2 Historical Decompositions

A fuller appreciation for the importance of the various shocks over different time periods in the history of the real exchange rates can be had by examining the fitted error historical decompositions. Figures 8 and 9 display the fitted error from the real exchange rate in
the VECM along with a decomposition of this historical error into the three underlying innovations. The historical decompositions in these figures are all drawn on the same scale for easy comparison.

The historical pattern of the U.S. dollar real exchange rates is remarkably similar across currencies. This pattern, beginning with a general dollar depreciation in the late 1970s followed by the very large dollar appreciation in the early 1980s and subsequent rapid depreciation following the Plaza accord and finally a slow appreciation in the 1990s, is common to all six real exchange rates examined to varying degrees.

The first permanent innovation played an important role for the DM/$ real exchange rate depreciation in the late 1970s. It also appears to have been important in explaining the first part of the dollar appreciation versus the yen in the 1980s. This innovation is also important the depreciation of the U.S. $ versus the Canadian $ immediately following the Plaza accord. The first permanent innovation played smaller roles in the behavior of the other real exchange rates.

The second permanent innovation played an important role in all but two of the real exchange rates, the CD/$ and DM/$. This shock appears to have been instrumental in moving the value of the dollar higher versus the pound, yen and lira in the middle 1970s and then the subsequent dollar depreciation versus these currencies and the French franc. This innovation also appears important in the large dollar appreciation versus the pound, mark, franc and lira in the early 1980s.

The transitory innovation is important in all six real exchange rates. Its most common effect is the large dollar appreciation in the 1980s versus the pound, mark and yen. This shock also played a secondary role in the dollar depreciation in the late 1970s.
6 Conclusions

This study uses a structural VAR methodology to determine the speed at which the nominal exchange rate and price levels converge to the PPP equilibrium after being subjected to various economic shocks. A virtue of this study versus others of its ilk is that the identification of the structural model is achieved with a minimum of arbitrary restrictions. Specifically, the feature of cointegration, which is a testable hypothesis, implies certain restrictions on the joint behavior of the germane variables that can be used to specify the structural relationships. This is combined with a weak exogeneity restriction, which is also testable within the framework employed, to yield the necessary set of restrictions to just identify the structural VAR.

The empirical results generate two important conclusions. First, from the VECM estimates it can be determined that the nominal exchange rate is the primary variable that changes in order to restore the PPP equilibrium when the system has been subjected to some shock. This conclusion is drawn from the relative magnitudes of the nominal exchange rate error-correction coefficients versus the price level error-correction coefficients. The second conclusion is drawn by examining the dynamic responses of the nominal exchange rate, price levels and real exchange rate to the structural innovations and obtaining a measure of the half-life of the responses. I find that the nominal exchange rate adjusts very slowly and can often be linked as the cause of the slow adjustment of the real exchange rate. This is especially true when the innovation is identified as a U.S. price level shock. The responses of the price levels to this innovation are generally much shorter than that of the nominal exchange rates. But there are examples among the results where I can attribute the slow adjustment of the real exchange rate, as measured by the half-life of the impulse response, to the slow adjustment of one or the other price levels. The best example of this effect is the £/$ real exchange rate in response to the second permanent innovation. So it would be
premature to attribute all of the long real exchange rate half-lives to slow nominal exchange rate adjustments.
Appendix A

Univariate Unit Root Procedures

The tests proposed by Ng and Perron are motivated by the DGP in (6),

\[ y_t = d_t + u_t, \quad u_t = \rho u_{t-1} + v_t \]  

where \( v_t = \varphi(L) e_t = \sum_{j=0}^{\infty} \varphi_j e_{t-j}, d_t = \zeta^t z_t = \sum_{i=0}^{p} \zeta_i t^i \) for \( p = 0, 1 \). ERS suggest using a GLS detrending method to improve the power of unit root tests. For any series \( \{x_t\}_{t=0}^{T} \) define \((x_0^\pi, x_T^\pi) \equiv (x_0, (1-\pi L) x_t)\) for some chosen \( \pi = 1 + \tau/T \). The GLS detrended series is defined as,

\[ \tilde{y}_t \equiv y_t - \tilde{\zeta}' z_t \]  

where \( \tilde{\zeta} \) minimizes \( S(\pi, \zeta) = (y^\pi - \zeta' z^\pi)'(y^\pi - \zeta' z^\pi) \). ERS suggest choosing \( \pi = -7.0 \) for \( p = 0 \) and \( \pi = -13.5 \) for \( p = 1 \). The test recommended by ERS is the \( DF^{GLS} \) statistic given in equation (8).

\[ \Delta \tilde{y}_t = \rho \tilde{y}_{t-1} + \sum_{j=1}^{k} \delta_j \tilde{y}_{t-j} + e_t \]  

Ng and Perron recommend two tests that have similar power to the \( DF^{GLS} \) but that also have superior size properties in the presence of MA errors. These tests are \( MZ_\rho, MZ_t, \) and \( MSB \), collectively referred to as the \( M \) tests. These are defined as,

\[ MZ_\rho = (T^{-2} \tilde{y}_t^2 - s_{AR}^2)(2T^{-2} \sum_{t=1}^{T} \tilde{y}_{t-1}^2)^{-1} \]  

\[ MSB = \left[ \frac{T^{-2} \sum_{t=1}^{T} \tilde{y}_t^2}{s_{AR}^2} \right]^{\frac{1}{2}} \]  

and \( MZ_t = MZ_\rho \times MSB \). All three tests are based on \( s_{AR}^2 \), an autoregressive estimate of
the spectral density at frequency zero of \( v_t \). This estimate is calculated as,

\[
S_{AR}^2 = \frac{\hat{\sigma}_k^2}{[1 - \delta(1)]^2}
\]

where \( \delta(1) = \sum_{i=1}^{k} \delta_i \) and \( \hat{\sigma}_k^2 = (T-k)^{-1} \sum_{t=k+1}^{T} \hat{e}_{tk}^2 \) and \( \delta_i \) and \( \{\hat{e}_{tk}\} \) are taken from estimation of (8) using OLS. The only piece left is to specify a lag truncation parameter \( k \). Ng and Perron suggest using a modified information criteria (MIC') as in (12),

\[
MIC(k) = \ln(\hat{\sigma}_k^2) + \frac{C_T(\tau_T(k) + k)}{T - k_{max}}
\]

where \( \tau_T(k) = (\hat{\sigma}_k^2)^{-1} \hat{\rho} \sum_{t=k_{max}+1}^{T} \tilde{y}_{t-1}^2 \) and \( k_{max} \) is the largest lag truncation considered.
Appendix B

Identification of the Complete Structural System Characterized by Cointegrating

The identification of a structural model from the dynamic reduced form has been extensively discussed since Sims (1980) first proposed the use of vector autoregressions (VARs) in analyzing the dynamic relationship among time series variables.\(^{18}\) The issues surrounding structural identification can be understood by specifying a reduced form VAR in (13),

\[
\Phi(L)X_t = \mu + \varepsilon_t
\]

where \(X_t\) is a \(p \times 1\) vector of stationary time series variables\(^{19}\), \(\Phi(L)\) is a matrix polynomial in the lag operator where \(\Phi_0 = I\), \(\mu\) is a vector of deterministic components (usually a constant) and \(\varepsilon_t\) is the reduced form error with covariance matrix \(\Omega\). A corresponding structural model is assumed to exist as in (14),

\[
A(L)X_t = \delta + \nu_t
\]

where \(E[\nu_t'\nu_t] = I\). The relationship between the structural and reduced form parameters is \(\Phi(L) = A_0^{-1}A(L), \mu = A_0^{-1}\delta\), and \(A_0\Omega A_0' = I\). Identification of the structural model from the reduced form estimates is simply an exercise in specifying \(A_0\) in such a way that a unique correspondence exists between the reduced form and structural parameters. In general, this would require \(p^2\) independent restrictions on (14). Arbitrary normalization of each reduced form VAR equation provides \(p\) restrictions. The assumption of structural error independence provides another \(p(p - 1)/2\) restrictions. Exact identification of the structural model then depends upon \(p(p - 1)/2\) additional restrictions to be imposed by the econometrician. These

\(^{18}\)The relevant citations include, but are not limited to, Bernanke (1986), Sims (1986), Shapiro and Watson (1987), Blanchard and Quah (1989), and Warne (1993).

\(^{19}\)Thus, \(X_t\) could be the first differences of I(1) variables.
restrictions take the form of restrictions on the $A_0$ matrix.

Sims (1980) original specification made $A_0$ a lower triangular matrix implying a contemporaneous recursive structure to the model. Bernanke (1986) and Sims (1986) independently suggested applying non-recursive exclusion and/or general restrictions on $A_0$ that were more justifiable based upon economic reasoning. Shapiro and Watson (1988) and Blanchard and Quah (1989) used long-run restrictions to identify the structural model from the reduced form estimates. This is achieved by noting that the VARs in (13) and (14) have invertible Wold moving average representations (MAR). The reduced form MAR is given by,

$$X_t = \zeta + C(L)\varepsilon_t$$

where $C(L) = \Phi(L)^{-1}$ and $\zeta = \Phi(L)^{-1}\mu$. The corresponding structural MAR is related to the reduced form MAR by noting that $D(L)$, the structural MA matrix polynomial, is equal to $C(L)A_0^{-1}$. Furthermore, the long run structural total impact matrix is related to the reduced form total impact matrix by $D(1) = C(1)A_0^{-1}$. General restrictions on the $D(1)$ matrix can be imposed by a suitable choice for $A_0$. These are then interpreted as long run as opposed to contemporaneous restrictions on the interactions of the variables in $X_t$. Blanchard and Quah (1989) argue that economic theory provides stronger implications for the long run interaction among macro aggregates than it does about the contemporaneous relationship between these variables. Such “neutrality” restrictions are more justifiable on theoretical grounds.

Note that for the long-run identification restrictions to be binding, some of the variables in $X_t$ must be the first differences of nonstationary variables. That is the $C(1)$ matrix must not vanish for these type of restrictions to be relevant. This issue is important since many important examples exist in macroeconomics and finance where the $C(1)$ matrix is not of full rank. This implies that only a subset of the innovations have a permanent impact on the
variables. The other innovations have only transitory effects and cannot be identified from restrictions on \( C(1) \). A relevant situation is when the variables of interest are cointegrated. The model used in this study sets \( p = 3 \) implying that the number of additional \( a \) priori restrictions needed to achieve exact identification is three, \( p(p - 1)/2 \). Assuming that the variables are I(1), PPP implies one cointegrating relation among the three variables. This means that the rank of \( C(1) \) is two or that two of the three structural innovations leave permanent imprints on the data. Furthermore, \( C(1) \) must satisfy the restrictions implied by cointegration\(^{20}\), namely that \( \beta'C(1) = 0 \) and \( C(1)\alpha = 0 \), where \( \alpha \) and \( \beta \) are \( p \times 1 \) full rank matrices such that \( \alpha\beta' = \Phi(1) \) from (13). These imply restrictions on \( C(1) \) that help aid in identification.

The relationship between identification of the complete \( p \)-dimensional structural VAR and the identification conditions discussed above is now easily seen. In standard structural VAR applications \( p(p - 1)/2 \) restrictions are required in addition to the \( p(p - 1)/2 \) innovation orthogonality constraints to obtain identification (after arbitrary normalization). In the case of cointegrated VAR systems we can also utilize the \( p(p - 1)/2 \) innovation independence restrictions. But, knowledge of cointegration rank \( r \) implies that \( r \) structural innovations leave no long-run imprint on the \( p \) variables in the system and this information is useful in establishing the identity of the innovations. These \( pr \) homogeneous restrictions deliver an additional \( (p - r)r \) independent restrictions that can be applied toward the identification of the model.\(^{21}\) These restrictions dictate the relative number of permanent and transitory shocks that underlie this system and parameterizations that adopt alternative numbers of permanent and transitory shocks are inherently misspecified. With the addition of the \( (p - r)(p - r - 1)/2 \) and \( r(r - 1)/2 \) restrictions required to sort out among the sets of permanent and transitory innovations respectively, the \( p(p - 1)/2 \) required for system identification are

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\(^{21}\)See Quah(1992) for a detailed technical discussion.
obtained. Knowledge of cointegration rank then reduces the number of restrictions required to identify the complete structure of the system by \( r(p - r) \). At the same time, the origin of structural innovations that characterize cointegrated systems may be more difficult to establish than in conventional VAR analysis because the innovations are formed from linear combinations of reduced form residuals and are not easily associated with individual reduced form equations. Therefore, the identification exercise becomes even more focused on the imprint each innovation leaves on the data, i.e. permanent or temporary. Given that the PPP system has three variables that can be characterized by cointegration rank \( r = 1 \), implying that \( p - r = 2 \), the above discussion implies that no restrictions, beyond structural error independence, are needed to identify the transitory innovation in the model. In order to identify the permanent innovations, however, I must impose one restriction. This restriction takes the form of a long-run neutrality restriction \( \text{a la} \) Blanchard and Quah (1989) and is determined by the weak exogeneity of one of the variables in the PPP system. Specifically, the weakly exogenous variable will have no long-run response to the other permanent innovation.
References


Table 1: Unit Root Tests Based on GLS Detrending

<table>
<thead>
<tr>
<th>Country</th>
<th>$q_t$</th>
<th>$k$</th>
<th>$\hat{\rho}$</th>
<th>Half-Life</th>
<th>$MZ_p$</th>
<th>$MZ_t$</th>
<th>$ERS_{pt}$</th>
<th>$MERS_{pt}$</th>
<th>$ADF$-GLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.K.</td>
<td>0</td>
<td>0.9665</td>
<td>20.34</td>
<td>-10.44</td>
<td>-2.28**</td>
<td>8.68</td>
<td>8.74</td>
<td>-2.32**</td>
<td></td>
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<tr>
<td>Germany</td>
<td>0</td>
<td>0.9815</td>
<td>37.12</td>
<td>-5.81</td>
<td>-1.69</td>
<td>15.82</td>
<td>15.65</td>
<td>-1.70</td>
<td></td>
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<tr>
<td>Japan</td>
<td>1</td>
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<td>-1.49</td>
<td>15.50</td>
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<tr>
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<td>-1.69</td>
<td>15.28</td>
<td>15.06</td>
<td>-1.78</td>
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</tr>
<tr>
<td>Italy</td>
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<td>0.9774</td>
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<tr>
<td>Canada</td>
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<td>-2.41</td>
<td>7.79</td>
<td>7.79</td>
<td>-1.91</td>
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5% critical: -17.30, -2.91, 5.48, 5.48, -2.91
10% critical: -1.98, -1.98, -1.98, -1.98

Note: $k$ is the lag truncation parameter chosen by the modified AIC of Ng and Perron (2001). $\hat{\rho}$ is the estimate of the sum of the AR(p) parameters using the GLS detrended data. $MZ_p$ and $MZ_t$ are the modified Phillips and Perron (1988) tests of Ng and Perron (20001). $ERS_{pt}$ is the point optimal test of Elliot et al. (1996). $MERS_{pt}$ is the modified point optimal test of Ng and Perron (2001). $ADF$-GLS is the ADF statistic of Said and Dickey (1984) calculated using GLS detrended data.

Table 2: Error-Correction Coefficients from VAR(1)

<table>
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<tr>
<th>Country</th>
<th>$\alpha_s$</th>
<th>$t$-$\alpha_s$</th>
<th>$\alpha_p$</th>
<th>$t$-$\alpha_p$</th>
<th>$\alpha_{ps}$</th>
<th>$t$-$\alpha_{ps}$</th>
<th>$\hat{\rho}$</th>
<th>Half-Life</th>
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<td>-2.47*</td>
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<td>Germany</td>
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<td>-0.0017</td>
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<td>0.0098</td>
<td>2.71*</td>
<td>0.0036</td>
<td>2.09*</td>
<td>0.9849</td>
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<td>France</td>
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<td>-0.0008</td>
<td>-0.18</td>
<td>-0.0065</td>
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<td>0.9765</td>
<td>29.20</td>
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<tr>
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<td>-1.00</td>
<td>0.0102</td>
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<td>-0.0012</td>
<td>-0.41</td>
<td>0.9785</td>
<td>31.82</td>
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<td>Canada</td>
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5% critical: ±1.96, ±1.96, ±1.96, ±1.96
10% critical: ±1.65, ±1.65, ±1.65

Note: $\alpha_j$ is the estimated error-correction coefficient from the $j^{th}$ equation in the VECM(1). $t$-$\alpha_s$ is the t-statistic on the error-correction term in the exchange rate equation in the VECM. $t$-$\alpha_p$ is the t-statistic on the error-correction term in the domestic price level equation in the VECM. $t$-$\alpha_{ps}$ is the t-statistic on the error-correction term in the U.S. price level equation in the VECM.
Table 3: Cointegration Tests

<table>
<thead>
<tr>
<th>Country</th>
<th>qt</th>
<th>k</th>
<th>HW</th>
<th>JOH</th>
<th>α_s</th>
<th>t-α_s</th>
<th>α_p</th>
<th>t-α_p</th>
<th>α_p*</th>
<th>t-α_p*</th>
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<tbody>
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<td>U.K.</td>
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<td>57.30*</td>
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<td>0.0005</td>
<td>0.43</td>
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<tr>
<td>Germany</td>
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<td>-0.0011</td>
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<tr>
<td>Japan</td>
<td>14</td>
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<td>0.0033</td>
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<td>0.0001</td>
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<tr>
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<tr>
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<td>-2.33*</td>
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<td>-1.50</td>
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<td>Canada</td>
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<td>5.93</td>
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<td>5% critical</td>
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<td>±1.96</td>
<td>±1.96</td>
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<tr>
<td>10% critical</td>
<td>6.43</td>
<td>26.79</td>
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<td>±1.65</td>
<td>±1.65</td>
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</table>

Note: k is the lag truncation parameter chosen by the AIC criterion. HW is the Wald statistic of Horvath and Watson (1995). JOH is the Johansen (1991) trace statistic for the null of no cointegration. t-α_s is the t-statistic on the error-correction term in the exchange rate equation in the VECM. t-α_p is the t-statistic on the error-correction term in the domestic price level equation in the VECM. t-α_p* is the t-statistic on the error-correction term in the U.S. price level equation in the VECM.
Table 4: Real Exchange Rate Forecast Error Variance Decomposition.

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Note: Results derived from structural model imposing the weak exogeneity restrictions to identify the permanent shocks.
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Note: Results derived from structural model imposing the weak exogeneity restrictions to identify the permanent shocks.
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Note: Results derived from structural model imposing the weak exogeneity restrictions to identify the permanent shocks.
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Note: Results derived from structural model imposing the weak exogeneity restrictions to identify the permanent shocks.
Real U.S. Dollar Exchange Rates
1972 to 1998

Real French Franc-U.S. Dollar Exchange Rate

Real Japanese Yen-U.S. Dollar Exchange Rate

Real British Pound-U.S. Dollar Exchange Rate

Real Italian Lira-U.S. Dollar Exchange Rate

Real German Mark-U.S. Dollar Exchange Rate

Real Canadian Dollar-U.S. Dollar Exchange Rate

Figure 1
Dynamic Responses of British Pound - U.S. Dollar PPP System

Response of Nominal Exchange Rate

Response of Domestic Price Level

Response of U.S. Price Level

Response of Real Exchange Rate

Figure 2
Dynamic Responses of German Mark - U.S. Dollar PPP System

Figure 3
Dynamic Responses of Japanese Yen - U.S. Dollar PPP System

Response of Nominal Exchange Rate

Perm Shock #1

Months

Response of Domestic Price Level

Perm Shock #1

Months

Response of U.S. Price Level

Perm Shock #1

Months

Response of Real Exchange Rate

Perm Shock #1

Months

Response of Nominal Exchange Rate

Perm Shock #2

Months

Response of Domestic Price Level

Perm Shock #2

Months

Response of U.S. Price Level

Perm Shock #2

Months

Response of Real Exchange Rate

Perm Shock #2

Months

Response of Nominal Exchange Rate

Transitory Shock

Months

Response of Domestic Price Level

Transitory Shock

Months

Response of U.S. Price Level

Transitory Shock

Months

Response of Real Exchange Rate

Transitory Shock

Months

Figure 4
Dynamic Responses of French Franc - U.S. Dollar PPP System

Figure 5
Dynamic Responses of Italian Lira - U.S. Dollar PPP System

Response of Nominal Exchange Rate
- Perm Shock #1
- Transitory Shock

Response of Domestic Price Level
- Perm Shock #1
- Transitory Shock

Response of U.S. Price Level
- Perm Shock #1
- Transitory Shock

Response of Real Exchange Rate
- Perm Shock #1
- Transitory Shock

Figure 6
Dynamic Responses of Canadian Dollar - U.S. Dollar PPP System

Response of Nominal Exchange Rate

Response of Domestic Price Level

Response of U.S. Price Level

Response of Real Exchange Rate

Response of Nominal Exchange Rate

Response of Domestic Price Level

Response of U.S. Price Level

Response of Real Exchange Rate
Figure 8
Historical Decomposition of U.S. Dollar Real Exchange Rates

![Graphs showing historical forecast errors and permanent/shock factors for various currencies.](image-url)