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Real Exchange Rate Behavior: New Evidence with Linear and Non-linear Endogenous Break(s)

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ABSTRACT

Using monthly frequency data from 1981 to 2005, we test for the potential mean reversion of Japan-US real exchange rates using newly improved unit root tests allowing for endogenous (unknown) break(s) in the linear as well as non-linear manner. Both countries have contributed vital proportion in global trading on top of being the major trading partner to each other since 1960s. We identify structural breaks in 1985 and 1994 respectively via the [Lumsdaine and Papell \(1997\)](#)'s linear test, but the results were against the PPP hypothesis. The [Saikkonen and Lütkepohl, \(2002\)](#)'s test, however, provides sufficient supports for non-linear adjustment of real exchange towards long run PPP. In addition, stronger evidence for PPP is found in the post-1994 period, in conjunction with the small persistence of real exchange deviations (half-life less than a year). Also, the exchange rate misalignment is less evident after the Plaza Accord 1985. In brief, our findings reveal that the Japanese authority has shown some form of PPP-oriented rule as a basis for their exchange rate policies, in the presence of structural break(s) and non-linearity.

Keywords: Real Exchange Rates, Endogenous Breaks, Non-linearity, Half-life

JEL Classification: C12; C23; F31; F40

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1.0 Introduction

Real exchange rate behavior has appeared as the center of policy and academic debates since the breakdown of Bretton Wood system about four decades ago. Due to its vital role in global trading and portfolio investments, countries with fixed exchange rates need to know what the equilibrium rate is likely to be and countries with variable exchange rates would like to know what level and variation in real and nominal exchange rates they should expect. Likewise, supposition about the real exchange rate property is elementary in many theoretical and empirical models of international finance. For instance, Purchasing Power Parity (PPP hereinafter) enquires a constant real exchange which at least exhibits reversion towards the long run mean rate over time, and not driven by stochastic trends. In broader terms, the knowledge of real exchange adjustments towards the equilibrium PPP helps to determine the extent to which the international macroeconomic system is self-equilibrating. Such issues have gained new attention lately, concerning the problem of exchange rate misalignment throughout the 1990s – a decade of financial turmoil and currency crises.

Having said that, high variability of real exchange rates cannot be consistent with the PPP hypothesis and any potential unit root in the series would violate the parity condition. But if real exchange rate behavior is indistinguishable from a random walk, the PPP serves no purpose, suggesting that international competition is too weak to stop prices in different countries from diverging as much as they want forever (Elliot and Pesavento, 2004). Such deduction reasoning is obviously against the conventional wisdom that in an integrated world, relative prices should not become arbitrarily large as more and more trading of goods and services (capital and labor, too) are promoted across borders.

Quite surprising, however, is the consensus arrived by recent literature survey (see *inter alia*, Rogoff, 1996; Taylor and Taylor, 2004) that despite the presence of excessive short-term exchange rate volatility, the deviations from the long run equilibrium PPP rates are too persistent with the estimated half-life¹ of real exchange shocks at about 3-5 years. The so-called PPP puzzle has challenged the common practice of the PPP concept in the exchange rate benchmarking as well as in the measurement of one nation's macroeconomic standing². The issue becomes more complex when regional integration and contagion effects are taken into consideration.

The present study aims to investigate the time series properties of real exchange between Japan and the US, which both has contributed vital proportion in global trading on top of being the major trading partner to each other since 1960s. Nonetheless, we only consider the monthly frequency observations during the post-Bretton Wood era (1981M1-2005M6) to prevent the potential sticky price effect in fixed exchange rate regime and the uncertainties during the end-1970s oil shock. Since the classical univariate unit root tests have suffered from power deficiency in discerning the unit roots and near unit roots for small samples, the newly improved unit root tests allowing for endogenous (unknown) break(s) are

¹ Half-life refers to the number of years it takes for at least half of the deviation from PPP to be eliminated, following a monetary or real shock (e.g. productivity, technology) on real exchange rates. It is of less useful to know PPP holds in the long run, if the degree of mean reversion in the real exchange rate is infinitely long. Common wisdom dictated that half-lives for real exchange rates should be less than two years, for the PPP-hypothesis to be operationally relevant.

² In many world organizations including the IMF, World Bank, EAEA and the Penn World Databank, the cross-country comparison of productivity and living standards (i.e. GDP, per capital income and balance of payment position) are often based on the macroeconomic series that adjusted for PPP.

applied. This paper further distinguishes itself from previous studies by modeling the type of structural break to a single and two endogenous break point(s) in the linear form (Lumsdain and Papell, 1997) as well as the non-linear manner for smooth transition (Saikkonen and LÄutkepohl, 2002). A different insight or perspective may be gained by the application of different estimation strategy.

The rest of the paper is structure as follows. Section 2 presents the brief review of literature. Section 3 elaborates the methodology and data description, Section 4 discusses the empirical results whereas Section 5 provides our conclusion remarks.

2.0 Brief Review of Literature

Empirical studies of PPP for developed and developing countries have documented evidence both in favor of and against PPP. Research during the recent float using a variant of the Augmented-Dickey-Fuller (ADF) tests on univariate real exchange rate time series for industrial countries has rarely rejected the unit root null to support for PPP. Among others, see Roll (1979), Hakkio (1984), Edison (1985), Mark (1990). It has become clear that such tests possess low power against local alternatives. Hence, the results from earlier studies say more about the low power of the conventional unit root tests than about PPP (Froot and Rogoff, 1995; Papell, 2002). Likewise, empirical evidence from the developing Asian economies based on floating regime are at best, mixed (e.g. Bahmani-Oskooee, 1993; Aggarwal and Mougoue, 1996; Chinn, 2000). In addition, a few authors have studied the PPP condition in South Africa (Aron, *et al.*, 1997; Tsikata, 1998; Subramanian, 1998). Aron, *et al.* (1997) observe that the results are sensitive to the choice of price aggregates and sample period. Also, fluctuations in the real exchange rate can be explained by variations in trade liberalization, terms of trade, government expenditures, capital flows, and official reserves.

In response to the low power of the standard unit root tests with long half-lives, a number of researchers have progressed into three directions. First, univariate techniques have been applied to long-horizon real exchange rates spanning one to two centuries (Lothian and Taylor, 1996; Mollick, 1999, Taylor, 2002). Second, panel unit roots have been applied on the post-1973 or the post-Asia crisis series. Still, homogenous supports for mean reversion behavior of real exchange rates were not observed (e.g. Wu, 1996; Papell, 1997; O'Connell, 1998; Bahrumshah, Chan and Arggawal, 2007; Bahrumshah, Chan and Fountas, 2008). Third, the use of median-unbiased estimation (e.g., Murray and Papell, 2002) has somewhat produced short half-lives to support the PPP, which is contradicting the earlier survey findings by Rogoff (1996).

On the other hand, numerous authors have also highlighted the importance of structural breaks or regime change owing to oil shocks, emerge of European monetary system, currency and financial crises, in influencing the assessment of PPP relationship. For instance, if real exchange rates are subjected to structural breaks, then large and permanent devaluations of the currencies during a currency crisis will bias the test toward acceptance of the unit root hypothesis. Of all, Perron (1989) and Rappoport and Reichlin (1989) are among the first to consider the importance of structural breaks for the implementation and interpretation of unit root tests. Nevertheless, the Perron (1989) method of assuming the break date as exogenously determined and known *ex ante* has often been considered inappropriate. Zivot and Andrews (1992) later developed the single endogenous structural break test of unit root which was widely applied in the PPP studies. Lumsdaine and Papell

(1997) then further the work of Zivot and Andrews (1992) to allow for two endogenous breaks under the alternative hypothesis and additionally allow for breaks in the level and the trend. Series are generally interpreted as broken trend stationary if the null hypothesis of unit root is rejected in favor of the alternative of two breaks. Alternatively, Saikkonen and Lütkepohl (2002) and Lanne, *et al.*, (2002) develop endogenous break model which adds to the deterministic term shift functions of a general nonlinear form using GLS de-trending. The deterministic component is subtracted from the original series and then ADF tests are applied to the adjusted series. Unlike much of the literature that followed dealt with the case in which a break occurs during one period only, nonlinear break tests follow the reasoning logic that breaks occur over a number of periods and display smooth transition to a new level. The approach is extended to a situation of an unknown break date by Lanne *et al.* (2003).

3.0 Methodology

If we let s_t be the log spot rate, p_t^* and p_t be the log foreign and domestic price levels³ respectively, the real exchange rates, q_t (in logarithm) is defined by

$$q_t = s_t + p_t^* - p_t \quad (1)$$

The estimation of q_t is truly appropriate for testing PPP as it allows one to compute the half-life of a random disturbance to measure the degree of mean reversion. The common approach in investigating the speed of convergence to PPP employs the following linear autoregressive model of order one, AR (1),

$$q_t = \rho q_{t-1} + \varepsilon_t \quad (2)$$

where $0 < |\rho| < 1$ and ε_t is a white noise innovation. For annual data, the half-life of deviations from PPP (τ) is the number of years (or months, for monthly data) required for the initial deviation from the long-run level to dissipate by half (with no future shocks). Suppose the long-run PPP level ($E[q_t] = 0$) as the starting point q_0 with an initial shock $\delta > 0$. Then, from $\delta / 2 = |q_t| = |\rho|^\tau \delta$, the half-life is given by $\tau \equiv \ln(1/2) / \ln |\rho|$, where absolute value is introduced to allow oscillation⁴. In practice, the half-lives are estimated by

$$\hat{\tau} = \frac{\ln(1/2)}{\ln|\hat{\rho}|} \quad (3)$$

where $\hat{\rho}$ is an OLS estimator of ρ in (2). By construction, the speed of adjustment, or the half-life, does not depend on the initial level of real exchange rate q_0 or the size of deviations (δ) in the linear AR (1) model.

³ The price level is usually represented by the consumer price index (CPI), the wholesale price index (WPI), or the GDP deflator.

⁴ When ρ approaches unity, the speed of adjustment $\ln|\rho|$ approaches zero from the left, and half-life τ approaches infinity, implying the absence of convergence towards PPP.

Despite the adjustment process, evidence of long run PPP can be provided by a test of unit root in real exchange rates. A common test of unit root rely on the augmented Dickey-Fuller (ADF) regression which is given by

$$\Delta q_t = \mu + \beta t + \varphi_1 q_{t-1} + \sum_{i=1}^{k-1} \gamma_i \Delta q_{t-i} + \varepsilon_t \quad (4)$$

where Δq_t is the first difference of real exchange rate, k is the number of lagged q_{t-i} and ε_t is the error term. To be consistent with the PPP hypothesis, the q_t must exhibit mean reversion behavior devoid of a unit root. The φ_1 is thereby to be significantly less than 0 or otherwise, the real exchange follows random walk, implying that deviations from PPP are permanent.

The ADF test may be distorted, however, if a potential structural break (currency crises, oil shocks, Great Crash, etc.) in the real exchange series is simply ignored. [Lumsdaine and Papell \(1997, LP hereinafter\)](#) further the work of [Zivot and Andrews \(1992\)](#) to allow for two endogenous breaks under the alternative hypothesis and additionally allow for breaks in the level and the trend. LP uses a modified ADF test, which is specified as follows:

$$\Delta q_t = \mu + \beta t + \theta DU1_t + \gamma DT1_t + \varpi DU2_t + \psi DT2_t + \alpha q_{t-1} + \sum_{i=1}^k c_i \Delta q_{t-i} + \varepsilon_t \quad (5)$$

where two structural breaks are allowed for in both the time trend and the intercept which occur at T_{B1} and T_{B2} . The time breaks in the intercept are shown in equation (5) by $DU1t$ and $DU2t$, respectively, whereas the slope changes (or shifts in the trend) are represented by $DT1t$ and $DT2t$. $DU1_t = 1$ if $t > T_{B1}$ and otherwise zero; $DU2_t = 1$ if $t > T_{B2}$ and otherwise zero; $DT1t = t - T_{B1}$ if $t > T_{B1}$ and otherwise zero; and finally $DT2t = t - T_{B2}$ if $t > T_{B2}$ and otherwise zero.

In addition, [Saikkonen and Lütkepohl \(2002, SL hereinafter\)](#) put forward that structural breaks may occur over a number of periods and display smooth transition to a new level. Say, a level shift function, which is here denoted by a general nonlinear form $f_t(\theta)' \gamma$, is added to the deterministic term, μ_t of the data generating process. Hence, the model of

$$q_t = \mu_0 + \mu_1 t + f_t(\theta)' \gamma + v_t \quad (6)$$

is shown, where θ and γ are unknown parameters, whereas v_t are residual errors generated by an $AR(p)$ process with possible unit root. In this study, we consider the shift function based on the exponential distribution function which allows for a nonlinear gradual shift to a new level starting at time T_B ,

$$f_t(\theta) = \begin{cases} 0, & t < T_B \\ 1 - \exp\{-\theta(t - T_B + 1)\}, & t \geq T_B \end{cases} \quad (7)$$

In the shift term $f_t(\theta)' \gamma$, both θ and γ are scalar parameters. The first one is confined to the positive real line ($\theta > 0$), whereas the second one may assume any value. The SL test of model (6) is based on the estimation of the deterministic term first by a generalized least squares (GLS) de-trending procedure under the unit root null hypothesis and subtracting it from the original series. An ADF-type test is then performed on the adjusted series which also includes terms to correct for estimation errors in the parameters of the deterministic part. The asymptotic null distribution is nonstandard and critical values are tabulated in [Lanne et al. \(2002\)](#).

4.0 Empirical Discussion

Table 1 shows the LP results and reported endogenous breaks at end-1985 and mid-1994 (see Figure 1 for graphical view). The first break is due to the Plaza Accord 1985⁵ that resulted in the appreciation of Japanese Yen against the US Dollar. The second break was corresponding to the Chinese Yuan pegged to the US Dollar that followed by the further appreciation of Japanese yen which later peaked in April 1995. The optimal lag length ($k=5$) is determined by the general to specific method suggested by [Ng and Perron \(1995\)](#), and we assume that $k_{\max} = 8$ as recommended by [Lumsdain and Papell \(1997\)](#) and [Ben-David et al \(2003\)](#). In other words, we started with $k=8$ and reduce stepwise the number of lags and choose the LP model with lag length where the last lag of the first differences is significant at the 10% or lower. This is reasonable given that our sample of study only covers the post-Bretton Wood era without the oil shock impact during the end-1970s.

Except for ϖ , the reported t statistics for θ , γ and ψ (see Table 1) are significant in majority of cases, suggesting that the estimated structural break dates are indeed significant and ‘not just included’ in the model. However, the estimated α values are less than critical values for both cases with and without trend, thus failing to reject the null hypothesis of unit root. The LP results indicate the absence of mean reversion behaviors in the Yen/US\$ real exchange series when linear level shifts are allowed. If this is true, then the deviations from PPP are permanent and the puzzle remains unsolved.

However, it is well noted lately that unit root tests might be biased by the presence of nonlinearities in the deterministic components. The alternative approach that captures the structural breaks with a smoother functional form for the transition period could be more informative. We estimate the SL test with the optimal lag length ($k=1$) being determined by the standard Akaike Info Criterion (see Table 2). The estimated coefficients of $dx(-1)$ stands for Δq_{t-1} ; $d(\text{const})$ stands for $Z_1 = [1, 0, \dots, 0]'$, the regressor for initial estimation of the constant; $d(\text{trend})$ stands for $Z_2 = [1, 1, \dots, 1]'$, the regressor for initial estimation of the trend; and $d(\text{shift})$ stands for $Z_3 = [f_1(\theta) : \Delta f_2(\theta) : \dots : \Delta f_T(\theta)]'$, the regressor for initial estimation of the exponential shift parameter γ . In both estimations with and without trend, the exponential shift parameters are highly significant to capture the nonlinear shift date at end-1985. This is consistent with the LP break date and the impact of Plaza Accord on Japanese exchange rate regime is confirmed. Moreover, the SL test without trend is able to reject the null hypothesis of unit root at 5% significant level, which provides sufficient supports for

⁵ The Plaza Accord was an agreement signed on September 22, 1985 at the Plaza Hotel in New York by 5 nations, namely the US, UK, Japan, France and West Germany. The five agreed to depreciate the US dollar in relation to the Japanese Yen and German Deutsche Mark by intervening in the currency markets.

non-linear adjustment of real exchange towards long run PPP. Such finding is supported, partly, by [Liew *et al.* \(2004\)](#) who found strong evidence of nonlinear behavior of Japanese Yen as well as US dollar based real exchange in the Asian region. The graphical representation of the exponential shift in real Yen/US\$ is further shown in Figure 2.

We then proceed to the half-life estimation to gauge the degree of mean reversion for real Yen/US\$ (see Table 3) in sub-samples. The exchange rate misalignment is less evident after 1985 and, stronger evidence for PPP is found in the post-1994 period as supported by the small persistence of real exchange deviations (half-life less than a year). This is consistent with [Bahrumshah, Chan and Fountas \(2008\)](#) who found higher degree of mean reversion among the Japan and selected Asian real exchange rates after the 1998 crisis.

5.0 Conclusion

Our study shows that stationarity test with linearity break is not sufficient to gauge the mean reversion behavior of the Yen/US\$ real exchange rates. Unit root is rejected, however, when exponential shift is allowed. In addition, the Plaza Accord, rather than the Japanese asset bubble or the 1998 Asia crisis, is more profound and appeared as significant shift in the Yen/US\$ real exchange property during the post-Bretton era. In a nutshell, the finding reveals that the Japanese authority has shown some form of PPP-oriented rule as a basis for their exchange rate policy. Misalignment of Yen/US\$ is temporal and can be corrected by appropriate policy responses. Emerging theoretical models, which suggest that exchange rate deviation may be governed by nonlinear factors, support our reasoning (e.g. [Dumas, 1992](#)).

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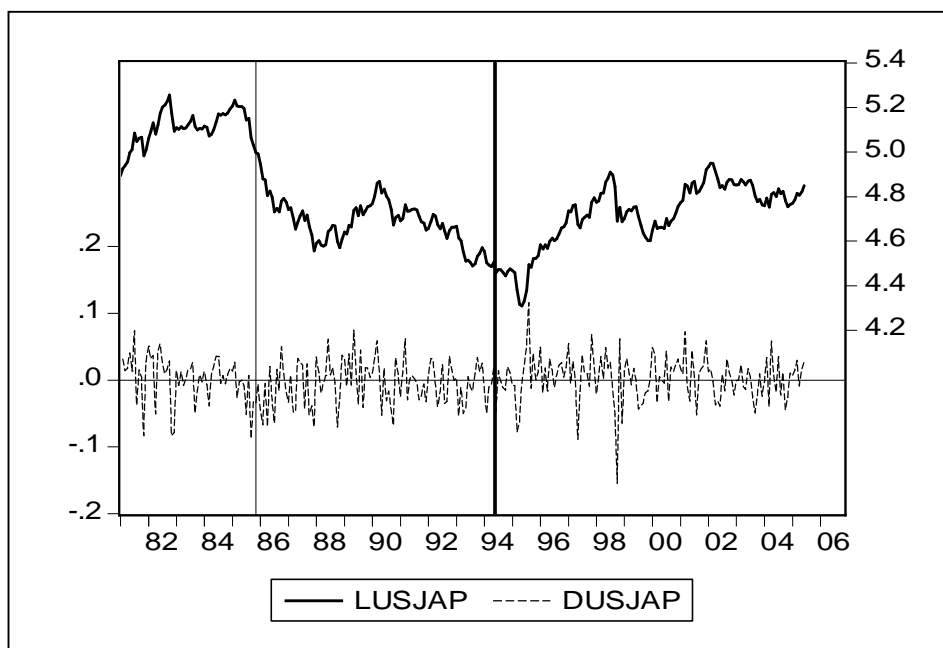
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Figure 1: The Japanese Yen /US\$ and Endogenous Breaks, 1981M1-2005M6



Notes: The two endogenously determined times of structural break (T_{B1} and T_{B2}) are shown above with solid lines.

Table 1: The LP Test on Yen/US\$ with Two Endogenous Breaks

	Breaks	Lag	θ	γ	ϖ	ψ	α
with trend	1985M11 1994M5	5	-2.185 (-2.076)	1.602 (4.445)	-0.010 (-1.019)	-0.010 (-2.149)	-5.475
without trend	1985M11 1994M6	5	1.038 (2.803)	1.602 (4.544)	-0.010 (-1.044)	-0.009 (-2.125)	-5.501

Notes: Critical values for α are -7.34(1%), -7.02(2.5%), -6.82(5%) and -6.49(10%) respectively. The t-statistics are reported in the parentheses.

Table 2: SL Test on Yen/US\$ with Exponential Shift

	Break	Lag	SL Statistic	Coefficients			
				d(const)	d(trend)	d(shift)	dx(-1)
with trend	1985M11	1	-2.36	132.92 (542.68)	0.17 (0.04)	-53.90 (-231.31)	0.07 (1.25)
without trend	1985M11	1	-3.020	133.07 (544.22)	-	-48.73 (-209.49)	0.07 (1.27)

Critical Values for SL Statistic			
	1%	5%	10%
with trend	-3.55	-3.03	-2.76
without trend	-3.48	-2.88	-2.58

Notes: Critical values are sourced from [Lanne et al. \(2002\)](#). Presented in the parentheses are t-statistics of respective coefficients.

Figure 2: Graphical Representation of SL Test, with and without Trend

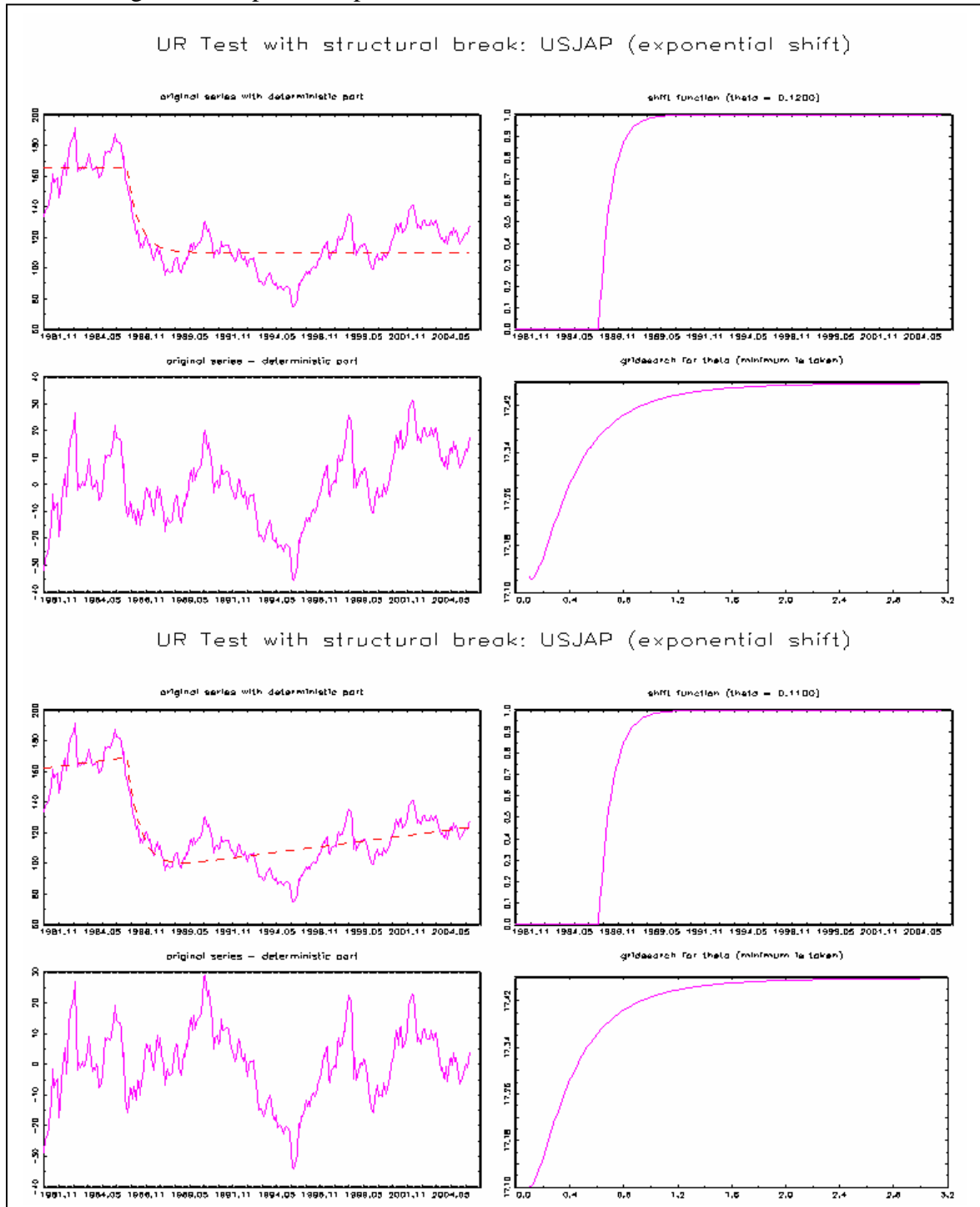


Table 3: Half-Life Estimation

	ρ	S_E	τ	CI
1981M1-2005M6	-0.0173	0.0097	39.7	[0.00, 83.84]
1981M1-1985M11	-0.0477	0.0226	14.2	[0.66, 27.70]
1985M12-1994M6	-0.1010	0.0318	6.5	[2.27, 10.75]
1994M7-2005M6	-0.1619	0.0610	3.9	[0.76, 7.09]

Notes: S_E represents the standard errors of estimated ρ , and τ denotes the estimated monthly half-life with CI being the corresponding 95% confidence intervals.