Parity convergence of real exchange rates: What role does price adjustment play?

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Abstract: The conventional view, as expounded by sticky-price models, is that price adjustment governs the reversion process toward purchasing power parity (PPP). Researchers have been puzzled because the empirical reversion rate appears too slow to be explained by price adjustment. What role does price adjustment really play? This study measures the individual contributions of price and exchange rate adjustments and shows that the reversion dynamics at both short and long horizons are driven mostly by exchange rate adjustment, not price adjustment. Also, exchange rate adjustment tends to amplify and prolong PPP deviations. PPP reversion thus exhibits dynamics substantially different from that suggested by standard exchange rate models.

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1. Introduction

The post-1973 experience with floating exchange rates leaves little doubt that departures from purchasing power parity (PPP), as gauged by real exchange rates, have generally been large and persistent.
This study dissects the PPP disequilibrium adjustment process and analyzes how exchange rates and prices, and hence real exchange rates, adjust toward parity. Rogoff (1996) observes that real exchange rates seem too persistence and volatile to be explained by existing exchange rate models. Sticky-price monetary models—originated from Dornbusch's (1976) analysis—attempt to reconcile exchange rate theory with several empirical facts of the recent float: short-term movements in exchange rates and real exchange rates are strongly correlated; exchange rates display much greater variability than prices; and the switch from fixed to floating rates is accompanied with a substantial rise in the volatility of real exchange rates (Mussa, 1986; Baxter and Stockman, 1989; Flood and Rose, 1995). By recognizing the different adjustment speeds of goods and asset markets, monetary disturbances are shown to produce large and volatile, albeit temporary, deviations from PPP. Distinct roles are typically prescribed for exchange rates and prices in explaining real exchange rate dynamics: the short-term volatility is spawned by sharp exchange rate movements under sticky prices, whereas the long-term persistence stems from sluggish price adjustment, through which PPP is gradually restored over time.

Rogoff (1996) poses a puzzle about the speed of parity reversion. Although growing evidence in support of PPP convergence has been documented (Frankel and Rose, 1996; Oh, 1996; Wu, 1996; Papell, 1997; Cheung and Lai, 1998; Taylor and Peel, 1998; Taylor and Sarno, 1998; Engel, 1999, gives an exception), consensus estimates of the reversion speed suggest an extremely slow rate of about 15 percent per year. The empirical rate of convergence is puzzling because it appears too torpid to be explained by price stickiness. Slow reversion may possibly be rationalized by predominance of real shocks to tastes and productivity, but such shocks are not volatile enough to account for the immense short-term exchange rate volatility. The findings of significant parity reversion also make it hard to suggest that real shocks are predominant.

The puzzle has two components. The first component concerns the importance of monetary shocks relative to real shocks. Several studies have assessed the relative importance of monetary and real shocks, and mixed findings have been reported (Clarida and Gali, 1994; Eichenbaum and Evans, 1995; Rogers, 1999). The second component concerns the actual role of price adjustment in parity reversion, which is the focus of our analysis. The kernel of the puzzle lies in the basic tenet of sticky-price models, namely, the proposition that the convergence toward PPP is driven mainly by price adjustment. Under sticky-price models, the speed of price adjustment fully determines how fast the real exchange rate can revert. Exchange rates are assigned no independent role in the reversion process—they simply adjust to and converge at the same rate as prices. The critical question then is, What role does price adjustment actually play in PPP reversion? If the reversion is not driven mostly by price adjustment, the reversion rate will not have to be tied to the price adjustment speed, regardless of the nature of underlying shocks. The puzzle should then be rethought to allow for an active role of exchange rate adjustment in PPP reversion.

Engel and Morley (1998) have questioned the validity of the stringent proposition that real exchange rates converge at the same speed as prices. These authors observe that the PPP puzzle may be resolved if PPP reversion is not entirely propelled by price adjustment. Empirical results, based on an unobserved components model of price and exchange rate dynamics, support different adjustment speeds: prices are found to adjust relatively fast, but exchange rates adjust very slowly. Accordingly, it is exchange rate adjustment, not price adjustment, that is responsible for the sluggish reversion. The finding leaves open an important question: why do exchange rates adjust so slowly? Presumably, exchange rates are asset prices, which move much faster than goods prices.

To gain new insight into the individual dynamics of price and exchange rate adjustments, this study applies impulse response analysis of a vector error correction model, which enables us to quantify their individual contributions to the reversion speed at both short and long horizons subsequent to different shocks. The observed persistence in real exchange rates is found to come mostly from exchange rate adjustment, not price adjustment, even at long horizons. The former can account for about 60 to 90 percent of the speed of convergence of real exchange rates. Interestingly, exchange rates actually adjust faster than prices, but not in the “right” direction toward parity all the time. Following a shock, exchange rates tend to move farther away from parity before reverting. Such non-monotonic exchange rate adjustment imparts similar non-monotonicity into real exchange rate dynamics, and the non-monotonicity delays and prolongs the process of parity convergence. Hence, the slow convergence of real exchange rates is reconcilable with relatively fast but non-monotonic exchange rate adjustment.

An issue regarding the potential uncertainty in estimating the persistence of real exchange rates should be noted. Cheung and Lai (2000) and Murray and Papell (1999) illustrate the existence of substantial sampling variability in measuring half-lives. The present study is not concerned with the half-life measurement issue. Instead, it takes the findings of extremely slow convergence as empirical facts and investigates how much price adjustment contributes to the slow convergence.

2. PPP convergence under sticky-price models

The PPP theory suggests a long-run equilibrium relationship between exchange rates and relative national price levels. The real exchange rate, which captures the deviation from PPP, is measured by

$$q_t = e_t - p_t \tag{1}$$

where all variables are expressed in logarithms; e_t is the nominal exchange rate (defined as the domestic price of foreign currency); and $p_t = p_t^d - p_t^f$ is the relative price ratio between the domestic price level, p_t^d, and the foreign price level, p_t^f. Although the empirical relevance of long-run reversion in q has been explored extensively, not much empirical work has been devoted to analyzing the disequilibrium adjustment behavior of e and p. The large, volatile PPP deviations observed after the advent of the modern float have bred the development of sticky-price monetary models—which stress the role of slowly adjusting prices in determining exchange rate dynamics, while PPP holds in the long run.

A notable feature of sticky-price models is that during the process of PPP convergence, both the exchange rate and the real exchange rate move toward their long-run values at the same rate governed by the speed of price adjustment. This can be illustrated by Dornbusch-type models. A monetary expansion, for example, induces a fall in domestic interest rates and leads to a capital outflow that will depreciates the domestic currency to the point where the expected rate of appreciation exactly offsets the interest differential. Moreover, aggregate demand is boosted by the currency depreciation and lower interest rates. In response to higher aggregate demand, prices begin to rise slowly, thereby reducing the real money supply and pushing domestic interest rates back up. The domestic currency then appreciates gradually over time, along with rising prices. The gradual price adjustment will drive both the exchange rate and the real exchange rate to converge asymptotically to their corresponding equilibrium levels.

More formally, consider the following model (with the (log) foreign price normalized to be zero):

$$de_t/dt = i_t - i_t^* \qquad (2)$$

$$m_t - p_t = \ \ y_t - \ \ i_t \qquad , \quad > 0 \qquad (3)$$

$$y_t = \ \ + \ \ q_t + \ \ (m_t - p_t) \qquad , \quad > 0 \qquad (4)$$

$$dp_t/dt = \ \ (y_t - \bar{y}) \qquad > 0 \qquad (5)$$

Equation (2) captures the uncovered interest parity condition, with i_t being the domestic nominal interest rate and i_t^* being the foreign rate. Equation (3) describes a money-market equilibrium relationship, where m_t is the nominal money supply and y_t is the real national income. Equation (4) states that the income level is demand determined: A rise in the real money supply raises demand so does a real depreciation of the domestic currency. Equation (5) is a scheme of price adjustment in response to the excess of aggregate demand over the natural output level ($\bar{y}$). Solving the model yields a system of differential equations:

$$de_t/dt = \quad ^{-1}(e_t - \bar{e}) + [1 - \ \ (\ \ + \ \ )] \ \ ^{-1}(p_t - \bar{p}) \qquad (6)$$

$$dp_t/dt = \quad (e_t - \bar{e}) - \ \ [\ \ + \ \ ](p_t - \bar{p}) \qquad (7)$$

where the overbars indicate the respective equilibrium values. Let $\ _1 < \ _2$ be the roots of the characteristic equation $|A - \ I| = 0$, where $A = \{a_{ij}\}$ is a 2 x 2 matrix with $a_{11} = \ / \ $, $a_{12} = [1 - \ (\ + \ )]/ \ $, $a_{21} = \ $, and $a_{22} = - \ [\ + \ ]$. Since $\ _1 \ _2 = |A| = - \ / \ < 0$, we have $\ _2 > 0 > \ _1$. In ruling out the unstable solution, the convergent paths are given by $p_t = (p_0 - \bar{p})\exp(\ _1 t) + \bar{p}$ and $e_t = (e_0 - \bar{e})\exp(\ _1 t) + \bar{e}$ Hence, e and p share the same reversion rate. The real exchange rate, given by $e - p$, will also revert at the same rate.

3. VEC modeling of PPP adjustment dynamics

The vector error correction (VEC) model of cointegrated series (Engle and Granger, 1987; Johansen, 1995) readily lends itself to the empirical analysis of the disequilibrium adjustment process toward PPP. Both the short- and long-term interactions between the exchange rate and the relative price can be captured simultaneously, and their implied dynamics of the real exchange rate can also be investigated at the same time. The following VEC system incorporates the long-run PPP restriction:

$$e_t = \mu_1 + \quad_1(e_{t-k} - p_{t-k}) + \quad^{k}_{i=0} \quad_{1i} \quad e_{t-i-1} + \quad^{k}_{j=0} \quad_{1j} \quad p_{t-j-1} + u_{1t} \tag{8}$$

$$p_t = \mu_2 + \quad_2(e_{t-k} - p_{t-k}) + \quad^{k}_{i=0} \quad_{2i} \quad e_{t-i-1} + \quad^{k}_{j=0} \quad_{2j} \quad p_{t-j-1} + u_{2t} \tag{9}$$

where   is the usual difference operator; $e_{t-k} - p_{t-k}$ represents the error correction term, which gives the deviation from PPP; and u_{1t} and u_{2t} are innovations to the exchange rate and the price, respectively. When $|\ _1| + |\ _2|$ Ʊ0, *e* and *p* are cointegrated, implying that PPP will prevail over the long run. The coefficients, $\ _1$ and $\ _2$, reflect how strongly deviations from parity feedback onto the system.

The data under study are monthly series of nominal exchange rates and consumer price indices. Specifically, the exchange rate data for four major European countries—France, Germany, Italy and the United Kingdom—vis-à-vis the United States are examined. Taken from the IMF's *International Financial Statistics* data CD-ROM, the data cover the sample period from April 1973 through December 1998. Following the common practice in the literature, all the data series are expressed in logarithms.

Table 1 reports the estimation results of the VEC model. The lag specification in each case is selected using the standard Akaike information criterion. In all the cases the error correction coefficients are statistically significant, confirming a long-run equilibrium relationship between *e* and *p*. Moreover, since $\ _1$ (the error correction coefficient in the exchange rate equation) and $\ _2$ (the error correction coefficient in the price equation) are uniformly significant, the results suggest that both exchange rates and prices adjust to deviations from parity. A formal evaluation of the individual adjustment speeds will be conducted using impulse response analysis of the VEC system. We observe that exchange rate disturbances consistently display much greater variability than price disturbances. This accords with the usual finding that exchange rate movements are more volatile than price movements.

Before examining the individual adjustment dynamics of exchange rates and prices, it is instructive to analyze the adjustment behavior of real exchange rates under the VEC model. Prior studies of real exchange rate dynamics are usually based on direct analysis of univariate series of q. In the univariate setting, innovations to q represent composite shocks, which mix exchange rate and price innovations together. The VEC system approach can provide similar analysis of real exchange rate dynamics as the univariate approach, while allowing for modeling of e and p individually. Under the VEC framework of e and p, the impulse response function of q with respect to a composite innovation is the square root of the persistence profile introduced by Pesaran and Shin (1996), who propose a method of persistence estimation that is invariant to the ordering of the system variables.

Consider in general a vector of m time series, $X_t = (x_{1t}, ..., x_{mt})'$, given by

$$A(L)X_t = \mu + u_t \qquad (10)$$

where L is the lag operator such that $LX_t = X_{t-1}$; $A(L) = I - A_1L - ... - A_kL^k$; $\mu = (\mu_{1t}, ..., \mu_{mt})'$ is a vector of constants; and $u_t = (u_{1t}, ..., u_{mt})'$ is a vector of white-noise innovations, with $E(u_t) = 0$ and $E(u_tu_t') =$. By writing $A(L) = A(1)L^k + \quad A^*(L)$, with $A^*(0) = I$, a VEC representation for (10) may be obtained as follows:

$$X_t = \mu - \quad X_{t-k} + \quad_1 \quad X_{t-1} + ... + \quad_{k-1} \quad X_{t-k-1} + u_t \qquad (11)$$

where $= A(1)$ and $_j = -(A_{j+1} + ... + A_k)$ for $j = 1, ..., k - 1$. If $1 \leq$ rank( ) $= r <$ m, can be written as $=$ $'$, where and are m x r matrices of full column rank. In addition, $z_t = \quad 'X_t$ gives r cointegrating relationships. With $X_t = (e_t, p_t)'$, $= (1, -1)'$, $r = 1$, and $z_{t-k} = e_{t-k} - p_{t-k}$ in our case, equation (11) can be reduced to the VEC system specified by (8) and (9).

According to Pesaran and Shin (1996), the persistence of the impact of a composite shock at time t on the evolution of the cointegrating relationship at time $t + n$ can be captured by

$$h_z(n) = (\quad 'C_n \quad C_n' \quad)/(\quad ' \quad) \qquad (12)$$

where C_n can be computed from a recursive equation:

$$C_n = A_1C_{n-1} + A_2C_{n-2} + ... + A_kC_{n-k}, \qquad n = 1, 2, ... \qquad (13)$$

with $C_0 = I$ and $C_n = 0$ for $n < 0$. The matrices $\{C_n, n = 1, 2, ...\}$ constitute the coefficient matrices of the moving-average representation of X_t. In our case where there is only one equilibrium relationship ($z_t = \; 'X_t = e_t - p_t$), it can be shown that the impulse response function of z_t (denoted by $\;_c^q$) to a unit composite innovation—a real exchange rate innovation defined by $\; 'u_t$—can be obtained as:

$$\;_c^q(n) = [h_z(n)]^{1/2} \tag{14}$$

Note that the impulse response function here is defined with respect to the entire vector of innovations, u_t, and not to a specific single element of u_t.

Estimates of the impulse responses of real exchange rates are exhibited in Figure 1. Graphs of the first 120 impulse responses—corresponding to a time span of 10 years for monthly data—are presented. All these graphs commonly show that the convergence of the real exchange rate, albeit it exists, is not monotonic. Specifically, the impulse response functions do not peak at the time of the innovation ($t = 0$) and fall monotonically to zero, as implied by Dornbusch's (1976) model. The impact of the innovation tends to magnify initially before dissipating. The results from VEC analysis here corroborate other findings of non-monotonicity by Cheung and Lai (2000) based on univariate analysis of q. The study identifies a potential role of non-monotonic dynamics in magnifying and prolonging PPP deviations. All these findings raise questions on where the non-monotonicity in real exchange rate dynamics comes from. The findings do not pin down anything about the individual contributions of exchange rates and prices. Does the non-monotonicity come from exchange rate or price adjustment? Is the parity-reversion part driven mainly by price adjustment? How much does price adjustment really contribute to the reversion?

4. Decomposing the real exchange rate dynamics

To address the unanswered questions, we decompose the real exchange rate dynamics and analyze the dynamic paths of exchange rate and price adjustments separately. In general, innovations to the real exchange rate, which can be real or monetary in nature, operate through either the exchange rate or the price or both.

This analysis does not attempt to identify the structural sources of exchange rate and price innovations, albeit exchange rate innovations are noted to have much greater variability than price innovations. Instead, the analysis focuses on the central issue concerning the contribution of price adjustment to the speed of PPP convergence, not the sources of the innovations. The relative importance of price and exchange rate adjustments is found to vary little under different types of innovations.

The generalized impulse response approach recommended by Pesaran and Shin (1998) is employed for the analysis. Unlike traditional impulse response analysis (e.g., Lütkepohl and Reimers, 1992), which considers orthogonalized shocks based on the Cholesky decomposition, the Pesaran-Shin approach yields unique impulse response functions that are invariant to the ordering of variables. Only in the limiting case of a diagonal error variance matrix do the orthogonalized and the generalized impulse response functions coincide. The generalized method takes the correlation among different innovations into account.

The generalized impulse response function measures the change in the *n*-period ahead forecast of each of the system variables that will be caused by a variable-specific innovation. Formally, the generalized impulse response function of X_t with respect to a unit innovation to the *j*th variable is given by

$$ {}_j^X(n) = C_n \quad {}_j / \quad {}_{jj} \qquad n = 0, 1, 2, ... \tag{15}$$

where C_n can be computed from the recursive relations in equation (13); ${}_j$ is a selection vector with unity as its *j*th element and zeros elsewhere; and ${}_{jj}$ is the *j*th diagonal element of . The ${}_j^X$ function will yield separate time paths of dynamic responses associated with exchange rate and price adjustments.

In regard to real exchange rate adjustment, the generalized impulse response function of $z_t = \ 'X_t$ with respect to a unit innovation to the *j*th variable is given by

$$ {}_j^z(n) = \ 'C_n \quad {}_j / \quad {}_{jj} \qquad n = 0, 1, 2, ... \tag{16}$$

The adjustment speed of the real exchange rate, i.e., the rate of PPP convergence, at time $t = n$ can be directly measured as $- \quad {}_j^z(n) / \ {}_j^z(n)$, which gives the rate of decrease in the impulse response at time $t = n$. Through this measure, we can assess the speed and the direction of adjustment along the entire path of the PPP adjustment process. Note that the real exchange rate will be moving farther apart from parity when $- \quad {}_j^z(n) / \ {}_j^z(n) < 0$, and it will be reverting toward parity when $- \quad {}_j^z(n) / \ {}_j^z(n) > 0$.

Since $X_t = (x_{1t}, x_{2t})' = (e_t, p_t)'$ and $\;\; = (1, -1)'$ in our case, the impulse response functions of q, e and p with respect to a variable-specific innovation are linked as follows:

$$ {}^{q}_{j}(n) = {}^{e}_{j}(n) - {}^{p}_{j}(n) \qquad\qquad j = 1, 2 \qquad (17)$$

where the superscript indicates the corresponding variable, and $j = 1$ for an exchange rate innovation and 2 for a price innovation. The relative size of ${}^{e}_{1}(n)/ {}^{q}_{1}(n)$ and ${}^{p}_{1}(n)/ {}^{q}_{1}(n)$ will show the relative contributions of exchange rate adjustment and price adjustment to real exchange rate adjustment at time $t = n$ following an exchange rate innovation at time $t = 0$. Likewise, the relative size of ${}^{e}_{2}(n)/ {}^{q}_{2}(n)$ and ${}^{p}_{2}(n)/ {}^{q}_{2}(n)$ will indicate how much exchange rate and price adjustments contribute individually to real exchange rate adjustment at time $t = n$ subsequent to a price innovation at time $t = 0$.

Comparing between the impulse response functions of the real exchange rate with respect to different types of innovations can help identify the relative importance of exchange rate and price innovations. ${}^{q}_{1}$ gives the effects of an exchange rate innovation on the real exchange rate; ${}^{q}_{2}$ indicates the effects of a price innovation on the real exchange rate; and ${}^{q}_{c}$ summarizes the combined effects of exchange rate and price innovations on the real exchange rate. If price innovations are predominant, ${}^{q}_{c}$ will look much more like ${}^{q}_{2}$ than ${}^{q}_{1}$. If exchange rate innovations are predominant, on the other hand, ${}^{q}_{c}$ will resemble closely ${}^{q}_{1}$, not ${}^{q}_{2}$, in shape.

4.1. Dynamic responses to a price innovation

The effects of a price innovation on q, e and p are first examined. A shock to parity can come about as an exchange rate innovation or a price innovation. The analysis of real exchange rate dynamics in section 4 implicitly lumped the two types of innovations together, and the impulse response results thus obtained depict the total effects of exchange rate and price innovations. Given that $q = e - p$, an increase in q can be induced by a decrease in p or an increase in e. To facilitate comparison among results, a negative innovation to p is considered next, and a positive innovation to e will be considered later.

The generalized impulse response functions of q, e and p with respect to a price innovation (${}^{q}_{2}$, ${}^{e}_{2}$ and

$_2^p$) are estimated and presented in Figure 2. The impact of a price innovation on p itself appears very persistent in every case. Following the price innovation, p keeps the momentum and continues to move farther away, thereby enlarging the initial deviation from parity. Indeed, p exhibits little or no tendency to revert back even long after the initial innovation. It is the exchange rate that mostly drives the real exchange rate to parity. This is highlighted by the finding that the shape of the impulse response function of q reflects principally the shape of the impulse response function of e.

Moreover, the convergence of the real exchange rate under a price innovation may follow a wide array of adjustment patterns. Among the four cases under study, the German mark case exhibits the simplest pattern, with the real exchange rate reverting monotonically toward parity (Figure 2c). All the other cases show non-monotonic adjustment during the early phase of the adjustment process—either with shock amplification or undershooting or both. In the British pound case, the real exchange rate diverges and magnifies the initial deviation from parity before reverting steadily toward parity (Figure 2a). This resembles the observed non-monotonicity in the real exchange rate dynamics ensuing from a composite shock (Figure 1a). In the French franc case, the initial shock amplification of the real exchange rate is relatively small, and is quickly followed by a large swing and substantial undershooting before moving back toward parity (Figure 2b). The Italian lira case has no initial shock amplification, but the real exchange rate falls sharply and ends in undershooting prior to converging back toward parity (Figure 2d). The occurrence of undershooting in two of the cases is noteworthy. If innovations are dominated by price disturbances, similar undershooting behavior should be detected in the real exchange rate under composite innovations. Evidently, no such undershooting dynamics can be observed from $_c^q$. All in all, except for the British pound case, the foregoing results show that $_2^q$ differs significantly from $_c^q$, suggesting that price innovations are not likely to be the predominant type of innovations buffeting the real exchange rate.

To quantify the individual contributions of exchange rate and price movements to the dynamics of the real exchange rate, $_2^q(n)$ is decomposed into two components, $_2^e(n)$ and $_2^p(n)$, at different time horizons after the price innovation. Since $q = e - p$, $_2^e(n)/\ _2^q(n)$ and $-\ _2^p(n)/\ _2^q(n)$ should add up to unity. $_2^e(n)/\ _2^q(n)$ gives the proportion of real exchange rate adjustment explained by exchange rate adjustment at time $t = n$, and $-\ {}^{p}_{2}(n)/\ {}^{q}_{2}(n)$ indicates the proportion explained by price adjustment.

Table 2 reports the decomposition of real exchange rate dynamics, along with estimates of the rate of convergence, after a price innovation. During the early phase of the adjustment process, the reversion speed can at times be negative (an exception is the German mark case), reflecting the existence of non-monotonic dynamics effectuated by either shock amplification or undershooting. More importantly, price movements during this phase generally offer no positive contributions to real exchange rate adjustment, suggesting that short-term real exchange rate dynamics are driven mainly by exchange rate movements. The next phase of the adjustment process is characterized by steady convergence of *q* toward parity. During this adjustment phase, *p* does contribute to the process of convergence, with its size of contribution varying somewhat across cases. Nonetheless, *e*, not *p*, is the principal engine propelling the process of convergence. About 60 to 90 percent of the reversion dynamics of the real exchange rate can be ascribed to exchange rate adjustment. The results presented next show that exchange rate adjustment remains to be the key contributor to the reversion process when an exchange rate innovation is considered.

4.2. Dynamic responses to an exchange rate innovation

The impulse response functions of *q*, *e* and *p* with respect to an exchange rate innovation (${}^{q}_{1}$, ${}^{e}_{1}$ and ${}^{p}_{1}$) are displayed in Figure 3. Apparently, the adjustment patterns in all the cases are very much alike. The exchange rate innovation elicits steady and monotonic responses from *p*. In contrast to the case of a price innovation, *p* adjusts gradually to reduce the PPP deviation following an exchange rate innovation. However, the short-run dynamics of the PPP deviation are still governed primarily by exchange rate movements. In response to the innovation, *e* tends to move farther away and magnifies the PPP deviation before reverting. Such amplified exchange rate responses are responsible for similar non-monotonicity in real exchange rate dynamics. Subsequent to the amplified responses, *e* then adjusts monotonically toward parity, along with converging *p*.

The amplification of exchange rate responses can not only add to the short-term volatility of the real exchange rate but also augment its persistence by lengthening the reversion process. The non-monotonic adjustment seems unexplained by traditional macroeconomic models of exchange rate dynamics. Taylor (1995) discusses an interesting role of foreign exchange market microstructure in generating short-term PPP deviations. For example, the rising importance of chartists in currency trading can extend and magnify short-term exchange rate movements. Based on survey expectations data for major currencies, Frankel and Froot (1990) report that, "at short horizons, [traders] tend to forecast by extrapolating recent trends, while at long horizons they tend to forecast a return to a long-run equilibrium such as purchasing power parity" (p.183). A question is, To what extent are short-term exchange rate movements actually spurred by currency trading based on extrapolative expectations? This remains to be determined in future research.

The importance of exchange rate innovations can be verified by comparing between the impulse response function of q with respect to an exchange rate innovation ($_1^q$) and the corresponding function of q with respect to a composite innovation ($_c^q$). The close similarity between these impulse response functions points to exchange rate disturbances as being the dominant source of real exchange rate fluctuations. Consistently, $_1^q$ matches $_c^q$ very closely in shape.

To measure how much real exchange rate movements are attributable to exchange rate and price adjustments individually, $_1^q(n)$ is broken down into two components: $_1^e(n)$ and $_1^p(n)$. $_1^e(n)/$ $_1^q(n)$ indicates the proportion of real exchange adjustment caused by exchange rate adjustment at time $t = n$, and $-$ $_1^p(n)/$ $_1^q(n)$ yields the respective proportion caused by price adjustment at time t = n. The computation results are presented in Table 3. They support that e, not p, plays the lead role in driving q to parity. After the initial shock amplification, q converges steadily toward parity. During this process of convergence, the proportion of real exchange rate adjustment attributable to exchange rate adjustment is about 60 to 90 percent, similar to those estimates reported earlier for the case of a price innovation.

4.3. Section summary

The above analysis has examined the reversion dynamics of the real exchange rate over different adjustment horizons by decomposing the dynamics into two components, one attributed to price adjustment and another explained by exchange rate adjustment. The findings generally underscore a pivotal role that exchange rate adjustment plays in the process of convergence toward PPP. Regardless of whether the shock to parity operates as a price innovation or an exchange rate innovation, the reversion process toward PPP is found to be driven primarily by exchange rate adjustment, albeit price adjustment does contribute to restoring parity as well.

5. Concluding remarks

This study has examined how much price and exchange rate adjustments contribute individually to the process of PPP reversion. The conventional view, as expounded by sticky-price models, is that price adjustment is the key driver of the PPP reversion process. Accordingly, the reversion rate is expected to be tied to the speed of price adjustment. Researchers have been puzzled, however, because the empirical rate of reversion appears excessively slow to be explained by price adjustment (Rogoff, 1996). What role does price adjustment really play? This study shows that the reversion process at both short and long horizons has been driven mostly by exchange rate adjustment, rather than price adjustment. The study also finds that exchange rate adjustment tends to amplify short-term PPP deviations and prolong the reversion of the real exchange rate. These results indicate that PPP reversion exhibits much more complicated dynamics than that implied by standard exchange rate models.

In finding that exchange rate adjustment takes a lead role in driving the PPP reversion process, the perplexedly slow reversion rate will no longer have to be explained by sluggish price adjustment alone. This contrasts with the traditional view that exchange rate adjustment drives the short-term real exchange rate volatility, whereas price adjustment governs the long-term persistence of real exchange rate reversion. Our empirical results suggest that exchange rate adjustment largely governs not only the volatility but also the persistence of the real exchange rate. The results raise a new question: How can we account for the observed behavior of exchange rate adjustment? This calls for the development of new models of PPP deviations which allow for a significant and independent role of exchange rate adjustment in explaining the puzzling behavior of the real exchange rate.

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Table 1. Estimation results of the VEC model of exchange rate and price dynamics

R.H.S. variable	Britain pound e_t	Britain pound p_t	French franc e_t	French franc p_t	Germany mark e_t	Germany mark p_t	Italian lira e_t	Italian lira p_t
c	-0.008	0.004	0.052	-0.003	0.010	-0.002	0.162	-0.036
	(0.005)*	(0.001)**	(0.018)**	(0.002)	(0.006)*	(0.001)**	(0.073)**	(0.012)**
EC	-0.019	0.006	-0.030	0.002	-0.018	0.002	-0.022	0.005
	(0.010)*	(0.003)**	(0.010)**	(0.001)*	(0.010)*	(0.001)*	(0.010)**	(0.002)**
e_{t-1}	0.399	0.033	0.276	0.003	0.312	0.013	0.392	0.026
	(0.057)**	(0.015)**	(0.057)**	(0.007)	(0.057)**	(0.007)*	(0.058)**	(0.010)**
e_{t-2}	-0.140	-0.006	-0.112	0.010	-0.073	-0.005	-0.101	-0.006
	(0.057)**	(0.015)	(0.059)**	(0.007)	(0.057)	(0.007)	(0.057)*	(0.010)
e_{t-3}			0.127	0.002				
			(0.059)**	(0.007)				
e_{t-4}			-0.055	-0.013				
			(0.057)	(0.007)*				
p_{t-1}	-0.008	0.267	-0.083	0.247	0.689	0.298	0.874	0.479
	(0.220)	(0.058)**	(0.464)	(0.056)**	(0.435)	(0.057)**	(0.335)*	(0.057)**
p_{t-2}	0.410	-0.006	0.999	0.027	0.053	0.109	0.118	0.067
	(0.218)*	(0.058)	(0.464)**	(0.057)	(0.436)	(0.057)*	(0.336)	(0.058)

Table 1 (Continued)

R.H.S. variable	Britain pound		French franc		German mark		Italian lira	
	e_t	p_t	e_t	p_t	e_t	p_t	e_t	p_t
p_{t-3}			0.289 (0.468)	0.214 (0.057)**				
p_{t-4}			1.016 (0.467)**	-0.012 (0.057)				
$_u$	0.0240	0.0063	0.0247	0.0030	0.0263	0.0035	0.0236	0.0040

Note: The error correction term, *EC*, is given by equation (8) or (9). The numbers in parentheses report the standard errors for the corresponding model coefficient estimates. Statistical significance is indicated by a single asterisk (*) for the 10% level and a double asterisk (**) for the 5% level. $_u$ is the standard deviation of the corresponding innovation term.

Table 2. Decomposition of real exchange rate adjustment following a price innovation

Time horizon n (in month)	Reversion speed of q (− $^{q}_{2}/$ $^{q}_{2}$ per month)	Proportion explained by: e	 p	Reversion speed of q (− $^{q}_{2}/$ $^{q}_{2}$ per month)	Proportion explained by: e	 p
	British pound:			***French franc:***		
0	-30.25%	0.42	0.58	-36.90%	-0.14	1.14
1	18.07%	1.17	-0.17	105.49%	1.11	-0.11
2	19.12%	1.07	-0.07	-134.77%	1.42	-0.42
3	10.12%	1.02	-0.02	-179.97%	1.11	-0.11
4	4.47%	0.89	0.11	-47.27%	1.08	-0.08
5	2.98%	0.76	0.24	-14.23%	1.26	-0.26
6	2.88%	0.74	0.26	-13.84%	1.27	-0.17
12	3.01%	0.76	0.24	0.75%	0.01	0.99
24	3.01%	0.76	0.24	3.54%	0.90	0.10
36	3.01%	0.76	0.24	3.82%	0.92	0.08
48	3.01%	0.76	0.24	3.85%	0.92	0.08
60	3.01%	0.76	0.24	3.85%	0.92	0.08
120	3.01%	0.76	0.24	3.85%	0.92	0.08
	German mark:			***Italian lira:***		
0	28.14%	1.89	-0.89	34.44%	2.29	-1.29
1	30.47%	1.80	-0.80	79.18%	1.57	-0.57
2	31.09%	1.51	-0.51	286.46%	1.47	-0.47
3	22.96%	1.54	-0.54	-93.61%	1.48	-0.48
4	15.96%	1.49	-0.49	-26.94%	1.54	-0.54
5	10.39%	1.44	-0.44	-10.99%	1.67	-0.67
6	6.49%	1.35	-0.35	-4.51%	0.48	0.52
12	2.59%	0.87	0.13	2.51%	0.59	0.41
24	2.49%	0.85	0.15	2.83%	0.59	0.41
36	2.49%	0.85	0.15	2.83%	0.59	0.41
48	2.49%	0.85	0.15	2.83%	0.59	0.41
60	2.49%	0.85	0.15	2.83%	0.59	0.41
120	2.49%	0.84	0.16	2.83%	0.59	0.41

Table 3. Decomposition of real exchange rate adjustment following an exchange rate innovation

Time horizon *n* (in month)	Reversion speed of *q* (− $^{q}_{1}$/ $^{q}_{1}$ per month)	Proportion explained by: *e*	 *p*	Reversion speed of *q* (− $^{q}_{1}$/ $^{q}_{1}$ per month)	Proportion explained by: *e*	 *p*
	British pound:			***French franc:***		
0	-36.31%	1.07	-0.07	-27.26%	1.02	-0.02
1	0.54%	-0.84	1.84	3.38%	0.71	0.29
2	4.98%	0.90	0.10	-7.19%	1.06	-0.06
3	4.07%	0.86	0.14	-1.02%	2.16	-1.16
4	3.28%	0.80	0.20	3.92%	0.74	0.26
5	3.04%	0.77	0.23	1.29%	0.57	0.43
6	3.00%	0.76	0.24	1.73%	0.60	0.40
12	3.01%	0.76	0.24	3.13%	0.87	0.13
24	3.01%	0.76	0.24	3.77%	0.91	0.09
36	3.01%	0.76	0.24	3.84%	0.92	0.08
48	3.01%	0.76	0.24	3.85%	0.92	0.08
60	3.01%	0.76	0.24	3.85%	0.92	0.08
120	3.01%	0.76	0.24	3.85%	0.92	0.08
	German mark:			***Italian lira:***		
0	-29.70%	1.04	-0.04	-36.44%	1.07	-0.07
1	-2.24%	1.08	-0.08	-4.23%	1.27	-0.27
2	2.38%	0.90	0.10	2.10%	0.54	0.46
3	2.76%	0.90	0.10	3.15%	0.69	0.31
4	2.64%	0.87	0.13	3.13%	0.67	0.33
5	2.55%	0.85	0.15	3.01%	0.64	0.36
6	2.51%	0.85	0.15	2.93%	0.62	0.38
12	2.49%	0.85	0.15	2.83%	0.59	0.41
24	2.49%	0.85	0.15	2.83%	0.59	0.41
36	2.49%	0.85	0.15	2.83%	0.59	0.41
48	2.49%	0.85	0.15	2.83%	0.59	0.41
60	2.49%	0.84	0.16	2.83%	0.59	0.41
120	2.49%	0.85	0.15	2.83%	0.59	0.41