The stationarity of Asian real exchange rates for 1984–2007: An empirical application of stepwise multiple testing to nonstationary panels with a structural break

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ABSTRACT

This paper investigates the stationarity of real exchange rates against the US dollar for ten Asian countries during the period of 1984Q1–2007Q4 by using two types of testing methods. First, to understand explicitly the different impacts of the Asian financial crisis in 1997–98 on their respective currencies, the unit root test for dependent panels is applied. This test allows that various structural breaks can occur at unknown time periods across countries. Next, this paper employs Romano and Wolf's (2005) stepwise multiple testing method to identify which country holds the PPP, i.e., the real exchange rate stationarity among them. This testing strategy controls the multiplicity problem that occurs when testing the multiple hypotheses simultaneously. Finally, the results show that the stationarity hypothesis of the real exchange rate can be significantly supported for some Asian countries.

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I. Introduction

The choice of exchange rate regime and anchor currency is a troublesome problem that the East Asian countries confronted. The experiences of the Asian currency crisis in 1997-98, the sub-prime mortgage problem since 2007, and the Lehman shock on September 15, 2008 require them to rethink three questions. First question is whether the officially declared or de facto dollar-peg regime is appropriate when they have a strong relationship with the United States and the other countries like EU members, India or Russia with viewpoint of trades and capital flows. Second question is how to solve the coordination failure pointed out by Ogawa and Ito (2002) under the well-developed financial market. One of the break-through can be found in case of the announcement of the Chinese authority on July 21, 2005, i.e., changing from de facto dollar-peg to a managed floating with a basket currency. Third question is which exchange rate regime and which anchor currency can be commonly accepted among them. Thus, we have to verify whether the PPP (Purchasing Power Parity) hypothesis holds under the existing regimes and the recent above-mentioned events.

Sarno and Taylor (2002) pointed out that the empirical evidence from the unit root literature on the PPP hypothesis is inconclusive. However, it is commonly accepted that the failure of rejecting the unit root hypothesis of real exchange rates does not necessarily mean the acceptance of this null hypothesis, which may be due to the lack of power of tests. Thus, many existing papers sought to find the solution to increase the power, by using the longer time series or the panel data.[1] As a result, Taylor (2009)

[1] Frankel and Rose (1996), Oh (1996), Papell (1998), and Taylor and Sarno (1998) are the examples of the first application study.

summarized that the recent empirical findings provide generally strong and robust support for the long-run PPP regardless of variety of exchange rates and sample periods.

On the contrary, if we focus on the evidence for the PPP hypothesis in Asian countries, it is still inconclusive, which may be brought about by the impacts of the financial crisis in 1997-98. According to Figure 1, we can observe apparent discontinuities of ten Asian real exchange rate series. The Asian financial crisis seems to have had heterogeneous impacts on these countries through different path with different time lag.

To cope with this discontinuous paths of the series, Liew *et al.* (2004) and Zhou (2008) used the non-linear approach while Wu *et al.* (2004) and Hooi and Smyth (2005) applied the panel unit root tests with one and two structural breaks. According to their results, the evidence for the PPP hypothesis in Asian countries cannot be found out consistently. In the light of this fact, this paper reinvestigates the stationarity of real exchange rates against the US dollar for ten Asian countries during the recent period by applying the panel unit root test under the existence of structural changes at various unknown time periods across countries.

Taylor (2009) pointed out that the evidence in favor of PPP is sensitive to the choice of the base currency, which may need to re-examine the PPP hypothesis by changing the anchor currencies. However, up to now, it is evident that almost all Asian countries have adopted officially or de-facto dollar-peg. Thus, another purpose of this paper is to identify which country satisfies the PPP hypothesis under the dollar-peg regime by coping with recent radical changes. As used by Hanck (2009), the stepwise multiple testing method invented by Romano and Wolf (2005) is applied for this purpose, but the method is extended here to consider the unknown structural breaks in each series being tested.

The rest of this paper is organized as follows: Section 2 refers to the panel unit root test with a break. The identification of stationary series based on multiple testing procedures is described in section 3. The data set, the individual and panel unit root test, and the multiple testing procedures are empirically presented and these results are commented in section 4. Finally, some conclusions are drawn.

II. Panel Unit Root Test with a Break

Matsuki and Usami (2009) have extended Maddala and Wu's (1999) panel-based unit root test to that permitting multiple level shifts in a series at unknown dates which are different for each cross-sectional unit.[2] They have assumed that the series y_{it} is generated by the following data generating process (DGP) under the null (Eq. (1)) and the alternative (Eq. (2)) hypotheses.

$$y_{it} = \alpha_i + y_{it-1} + \varepsilon_{it} \tag{1}$$

$$y_{it} = \alpha_i^{'} + \beta_i t + \rho_i y_{it-1} + d_{it} + \varepsilon_{it}, \quad |\rho_i| < 1 \tag{2}$$

$$i = 1, \ldots, N, \quad t = 1, \ldots, T$$

where ε_{it} is independently and identically distributed across i and t with a zero mean and a finite variance. d_{it} denotes a variable of break. This paper makes a particular assumption about two types of shifts: $d_{it} = \delta_i^l DU_{it}$ and $\delta_i^s DT_{it}$ represent a

[2] Maddala and Wu (1999) do not allow for a structural break because they simply apply Fisher's (1932) p-value combination method to N augmented Dickey-Fuller t-tests.

shift in level and in slope in a series, respectively, where δ_i^l and δ_i^s are the parameters of the break variables; $DU_{it} = 1$ for $t > \tau_i T$ or zero otherwise, and $DT_{it} = t - \tau_i T$ for $t > \tau_i T$ or zero otherwise, where τ_i denotes the fraction of a break defined as $\tau_i = TB_i / T$ for all T, in which $0 < \tau_i < 1$, where TB_i denotes the date of a break.[3] The regression model nests the DGPs (1) and (2) as follows:

$$\Delta y_{it} = \hat{\alpha}_i + \hat{\beta}_i t + \hat{\phi}_i y_{it-1} + d_{it} + \sum_{l=1}^{\bar{l}_i} \hat{a}_{il} \Delta y_{it-l} + error \quad (3)$$

where $\Delta y_{it} = y_{it} - y_{it-1}$ and $\hat{\phi}_i = \hat{\rho}_i - 1$. $\bar{l}_i$ denotes a lag order parameter and is specified by following the 'general-to-specific' procedure suggested in Ng and Perron (1995).[4] Let t_i denote the *t*-statistic for the parameter $\hat{\phi}_i$ in Eq. (3). As employed in Zivot and Andrews (1992), the break date TB_i is endogenously determined at the point where the left-hand sided t_i-statistic is minimized in sequential estimations over all possible break dates within the range $0 < \tau_i < 1$.

Next, following Fisher's sum of log *p*-values combination approach, the panel-based unit root test is defined as follows:

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[3] For the purpose of formulating the effects of the Asian currency crisis occurred in 1997-98 on the time path of the real exchange rate series, only one-time shift in the level and/or the slope in the trend function of the series is considered here under the stationarity alternative model (2), though Matsuki and Usami (2009) permit up to two time shifts in their model.

[4] Beginning with $\bar{l}_i = 8$, the value of $\bar{l}_i$ is reduced one by one until $\hat{a}_{i\bar{l}}$ is estimated to be different from zero at the 10% significance level.

$$Fisher\_B = -2\sum_{i=1}^{N} \log p_i \qquad (4)$$

where p_i denotes a *p*-value associated with the minimum value of t_i-test. The null and alternative hypotheses of this test are specified as $H_0: \ \rho_i = 1$ and $\delta_i^j = 0$ ($j = l, s$) for all i and $H_1: \ \rho_i < 1$ and $\delta_i^j \neq 0$ ($j = l, s$) for some i, respectively.

If the t_i-test statistics are independent across cross-sectional unit i, the Fisher_B test statistic defined in Eq. (4) has a chi-square distribution with 2*N* degrees of freedom. However, it no longer follows a chi-square distribution if the t-statistics or the corresponding p-values are mutually correlated.[5] Such correlation among t-statistics or p-values principally stems from the presence of the cross-sectional dependence among error terms in DGP. Bai and Ng (2004), Moon and Perron (2004), and Pesaran (2007) have formulated this dependence structure by using unobservable common factors. Taylor and Sarno (1998), O'connel (1998), Wu and Wu (2001), and Breitung and Das (2005) have assumed the contemporaneous correlation structure among errors. This paper focuses on the presence of the cross-sectional dependence among error terms and adopts the latter type of formulations of the dependent structure in panels. By using the bootstrap sample obtained by Hanck's (2009) resampling scheme, the empirical distribution of the Fisher_B test is generated through simulation.[6] The appropriate

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[5] The sample correlation matrix of the series shows non-zero coefficients for almost all pairs of countries.

[6] Hanck (2009) has first estimated the AR coefficient vectors of the first-differenced series, then, calculated the residuals from the AR model. To preserve cross-sectional dependent structure between the residuals, Hanck follows Maddala and Wu (1999) or

small-sample critical values for the test can be obtained from the distribution, which will be shown in Table 4.

III. Identification of Stationary Series based on Multiple Testing Procedure

When the panel unit root test shown in Eq. (4) suggests the significant rejection of the null hypothesis that all N series follow a unit root process, it is possible to identify which series hold the stationarity among all of them. For this purpose, this section employs Romano and Wolf's (2005) resampling-based multiple testing method. Their method (studentized StepM) controls the familywise error rate, which is defined as the probability of erroneously rejected at least one null hypothesis in the whole test. [7][8]

Wu and Wu (2001) resampling strategy.

[7] There are many other multiple testing procedures controlling familywise error rate at a pre-specified significance level α (e.g. 5 or 10%) such as Bonferroni and Holm (1979) for the independent panels and Simes (1986) for the dependent panels. Benjamini and Hochberg's (1995) method is a stepwise testing procedure under the multiple null hypotheses, to control the false discovery rate (Benjamini and Hochberg, 1995, p.291), which is the expected proportion of erroneously rejected null hypotheses among all rejected ones. Hochberg and Tamhane (1987) and Tamhane (1996) provide comprehensive surveys on multiple testing methods and related topics.

[8] Ng (2008) suggested a new method to determine the ratio of I (0) to I (1) in mixed panels, based on the existence of a time trend in variance of nonstationary series. However, this method does not allow for the presence of a break in the series.

This section investigates which country can significantly reject the null hypothesis among ten countries. If some significant rejections of the null hypothesis are obtained by this procedure, the real exchange rate series corresponding to the rejected hypotheses can be considered to be stationary. (Moreover, this stationarity of the series supports the PPP hypothesis among the countries corresponding to the rejected hypotheses.)

Romano and Wolf's stepwise testing method assumes the following individual hypothesis of interest to test which hypotheses can be supported.

$H_0:\ \rho_i = 1$ and $\delta_i^j = 0$ $(j = l, s)$

$H_1:\ \rho_i < 1$ and $\delta_i^j \neq 0$ $(j = l, s)$ for $i = 1, \ldots, N$

The test statistics is $t_i = T\hat{\phi} / \hat{s}_i = T(\hat{\rho}_i - 1) / \hat{s}_i$, where $\hat{s}_i$ is the estimated standard error of ϕ_i.

Let $t_{(1)} \leq t_{(2)} \leq \cdots \leq t_{(N)}$ be the ordered t-values of $(t_1, t_2, \ldots, t_N)$ and correspond to the null hypotheses $H_{(1)}, H_{(2)}, \ldots, H_{(N)}$, respectively. In this case, $t_{(1)}$ corresponds to the smallest t-value and $t_{(N)}$ corresponds to the largest one. Then, construct a rectangular joint confidence region for the vector $(\rho_{r_1}, \ldots, \rho_{r_N})'$ with nominal joint coverage probability $1-\alpha$. The joint confidence region is given by

$$(-\infty,\ \hat{\rho}_{r_1} + \hat{s}_{r_1} \cdot \hat{d}_1] \times \cdots \times (-\infty,\ \hat{\rho}_{r_N} + \hat{s}_{r_N} \cdot \hat{d}_1],$$

where $\hat{d}_1$ is defined as

$$\hat{d}_j \equiv d_j(1-\alpha, \hat{P}) = \inf\left\{ x : \Pr_{\hat{P}}\left\{ \max_{R_{j-1}+1 \leq s \leq N} (\hat{\rho}_{r_s} - \rho_{r_s}) / \hat{s}_{r_s} \leq x \right\} \geq 1-\alpha \right\}.$$ [9]

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[9] As shown in the proof of Theorem 3.1 in Romano and Wolf (2005), the usual t-statistic $t_i = T(\hat{\rho}_i - 1) / \hat{s}_i$ can be utilized here to construct a joint confidence region.

Where $\hat{P}$ is the estimated probability mechanism based on the data. The testing procedure is as follows: in the first step, we set $j=1$ and $R_0 = 0$. For $R_{j-1}+1 \le s \le N$, if $0 \notin (-\infty, \hat{\rho}_{rs} + \hat{s}_{rs} \cdot \hat{d}_j]$, the r_Sth unit root null hypothesis $H_{(r_S)}$ will be rejected. Then, let $j = j+1$, for $R_{j-1}+1 \le s \le N$ the same step repeats. If no hypothesis is rejected, this step stops. $\hat{d}_j$ is determined by bootstrap method explained in Algorithm 4.2 in Romano and Wolf (2005).

IV. Empirical Analysis

IV-1. Data

The real exchange rate q_t is constructed by $q_t = s_t + p_t^* - p_t$, where s_t is the bilateral nominal exchange rate, and p_t^* and p_t are the foreign and domestic price levels, respectively. This paper uses the US dollar as the base currency in calculation of the bilateral real exchange rate. Accordingly, s_t is the nominal exchange rate based on the US dollar, p_t^* is the consumer price index (CPI) in the US market, and then p_t is the CPI in the domestic market for ten Asian countries.

Except for Taiwan and China, quarterly CPIs and end-of-period bilateral nominal exchange rates during the period from 1984Q1 to 2007Q4 are obtained from IFS online database. The Taiwanese CPI and nominal exchange rate series are obtained from the government's web site of the National Statistics, Republic of China, while the Chinese two series are collected from Monthly Bulletin of Statistics-China. Both data sources report monthly data over the sample period; thus, we constructed the quarterly series from the monthly series by taking simple averages of the monthly data over each quarter.

All the series used in this study are taken in natural logarithms.

IV-2. Individual Unit Root Tests and Panel Unit Root Test

We first conduct single unit root tests, which are the augmented Dickey-Fuller (hereafter, ADF) test and Zivot and Andrews (1992) (hereafter, ZA) test, to the real exchange rate series for each country. The results of ADF test and ZA test are shown in Tables 1 and 2, respectively. ADF test results suggest the stationarity around a mean or a time trend for three or two out of the ten series. On the contrary, ZA test results, where the regression equation with only one-time shift is employed, indicate that the maximum number of rejected series is six, which means that these real exchange rate series have the mean- or trend-reverting property.

As shown in Table 3, the panel-based unit root test is applied to the series. The evidence for the stationary real exchange rates is still found. From Tables 1-3, in general, not only individual but also panel tests show the consistent results in support of the stationary real exchange rates even if some different formulations are executed in a regression equation (e.g. with or without break variable, the types of a break, and with or without a constant term and/or trend). For example, when the regression equation has only a constant term, the test with no break (ADF test) show that the stationarity of the real exchange rates is supported by the results of both the individual test and panel test. The test with one break (ZA test) suggest that the evidence in favor of the stationary real exchange rates in case of the individual test and whole test with the level-shift in the regression having a constant or both a constant and time trend and with the level and slope-shift in the regression having a constant.

IV-3. Multiple Testing Procedure

As shown in Table 5, some countries seem to have a level or trend stationary real exchange rate. In the case of one level break, six out of ten series turn out to be stationary for the regression with a constant. At the same case for the regression with a constant and time trend, two out of ten series hold the stationarity. In both regressions, the procedure consistently rejects the null hypotheses for Malaysia and Thailand. In the slope break case, the Japanese exchange rate is significantly rejected for the constant and trend case.[10]

V. Conclusion

This paper investigated the PPP, i.e., stationarity of the real exchange rates against the US dollar for ten Asian countries. Firstly, the individual unit root tests with or without a break can significantly reject the unit root null hypothesis for some countries. Secondly, the panel unit root test allowing for one break shows the consistent test results with those of individual test.

Moreover, the resampling-based multiple testing method proposed by Romano and Wolf (2005) is employed to identify exactly the stationary series among the underlying

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[10] We also apply Benjamini and Hochberg (1995) procedure to the cases of no break and one break; however, a few significant rejections of the null can be observed in only a few cases. This may be due to the lack of power of this procedure because it is conservative in the sense that it does not necessarily reach the predetermined bound of the false discovery rate.

ten countries by controlling the familywise error rate. This method is very appropriate to understand explicitly the different impacts of the Asian financial crisis in 1997–98 on their respective currencies because of allowing that various structural breaks can occur at unknown time periods across countries. The stationarity for the real exchange rates against the US dollar can be found consistently for six out of ten countries.

Finally, this paper finds out that more than half of Asian countries hold PPP even if the recent financial crisis is considered. This result is consistent with the recent empirical findings providing strong and robust support of long-run PPP.

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Figure 1. Real exchange rates of Asian countires

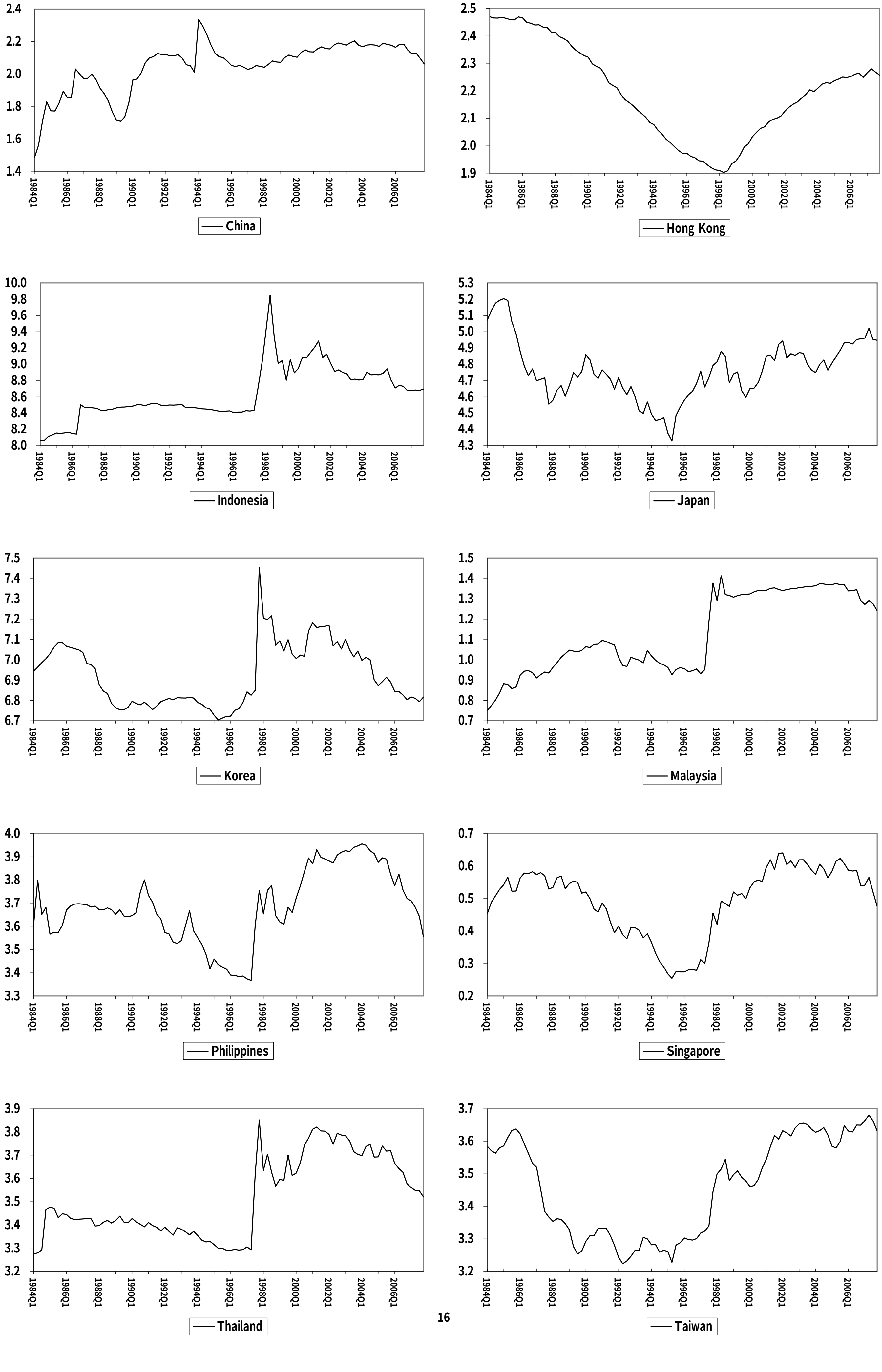

Table 1. The ADF test results for the real exchange rate series for each country

Country	Regression Equation			
	constant		constant & time trend	
China	-3.903	***	-3.652	**
Hong Kong	-3.044	**	-2.868	
Indonesia	-2.000		-1.953	
Japan	-3.090	**	-3.386	*
Korea	-2.085		-2.098	
Malaysia	-1.913		-1.782	
Philippines	-1.704		-1.565	
Singapore	-2.006		-2.133	
Thailand	-1.943		-1.834	
Taiwan	-1.455		-2.669	

***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The per cent points of the distribution of the test statistic are from Fuller (1996, Table 10.A.2).

Table 2. The minimum t-test results for the real excahge rate series for each country

Type of Break	Country	Regression Equation					
		constant			constant & time trend		
		t		break date	*t*		break date
Level	China	-5.736	***	1989Q3	-5.151	*	1989Q3
	Hong Kong	-3.544		1987Q3	-4.742		1998Q3
	Indonesia	-4.799	**	1997Q2	-4.355		1997Q2
	Japan	-4.518	*	1999Q3	-4.856		1990Q2
	Korea	-2.727		1997Q3	-5.415	**	1997Q2
	Malaysia	-7.073	***	1997Q2	-6.152	***	1997Q2
	Philippines	-2.955		1997Q2	-3.530		1997Q2
	Singapore	-2.588		1999Q4	-4.882	*	1997Q2
	Thailand	-5.404	***	1997Q2	-6.788	***	1997Q2
	Taiwan	-4.888	**	1997Q2	-4.868	*	1997Q2
Slope	China	-3.825		1988Q2	-4.093		2005Q2
	Hong Kong	-3.026		1995Q4	-4.484		1996Q4
	Indonesia	-1.978		2006Q3	-2.861		2001Q1
	Japan	-4.067	*	1995Q2	-4.930	*	1994Q2
	Korea	-2.170		2003Q4	-2.477		1988Q1
	Malaysia	-1.981		1992Q1	-2.277		2005Q1
	Philippines	-1.604		2005Q3	-1.983		2005Q3
	Singapore	-2.243		1994Q1	-2.150		1993Q3
	Thailand	-1.990		1994Q4	-2.332		2002Q3
	Taiwan	-3.172		1993Q4	-4.031		1987Q2

***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The test here is conducted based on the corresponding per cent points on the left tail of the finite sample distribution of the test statistic, which are obtained from a Monte Carlo simulation with 96 observations based on 50000 replications. When the regression equation has both a constant term and a linear time trend, the 1, 5, and 10 per cent points are -5.769, -5.170, and -4.866 for a level shift, and -5.562, -4.949, and -4.635 for a slope shift, respectively. When the regression equation has only a constant term, they are -5.166, -4.613, and -4.304 for a level shift, and -4.864, -4.234, and -3.905 for a slope shift, respectively. The left tail percentages of the limiting distribution of the test statistic as $T \rightarrow \infty$ are given by Zivot and Andrews (1992, Tables 2 and 3).

Table 3. The results of the panel unit root tests[a]

Regression Equation	MW test (No Break)		Fisher_B test	
			level	slope
constant	46.611	***	48.258 ***	20.469
constant & trend	27.182		41.476 **	18.238

***, **, and * denote statistical significance at the 1%, 5%, and 10% levels,

[a] In the case of cross-sectionally dependent errors in the DGP, the critical values of the MW test and the Fisher_B test are tabulated in Table 4.

Table 4. The critical values of the Maddala and Wu (1999) test and the Fisher_B test in the case of cross-sectionally dependent errors

Test		Regression Model	10%	5%	1%
MW test		constant	29.944	33.201	40.824
		constant & trend	29.784	33.032	41.508
Fisher_B test	Level	constant	29.451	33.776	40.785
		constant & trend	29.432	33.155	41.575
	Slope	constant	29.599	33.081	40.962
		constant & trend	29.672	33.321	40.349

Table 5. The results of multiple test

Type of Break	Country	Regression Equation			
		constant		constant & time trend	
		p-value[a]	Studentized StepM	p-value[a]	Studentized StepM
No break	China	0.001	*	0.014	*
	Hong Kong	0.031	*	0.213	
	Indonesia	0.261		0.597	
	Japan	0.022	*	0.038	*
	Korea	0.176		0.491	
	Malaysia	0.254		0.641	
	Philippines	0.365		0.752	
	Singapore	0.250		0.501	
	Thailand	0.238		0.646	
	Taiwan	0.535		0.248	
One break					
Level	China	0.028	*	0.194	
	Hong Kong	0.288		0.107	
	Indonesia	0.072	*	0.363	
	Japan	0.021	*	0.037	
	Korea	0.734		0.372	
	Malaysia	0.006	*	0.057	*
	Philippines	0.616		0.653	
	Singapore	0.786		0.065	
	Thailand	0.045	*	0.036	*
	Taiwan	0.030	*	0.111	
Slope	China	0.039		0.162	
	Hong Kong	0.457		0.195	
	Indonesia	0.817		0.801	
	Japan	0.030		0.021	*
	Korea	0.735		0.929	
	Malaysia	0.793		0.962	
	Philippines	0.940		0.994	
	Singapore	0.713		0.989	
	Thailand	0.810		0.958	
	Taiwan	0.264		0.245	

* denotes statistical significance at the 5% level in terms of the familywise error rate.

[a] The p-values are calculated from the finite sample distribution of the test statistic obtained from a Monte Carlo simulation with 96 observations based on 5000 replications.