Random Walk and Martingale Difference Hypotheses for Pacific Basin Foreign Exchange Markets

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Abstract

This paper examines the random walk (RW) and the martingale difference sequence (MDS) processes for the Australian dollar and seven Asian currencies relative to three benchmark currencies between 1993 and 2008. We use Wright's (2000) non-parametric variance ratio test for the RW and Kuan and Lee's (2004) test for the MDS. The results show that (i) the hypotheses of RW and MDS are rejected for all eight currencies for the entire study period as well as for the sub-period leading up to the Asian financial crisis in 1997; (ii) for the sub-period following the Asian crisis, only the Australian dollar and Korean won behave as weak-form efficient while the six other Asian emerging currencies show no discernible improvement toward market efficiency; (iii) on balance, the rejection of random walk is more robust by Kuan and Lee's martingale test as compared to that by Wright's sign and rank variance ratio test.

JEL Classification: F31, G14

Keywords: Efficiency of foreign exchange markets; Random walk and martingale difference hypotheses, E emerging currency markets

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1. Introduction

Since Meese and Rogoff's (1983) seminal work on the predictability of the foreign exchange rate based on a random walk model, there has been a proliferation of economic and time series models in the literature which tried to beat the forecasting accuracy of the random walk model. However, as reported by Kilian and Taylor (2003) and Lee, Kim and Newbold (2004), the results of these competing models have been mixed in disproving Meese and Rogoff's finding that changes in exchange rates essentially follow a random walk. In fact, in the world of foreign exchange trading, both academics and practitioners have long embraced the attributes of trading models, such as "technical analysis," and "filter trading," which have purportedly yielded risk-adjusted excess profits in foreign exchange markets.[1]

There is one postulate common to these trading models that is antithesis to the efficient market hypothesis (EMH) relevant to foreign exchange markets: Traders not only can identify the intertemporal trends of an exchange movement but also exploit the time-varying movement of a currency against the trends for profitable trading by "technical" or "filter" rules.[2] While this postulate is being modified to incorporate a fresh theoretical paradigm that is consistent with the EMH,[3] it still remains an *ad hoc* proposition yet to be related to a standard model that is consistent with the rational expectation hypothesis upon which EMH is built.

There is strong evidence in the literature that changes in nominal exchange rates generally follow a random walk process or a Martingale difference sequence – the two patterns of currency movement analyzed under the two common names; the random walk hypothesis (RWH) or the martingale difference hypothesis (MDH). Under both hypotheses, markets are assumed at least weak-form efficient so that future movements of foreign exchange rate are unpredictable from past prices or publicly available information. Thus, it is not possible for currency traders to consistently beat the market by "technical" or "filter" rules except for one phenomenon unique to foreign exchange markets: Namely, opportunities associated with

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[1] See Neely, Weller and Ulrich (2007) for developed country currencies, and Lee, Gleason and Mathur (2001) and Martin (2001) for emerging country currencies.

[2] Time-varying movements of currency can be exploited by mechanical rules such as "moving average cross-over rules" or "filter rules" derived from an ARIMA or a Markov process. See Neely, Weller and Ulrich (2007) for their exhaustive evaluation of technical trading rules.

[3] One such attempt is the adaptive market hypothesis (AMH), proposed by Lo (2004) and expanded by Neely, Weller and Ulrich (2007). Under AMH, different groups of economic agents compete for profit in trading, and through competitive processes agents deplete existing trading opportunities but learn to create new trading opportunities. See Neely, Weller and Ulrich (2007) for detail.

interventions by monetary authorities that may or may not provide predictable moves in the exchange rates.

Variance ratio (VR) analysis has been most widely used in testing RWH and the empirical validity of the hypothesis is still debated in the foreign exchange literature. For instance, Fong, Koh and Ouliaris (1997), and Kilian and Taylor (2003) support RWH and Liu and He (1991) reject it, while Yilmaz (2003) and Lee, Kim and Newbold (2004) partially support RWH. It should be noted that all these studies, that employ VR models, use *parametric* VR models of the Lo and MacKinley (1989) or Chow and Denning (1993) variety, and that RWH is often erroneously rejected by these VR tests. (Lee, Kim and Newbold, 2004).

As discussed in Section 2, a simple random walk process is a special case of the martingale difference process. The martingale process has generally been tested using information contained in the second moments of a process, and the property of the martingale difference sequence is known as mean-independence or conditional-mean-independence. (Domingues and Labato (2003). In this sense, tests of MDH evaluate the empirical validity of the assumption implicit in the "technical" or "filter" rules that returns revert to their historical or time-varying means.

In this study, we use the *non-parametric* VR test of Wright (2000) and the martingale difference sequence test of Kuan and Lee (2004). Wright shows that his non-parametric rank and sign VR test is robust and statistically more powerful than the Lo and MacKinlay (1989) and Chow and Denning (1993) VR tests, especially when there are significant conditional heteroskedasticity and serial correlation in time series[4]. And Kuan and Lee demonstrate that their test is more powerful than several other tests of MDH, for their test is insensitive to the

[4] The main difference between the Lo-MacKinlay and Chow-Denning VR versions is that the former covers a single holding period while the latter simultaneously tests the equality of the VR to one over multiple holding periods. Hoque, Kim, and Pyun (2006) report that the two versions yield similar results.

assumption of conditional homoskedasticity and requires a weaker moment condition. It should be pointed out that previous studies of RWH focus on the least restrictive (weakest) form known as the RW-type III, which assumes that asset returns are linearly independent. By contrast, MDH for asset returns denies the presence of any linear or *non-linear* combinations of past asset returns that could improve their forecastability.

We examine the weak-form market efficiency of the Australian dollar and seven Asian emerging market currencies in terms of the three world reserve currencies: The U. S. dollar, the Japanese yen and the Euro during the period between 1993 and 2008. The seven Asian currencies are the Indonesian rupiah, the Malay ringgit, the Philippine peso, the Singapore dollar, the South Korean won, the Taiwanese dollar and the Thai baht. We analyze the sixteen year period with the Asian financial crisis in 1997 as a structural break point.

The motivations for our study are reinforced by the following considerations: First, in the aftermath of the Asian financial crisis in 1997, the seven Asian emerging economies, except Malaysia which issued a moratorium, implemented drastic reforms, which opened their capital accounts and changed their exchange rate regimes from de facto pegs to floating systems immediately after the Asian financial crisis in 1997.[5] Second, there has been significant changes in cross-border trade and investment in the Pacific-East Asia region, which was once dominated by the U. S. dollar. Recently, trade between the seven Asian countries and Japan has significantly increased, giving rise to a trading bloc dominated by the Japanese yen and to some

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[5]By most accounts, the exchange rate systems in these countries are still evolving within the broad framework of managed or independent float systems. The so called "managed floating" and "independent floating" regimes involve at least two key issues: (i) The optimal currency basket as the anchoring reference currency and (ii) the announced or unannounced band within which the basket currency value may be allowed to fluctuate. It appears that Singapore pursues a managed floating with a basket of currencies (See Ee, *et al.* (2003), and that Korea was under a managed floating regime until April 2002 but is now under "free floating" or "complete liberalized regimes. See Kim and Ryou (2001), Ryou (2001) and Eom, Hahn and Joo (2008) .

extent by the rapidly expanding trade and financial transactions with Australia (Bowman, 2006). It stands to reason that the efficiency of the seven Asian currencies is increasingly tied to the Japanese yen and Australian dollar, not only through trade but also through cross-currency transactions, which involve forward, futures and options contracts involving offshore transactions.[6] Third, the relative strength of the currencies of Australian and the seven Asian countries has been significantly altered by recent governments' actions aimed at the repositioning of their massive official reserves from U.S. dollar-denominated assets to euro-denominated assets. Fourth, there has been active and continuing discussion in official and academic circles regarding the integration of regional currencies in East Asia, like the euro for the European Union [Eichengreen and Park (2004) and Rana (2002)]. Successful integration of regional currencies requires statistical assessments of not only the relative efficiency of the individual currencies in the region but also the sustainability of government policies related to, and intervention in, foreign exchange markets.

The major findings of our study are: (i) the Wright and the Kuan-Lee non-parametric tests are useful tools for evaluating the two hypotheses under study; (ii) only the Australian dollar and the Korean won behave as a random walk and a martingale difference; and (iii) the other Asian emerging exchange markets have shown no discernible improvement toward weak-form efficiency in the post-Asian crisis. Corollary to these findings are that there are lessons to be learned from the foreign exchange policies of Australia, particularly with respect to its deliberate nurturing of the *onshore* non-deliverable forward (NDF) in the 1990's in contrast to

[6] Besides offshore non-deliverable forward markets for Asian currencies, the Chicago Mercantile Exchange offers futures and options trading for the Asian currencies. See (Ma, Ho and McCauley, 2004) and http://www.cme.com/trading/prd/fx

the *offshore* NDF of the Asian currencies that are active offshore due to their currency transaction restrictions.[7]

The remainder of this paper is organized as follows. Section 2 provides a brief review of the relevant literature. Section 3 discusses the data and Section 4 outlines the methodology. Section 5 presents the empirical findings. Section 6 concludes the paper.

2. Related Literature

The principal tools used for testing the efficiency of foreign exchange markets can be grouped into two categories. The first category is time series analysis of parity or alignment of exchange rates in models that include key macroeconomic variables like interest rates, prices and money supply. In this sense, market efficiency tests are tests of joint hypothesis related to market equilibrium price and additional analytical structure, that is contemporaneous to changes in the market price of the currency concerned (Lo (1997, pp. xix-xx). The second category includes time series examinations like the Lo and MacKinlay (1988) and the Chow and Denning (1993) VR tests, and the Kuan and Lee (2004) martingale difference hypothesis test based on moment conditions. This category also includes tests of unit root and cointegration, and ARIMA and GARCH processes.[8]

The seminal work of Meese and Rogoff (1983) examined three structural models (the flexible-price model, the sticky price monetary model and the sticky price asset model) and two time series models (univariate and vector autoregressive models) with no additional exogenous independent variables Kilian and Taylor (2003) analyze the random walk forecast of exchange

[7] See Debelle *et. al.* (2006) on the Australian experience.

[8] See, for example, Liu and He (1991), Urrutia (1992), Ajayi and Karemera (1996), and Lee, Pan and Liu (2001) for the Lo-MacKinlay VR test; Lima and Tabak (2005) for the bootstrap test; Cheung, Chin and Pascual (2005), and Kilian and Taylor (2003) for OLS and the exponential smooth transition autoregressive models, respectively; Baharumshah, Haw and Fountas (2005) for unit root tests; Jeon and Seo (2003) for cointegration tests; and Gau (2005) for periodic GARCH. Belaire-Franch and Opong (2005) also use the Wright procedure to test the behavior of the Euro against other major currencies.

rates by a nonlinear exponential smooth transition autoregressive model. It is a time series model testing the nominal exchange rate by a bootstrap test of the random walk hypothesis.

Lee, Kim and Newbold (2004) examines a simple random walk process of foreign exchange markets with a deterministic structural break for the Canadian dollar, German mark, Italian lira and Swiss franc. They show the importance of a structural break in its drift term, which can be analyzed by time series models usingt he standard VR analysis in comparison to the martingale hypothesis test: The rejection of the martingale hypothesis by the Lo-MacKiney (1989) VR test may be caused by ignoring the presence of structural breaks.

Eom, Hahn and Joo (2008) examine the effect of market liberalization as the key information efficiency variable in their analysis of autocorrelation of the U. S dollar price of the Korean won in the Korean foreign exchange market during a study period in which a significant shift took place when the countries' exchange rate systems shifted from a managed floating to an independent floating rate. They find the disappearance of autocorrelation as a result of the liberalization of Korean foreign exchange market, which they interpret as an improvement in the informational efficiency of the Korean won.

A simple random walk process is a special case of the martingale difference process Thus, if the exchange rate time series follows this process, we cannot predict the future exchange rate using publicly available information. The MDH has generally been tested using information contained in the second moments of a process; that is, using test statistics based on sample autocovariances for a time domain or periodgrams for a frequency domain. While the martingale process has been assumed as a common attribute in rational expectation models, testing the process has been challenging. In financial time series analysis, the common way of testing the process consists of testing that the process is uncorrelated in sample autocorrelations. In econometric study, the property of the martingale difference sequence is known as mean-independence or conditional mean independence. (Dmingues and Labato (2003).

This paper focuses on time series analysis of the exchange rates themselves with no additional exogenous independent variables. Two studies that address emerging Asian foreign exchange markets with additional analytical variables are noteworthy. Jeon and Seo (2003) examine the impact of the Asian financial crisis on the efficiency of foreign exchanges of Indonesia, Korea, Malaysia, and Thailand. Using unit root and cointegration procedures, they test market efficiency within-country and across-countries over the pre- and post-crisis periods. Their results are consistent with across-country efficiency in all four markets. Another study that allows for the role of additional exogenous independent variables is Gau (2005), who uses intraday market volatility as the information variable in his periodic GARCH-based examination of the calendar anomalies of the Taipei foreign exchange market. He reports intraday seasonality and calendar effects in this market.

The use of VR tests for studying the RWH in foreign exchange rates of emerging markets is relatively sparse as compared to the use of the same econometric tool for examining the behavior of emerging stock markets. As Hoque, Kim and Pyun (2007) report, out of eighteen articles published on the RWH in emerging stock markets, all but two studies use Lo-MacKinlay, Chow-Denning or Wright VR tests. One possible reason for the paucity of VR tests when studying the efficiency of foreign exchange markets (as opposed to stock markets) may lie in the fact that the two markets are fundamentally different in their structures and *modus operandi*. In stock markets, governments seldom intervene as buyers or sellers. In foreign exchange markets, not only do governments intervene directly, but they also possess policy tools to modulate demand and supply forces. In addition, official policy pronouncements could be quite different from what governments actually do in foreign exchange markets (Calvo and Mishkin, 2003). For example, an emerging economy may officially follow a floating regime but without being fully transparent on its precise policy targets or how the central bank intends to align its exchange value within the currency band.

Three recent papers employ VR tests to evaluate the behavior of foreign exchanges in emerging markets. Ajai and Karemera (1996) use the Lo-MacKinlay VR test to study the exchange rates of seven Asian emerging markets[9]. Their results reject the RWH. Using essentially the same testing procedure, Lee, Pan and Liu (2001) argue that many Asian and non-Asian currencies generally follow a random walk process. And on the basis of a bootstrap analysis, Lima and Tabak (2005) also report that several Asian and Latin American currencies are consistent with RWH. Results reported by Lee, Pan and Liu (2001) and Belaire-Franch and Opong (2005) suggest that contradictory evidence in the above studies on the random walk behavior of foreign exchange markets may be caused by using the traditional VR test, which is particularly sensitive to conditional heteroscedasticity. Belaire-Franch and Opong demonstrate that the Wright non-parametric VR test presents a significant improvement over traditional VR tests.

Prior research suggests that foreign exchange rates may exhibit non-linear dependence and thus violate a martingale sequence. Arising out of games of chance, the martingale hypothesis belongs to the earliest attempts to model financial asset prices. A stochastic process $\{x_t\}$ is a martingale if it satisfies:

$$E(x_{t+1} \mid x_t, x_{t-1}, \ldots) = x_t, \quad (1)$$

[9] The currencies are those of Hong Kong, Indonesia, Korea, Malaysia, Philippines, Taiwan and Thailand.

If x_t represents the log of an asset price, then its first difference (return) behaves according to a martingale difference process if:

$$E(\Delta x_{t+1} \mid x_t, x_{t-1}, ...) = 0 \tag{2}$$

where $E(x_t, x_{t-1}, ...)$ is an increasing sequence of information sets that contains the past information process. When assets returns follow a martingale difference process, the best forecast of tomorrow's return is simply today's return and there is no combination (whether linear or non-linear) of previous returns that could improve the forecasts of future returns. Clearly, the martingale difference hypothesis has strong implications for whether asset returns behave according to market efficiency in the weak sense, particularly when time series are analyzed with structural breaks (Lee, Kim and Newbold, 2004). Available evidence on this hypothesis in foreign exchange markets is largely mixed. For example, while Fong, Koh and Ouliaris (1997) and Dominguez and Lobato (2001) report supporting results in foreign exchange markets; Hong and Lee (2003) and Yilmaz (2003) do not.

3. Data and Summary Statistics

Our data are daily nominal exchange rates of the Australian dollar and seven Asian currencies relative to the U.S. dollar (USD), the Japanese yen (JPY) and the Euro from January 4, 1993 through December 31, 2008 (data source: http://fx.sauder.ubc.ca)[10]. The currencies under study are the Australian dollar (AUD), the Indonesian rupiah (IDR), the Malaysian ringgit (MYR), the Philippians peso (PHP) the Singapore dollar (SGD), the South Korean won (KRW), the Taiwanese dollar (TWD), and the Thai baht (THB). The number of daily observations of individual currencies under study is approximately 4033, with slight variations in the sample

[10] The date for Indonesia and the Philippines are from November 16, 2005 to December 2008.

numbers attributable to different days of market closing. The Hong Kong dollar is excluded from the study, as it is pegged to the U.S. dollar on a currency board regime. The Australian dollar is included because it is fast becoming a major trading currency in the region (Bowman, 2005).[11]

While the official exchange rate regimes of the eight countries under study are a matter of public record as documented in their official homepages and various IMF publications, the manner in which their exchange regimes are actually administered has often been quite different from their official pronouncements. The exchange regimes of the seven Asian emerging countries underwent significant structural changes following the Asian financial crisis in 1997. Thus, we divide our sample into two sub-samples: The first covers the period from January 1993 through November 1997 for all currencies (except for the Thai baht where its first sub-sample ends in June 1997)[12]; and the second sub-sample spans the period from December 1998 through December 2008 for all currencies (except for the Thai baht whose second sub-sample begins in July 1997). We perform tests for the full period as well as for the two sub-periods occasioned by the Asian financial crisis in 1997 as the structural break point.

Descriptive statistics for the daily exchange rates relative to the USD, Euro and JPY are reported in Table 1. The skewness of daily exchange rates for all currencies is positive when the USD and Euro are the base currency and negative for AUD, MYR, SGD, TWD and THB when JPY is the base currency. The positive skewness implies that the exchange rates are flatter to the right compared to the normal distribution. The kurtosis reported for each currency indicates that the distributions of the exchange rates have sharp peaks compared to the normal distribution. One general inference drawn from Table 1 is that the distributions of all currency series under

[11] For example, Kang and Wang (2002) report that for every 10 percent increase in the yen/dollar rate, Korea's export prices decline by 2.7 percent.
[12] The Thai baht effectively floated starting in July 1997.

study are not likely normal. In fact, Jarque-Bera's statistics suggest the presence of significant non-normality in the six exchange rates.

Insert Table 1 about here
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4. Methodology

4.1. The Wright Non-Parametric VR Test

Since Wright's procedure for testing the RWH improves over the traditional VR test of Lo and MacKinlay (1989), a brief discussion of both tests is in order.

The traditional VR test is based on the assumption that the variance of the random walk increments in a finite sample is linear in the sampling interval. It is derived from the assumption that if the natural logarithm of a time series x_t is a pure random walk, the variance of its *kth* difference grows proportionally with the difference *k*; that is, the variance of its *kth* difference variable would be *k* times the variance of its first difference. Therefore, if we obtain $n + 1$ observations x_0, x_1, x_2, x_3,……., x_n at equally spaced intervals, $1/k$ of the variance of x_t, x_{tq} is expected to be the same as the variance of x_t - x_{t-1}, for a time series characterized by a random walk. The variance ratio at lag *k*, VR (*k*), is defined as:

$$VR(k) = \frac{\sigma_k^2}{\sigma_1^2} \tag{3}$$

$$\sigma_1^2 = \frac{1}{nk-1}\sum_{t=1}^{nk}(x_t - x_{t-1} - \hat{\mu})^2 \tag{4}$$

$$\sigma_k^2 = \frac{1}{m}\sum_{t=k}^{nk}(x_t - x_{t-k} - k\hat{\mu})^2 \tag{5}$$

where $$\hat{\mu} = \frac{1}{nk}(x_{nk} - x_0) \tag{6}$$

and $$m = k(nk - k + 1)\left(1 - \frac{k}{nk}\right) \tag{7}$$

where x_0 and x_{nq} are the first and last observations in the series. Under the assumptions of homoskedasticity and heteroskedasticity, Lo and MacKinlay develop the following statistics for testing the null hypothesis of a random walk:

$$z_1(k) = \frac{(VR(k)-1)}{[\phi(k)]^{1/2}} \sim N(0,1) \text{, and} \tag{8}$$

$$z_2(k) = \frac{(VR(k)-1)}{[\phi^*(k)]^{1/2}} \sim N(0,1) \tag{9}$$

The above test is robust with respect to many forms of heteroskedasticity and non-normality of the stochastic disturbance term. Although this procedure is quite powerful in testing for homoskedastic or heteroskedastic *iid* nulls (Smith and Ryoo, 2003), it is important to note that the sampling distribution of the VR statistic can depart from normality in finite samples with considerable biases and right skewness. These finite sample deficiencies may result in serious size distortions and low empirical power, leading to erroneous inferences.

Wright (2000) overcomes these problems by transforming the traditional VR test to a non-parametric version, based on ranks and signs, which bypasses the asymptotic arguments when approximating sampling distributions. Wright demonstrates that the non-parametric VR test is more powerful than the traditional parametric VR test, particularly when the data are highly non-normal and/or non-stationary.

To derive the non-parametric VR statistic based on ranks, Wright substitutes two linear transformations of the rank of the variable in question with the time series used in the traditional Lo and MacKinlay test statistic. Let $r\ (p_t)$ be the rank of p_t among $p_1, p_2, \ldots, p_n$, where $r_{1t} = \dfrac{\left(r(p_t) - \dfrac{N+1}{2} \right)}{\sqrt{\dfrac{(N-1)(N+1)}{12}}}$, $r_{2t} = \dfrac{r(p_t)}{\lambda(N+1)}$, and λ is the standard normal cumulative distribution function. Substitute r_{1t} and r_{2t} in place of x_t in the Lo and MacKinlay tests statistics z_1 and z_2. Wright's rank statistics, R_1 (under homoskedasticity) and R_2 (under heteroskedasticity) are:

$$R_1 = \left(\frac{\frac{1}{Nk} \sum_{t=k+1}^{N} (r_{1t} + r_{1t-1} \ldots\ldots + r_{1t-k})^2}{\frac{1}{N} \sum_{t=1}^{N} r_{1t}^2} - 1 \right) \times \left(\frac{2(2k-1)(k-1)}{3kN} \right)^{-1/2} \tag{10}$$

$$R_2 = \left(\frac{\frac{1}{Nk} \sum_{t=k+1}^{N} (r_{2t} + r_{2t-1} \ldots\ldots + r_{2t-k})^2}{\frac{1}{N} \sum_{t=1}^{N} r_{2t}^2} - 1 \right) \times \left(\frac{2(2k-1)(k-1)}{3kN} \right)^{-1/2} . \tag{11}$$

Wright provides another non-parametric test using the signs of the series instead of the ranks, resulting in new statistics, S_1 and S_2. Specifically, for any series y_t, let $\omega(y_t, q) = 1(y_t > q) - 0.5$. Thus, $\omega(y_t, 0)$ is ½ if y_t is positive and -½ otherwise. Let $s_t = 2\omega(p_t, 0) = 2\omega(\varepsilon_t, 0)$, where s_t is an iid series with zero mean and unitary variance. Each s_t is equal to 1 with a probability ½ and is equal to -1 otherwise. The VR sign-based statistic using s_1 is:

$$S_1 = \left(\frac{\frac{1}{Nk} \sum_{t=k=1}^{N} \left(s_t + s_{t-1} \ldots. + s_{t-k}\right)^2}{\frac{1}{N} \sum_{t=1}^{N} s_t^2} - 1 \right) \times \left(\frac{2(2k-1)(k-1)}{3kN} \right)^{-1/2} . \tag{12}$$

S_1 assumes a zero mean, but this assumption is relaxed under S_2 [see Wright (2000) for the derivation of S_2). Both S_1 and S_2 provide valid and exact tests even under conditional heteroskedasticity, although S_2 is more conservative. Wright shows that the rank-based test outperforms the sign-based test. However, both versions of the non-parametric tests are more powerful than the traditional VR test.

Since we perform individual VR tests in a joint hypothesis of the random walk, results from the Wright test may be flawed by size distortions arising from sequential testing for different k intervals. Following Belaire-Franch and Opong (2005), we mitigate these distortions by using the Sidack adjusted *p*-values and a bootstrapping technique.

4.2. Kuan and Lee's Test

Recently, Kuan and Lee (2004) proposed a new procedure to test MDH. The advantage of Kuan and Lee's test is its insensitivity to the assumption of conditional homoskedasticity and it requires a weaker moment condition. A brief account of the test is in order.

Let y_t, $t = 1, 2, ..., T$ be a series of daily returns and let β be the reciprocal of the sample standard deviation of the series y. Following similar notation to that of Kuan and Lee, define

$$\varphi_c(y) = \frac{1}{1+\beta^2 y^2} \tag{15}$$

$$\varphi_s(y) = \frac{\beta y}{1+\beta^2 y^2} \tag{16}$$

and, for $k > 1$ and $k < t \le T$, define functions $\varphi_c(y, t-1, k)$ and $\varphi_s(y, t-1, k)$ recursively by

$$\varphi_c(y, t-1, k) = \varphi_c(y, t-1, k-1)\varphi_c(y_{t-k}) - \varphi_s(y, t-1, k-1)\varphi_s(y_{t-k}) \tag{17}$$

$$\varphi_s(y, t-1, k) = \varphi_c(y, t-1, k-1)\varphi_s(y_{t-k}) + \varphi_s(y, t-1, k-1)\varphi_c(y_{t-k}) \tag{18}$$

where

$$\varphi_c(y, t-1, 1) = \varphi_c(y_{t-1}) \tag{19}$$

$$\varphi_s(y, t-1, 1) = \varphi_s(y_{t-1}). \tag{20}$$

If then, we define

$$\psi_j(y, t, k) = y_t \varphi_j(y, t-1, k) \text{ for } j = c, s \tag{21}$$

and, for a given k,

$$\overline{\psi}_j = \frac{1}{T-k} \sum_{t=k+1}^{T} \psi_j(y,t,k) \text{ for } j = c, s \tag{22}$$

$$\hat{\sigma}_j^2 = \frac{1}{T-k} \sum_{t=k+1}^{T} \left(\psi_j(y,t,k)\right)^2 \text{ for } j = c, s \tag{23}$$

$$\hat{\sigma}_{cs} = \frac{1}{T-k} \sum_{t=k+1}^{T} \left(\psi_c(y,t,k) \times \psi_s(y,t,k)\right) \tag{24}$$

$$J = \frac{T-k}{\hat{\sigma}_c^2 \hat{\sigma}_s^2 - \hat{\sigma}_{cs}^2} \left[\hat{\sigma}_s^2 \overline{\psi}_c^2 + \hat{\sigma}_c^2 \overline{\psi}_s^2 - 2\hat{\sigma}_{cs} \overline{\psi}_c \overline{\psi}_s\right] \tag{25}$$

Under certain assumptions, Kuan and Lee show that p -values can be derived from $J \overset{D}{\rightarrow} \chi^2(2)$.

5. Empirical Results

5.1. Results for the RWH

Under the null hypothesis that foreign exchange rates follow a random walk, the traditional variance ratios should equal to one. This paper uses instead the more powerful Wright's (2000) non-parametric VR test based on ranks and signs. We compute the VR statistics (for multiples of 2, 5, 10, and 30 days) for the full sample period as well as for the pre- and post-Asian financial crisis sub-periods. We assemble the results in Tables 2, 3 and 4, respectively.

Insert Tables 2-4 about here

Table 2 indicates that several estimates of the three VR statistics, R_1 (k), R_2 (k) and S_1 (k) for lags k = 2, 5, 10, and 30 are different from unity at least at the 10% level of significance for all currencies studied. Thus, whether the Euro, the USD or the JPY is used as the base currency, the RWH is rejected for all eight currencies under the assumptions of both homoskedasticity and heteroskedasticity over the full sample period. The RWH is similarly rejected for all eight currencies over the pre-Asian financial crisis (see Table 3). As for the evidence for the post-

Asian financial crisis period in Table 4, the results continue their rejection of the RWH for all currencies except AUD and KRW. In this second sub-period, the Australian dollar and the South Korean won appear consistent with the RWH when measured in terms of the USD, Euro and the Yen. This finding for AUD accords well with the evidence reported by Belair-Franch and Opong (2005). Our findings regarding KRW almost mirror those by Eom, Hahn and Joo (2008)

5.2. Results for the MDH

We also test the MDH by computing Kuan and Lee's $J(k)$ statistics for the full sample period as well as for the pre- and post-Asian financial crisis sub-periods. For compatibility with the Wright test, Tables 5-7 report the respective results from Kuan and Lee's test for multiples of 2, 5, 10, and 30 days. The results we obtained for the full period (see Table 5) are

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Insert Tables 5-7 about here
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not consistent with the MDH, as many values of the $J(k)$ statistics across the eight currencies prove statistically significant with respect to one or more of the base currencies. Indeed, the degree of rejection of the MDH is stronger and at a higher frequency compared with the rejection of the RWH from the Wright test. The verdict is the same over the post-Asian crisis period (see Table 7) except for the Australian dollar and South Korean won for which the Martingale difference process is not violated when they are measured against the three benchmark currencies. Thus, both RWH and MDH tests lead us to surmise that the Australian dollar and the Korean won show a marked improvement in the efficiency of their respective markets following the Asian crisis of the late 1990s.

6. Concluding Remarks

This paper tests the random walk and the Martingale difference hypotheses for the Australian dollar, the South Korean won, the Indonesian rupiah, the Malay ringgit, the Philippine peso, the Singapore dollar, the Thai baht and the Taiwan dollar under the floating rate system, in a time span bisected by the Asian financial crisis. We use Wright's (2000) non-parametric test to investigate the RWH and Kuan and Lee's (2004) test to investigate the MDH. Our results suggest that (i) the Wright and the Kuan-Lee tests are useful for evaluating the two hypotheses under study, especially Wright's nonparametric VR tests, once size distortions are corrected: (ii) only the Australian dollar and the Korean won behave as a random walk and a martingale difference since the Asian financial crisis; and (iii) the other Asian foreign exchange markets under this study have shown little discernible improvement toward weak-form efficiency following the Asian financial crisis in 1997-98.

On balance, these findings are consistent with the conclusions of Ahn, *et. al.* (2002) and Ryoo (2001), Yilmaz (2003) and Eom, Hahn and Joo (2008) for the Korean won in that noise trading, which may have existed, especially in the inter-bank exchange transactions (see Ahn, *et. al.* (2002) and Ryoo (2001), may no longer be as replicable, as the liberalization of foreign exchange rules and regulations implemented by the Korean government in the aftermath of the Asian financial crisis seems to have enhanced the overall efficiency of the won against the three world reserve currencies. Our finding in this respect is as much about the efficiency of the Korean won as it is about the country's concerted efforts in liberalizing the financial markets in recent years. Our finding on the strength and relative efficiency of the Australian dollar also supports those reported by Bowman (2006).

From our tests of the MDH which covers both linear and nonlinear moments, we can infer that the Australian dollar and the Korean won are semi-strong efficient, and that the

Australian experience in handling of its *onshore* as compared to *offshore* NDF markets by the country's central bank in the 1980's provides a roadmap for policy-makers of Korea and the other Asian currencies covered in this study.

Central bank interventions in emerging foreign exchange markets have often been pronounced. This is particularly true for the period examined in this paper during which the Euro has remarkably appreciated against the US dollar, resulting in massive shifts in many Asian countries away from the US dollar towards Euro-based assets. Despite these currency realignments, the evidence we obtained suggests that except for the Korean won, the other emerging foreign exchange markets in the region have not improved their efficiency when moving from pegged exchange rate systems to current floating rate systems. With the recent growth in offshore non-deliverable forward, options and futures markets in many Asian currencies, an evaluation of relative inter-country exchange efficiency seems a promising topic for future research.

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Table 1: Descriptive Statistics of Daily Data for the exchange rates under study: Jan. 1993 – Dec. 2008

Base Currency - USD

	AUD_USD	IDR_USD	MYR_USD	PHP_USD	SGD_USD	KRW_USD	TWD_USD	KRW_USD
Mean	0.750414	0.000158	0.445529	0.023459	0.689973	51.32958	1.711221	51.32958
Median	0.735240	0.000111	0.268480	0.020807	0.617060	0.000972	0.031012	0.000972
Maximum	1.576700	0.000499	2.692100	0.038993	1.661100	816.1700	26.98700	816.1700
Minimum	0.483140	6.21E-05	0.214720	0.017716	0.539500	0.000512	0.028481	0.000512
Std. Dev.	0.214530	0.000110	0.557863	0.006394	0.247511	196.7790	6.438072	196.7790
Skewness	2.278827	1.903363	3.518489	1.413410	3.294349	3.572662	3.574536	3.572662
Kurtosis	8.548537	4.809772	13.52492	3.776821	12.54510	13.76515	13.78361	13.76515
Jarque-Bera	8663.972	2439.184	26935.90	1179.934	22604.94	28053.58	28129.40	28053.58
Probability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sample size	4033	3295	4033	3295	4033	4033	4033	4033

Base Currency - Euro

	AUD_EUR	IDR_EUR	MYR_EUR	PHP_EUR	SGD_EUR	KRW_EUR	TWD_EUR	THB_EUR
Mean	0.670112	0.000137	0.432225	0.020576	0.626659	59.06401	1.960219	1.880633
Median	0.604380	0.000104	0.256590	0.019853	0.547670	0.000837	0.028650	0.024378
Maximum	1.855200	0.000372	3.229000	0.033933	2.050900	994.9200	32.29900	31.77800
Minimum	0.484790	5.62E-05	0.192480	0.013024	0.448300	0.000460	0.020566	0.016505
Std. Dev.	0.274117	9.01E-05	0.668926	0.005713	0.331373	228.4687	7.473371	7.179075
Skewness	3.529276	1.760241	3.590337	0.653174	3.478445	3.612197	3.610386	3.614086
Kurtosis	13.75434	4.452044	13.99261	2.319546	13.53895	14.06048	14.04243	14.07934
Jarque-Bera	27710.82	1991.035	28869.74	297.8628	26704.21	29225.84	29150.26	29304.90
Probability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sample size	4033	3295	4033	3295	4033	4033	4033	4033

Base Currency - JPY

	AUD_JPY	IDR_JPY	MYR_JPY	PHP_JPY	SGD_JPY	KRW_JPY	TWD_JPY	THB_JPY
Mean	73.82858	0.018024	31.56691	2.701141	66.09061	0.565855	3.400311	3.062743
Median	77.76300	0.012926	31.95900	2.442500	68.54900	0.106281	3.546000	3.013050
Maximum	107.3530	0.052885	50.68800	4.817900	88.10700	8.036300	4.602200	5.016300
Minimum	0.011691	0.007768	0.020563	1.821000	0.013155	0.062473	0.201750	0.202730
Std. Dev.	22.20645	0.012307	9.665794	0.742043	18.32478	1.753878	0.873792	0.936403
Skewness	-2.141955	1.879246	-1.860791	1.184297	-2.871460	3.595344	-2.903222	-1.329119
Kurtosis	8.033051	4.739062	7.754270	3.355170	10.87414	13.98796	11.03389	5.996668
Jarque-Bera	7340.646	2354.635	6125.667	787.5576	15961.14	28977.33	16511.47	2695.770
Probability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sample size	4033	3295	4033	3295	4033	4033	4033	4033

Table 2: Wright's VR Test Results for the RWH (The Full Period: Jan.1993 - Dec. 2008)

R_1

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	0.63	-0.35	-1.12	-0.84	-1.15	-0.62	0.83	-0.83
k=2(usd)	1.10	-0.87	-0.94	-0.26	-2.72*	-0.82	0.94	-0.94
k=2(yen)	0.45	-1.23	-0.83	-0.93	-0.83	-1.12	0.62	-1.34
k=5(eur)	-0.72	-0.65	-2.87*	-1.19	-2.25*	-0.93	-1.02	-1.24
k=5(usd)	-0.87	-2.81*	-1.15	-0.37	-1.02	-0.72	-2.67*	-0.89
k=5(yen)	-0.62	-0.92	-2.42*	-0.73	-0.37	-1.15	-0.73	-2.56*
k=10(eur)	-1.12	-1.12	-1.15	-2.65*	-0.92	-2.72*	-0.92	-0.83
k=10(usd)	-1.02	-0.97	-0.93	-1.17	-0.26	-1.15	-1.12	-1.24
k=10(yen)	-0.76	-0.83	-0.87	-2.81*	-2.26*	-0.83	-2.78*	-0.78
k=30(eur)	-1.24	-3.02*	-1.12	-1.12	-0.67	-0.67	-1.35	-2.73*
k=30(usd)	-1.31	-0.09	-0.87	-1.22	-0.81	-0.83	-1.13	-0.89
k=30(yen)	-0.83	-2.12*	-2.65*	-0.83	-0.39	-0.52	-1.18	-2.36*

R_2

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	-0.89	-0.89	-0.78	-0.89	-0.67	1.28	0.67	-0.18
k=2(usd)	-0.73	-1.26	-0.56	-0.67	-0.38	0.90	0.89	-0.89
k=2(yen)	-1.14	-0.38	-0.46	-0.56	-1.23	1.03	1.25	-1.12
k=5(eur)	-0.92	-0.89	-2.13*	-1.13	-1.86*	0.89	0.56	-0.89
k=5(usd)	-2.17*	-1.35	-0.89	-2.16*	-0.78	0.46	1.26	-0.56
k=5(yen)	-1.03	-0.67	-0.67	-0.89	-1.23	1.03	0.89	-1.34
k=10(eur)	-0.78	-2.45*	-1.15	-1.98*	-0.78	0.78	1.78*	-2.02*
k=10(usd)	-0.56	-0.67	-1.24	-0.89	-2.15*	2.15*	0.67	-0.99
k=10(yen)	-1.37	-0.92	-2.11*	-0.56	-1.02	1.06	1.04	-0.78
k=30(eur)	-1.26	-093	-0.89	-0.87	-0.89	0.67	-0.89	-1.03
k=30(usd)	-0.89	-2.35*	-0.67	-1.11	-0.56	1.07	-2.71*	-1.89*
k=30(yen)	-0.56	-0.56	-0.45	-1.89*	-1.24	0.89	-0.89	-0.89

S_1

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	-0.67	-0.78	-0.78	-0.89	-0.90	-0.89	-0.36	1.21
k=2(usd)	-0.56	-1.25	-1.03	-1.03	-1.08	-1.26	-1.93*	1.02
k=2(yen)	-1.03	-1.12	-0.89	-0.48	-0.78	-0.56	-1.26	0.98
k=5(eur)	-0.38	-1.98*	-0.48	-1.83*	-0.88	-1.26	-0.48	-0.89
k=5(usd)	-0.89	-0.67	-2.12*	-1.29	-1.89*	-0.81	-0.67	-1.23
k=5(yen)	-0.28	-0.93	-1.32	-0.89	-1.37	-1.89*	-1.36	-0.81
k=10(eur)	-2.28*	-1.23	-1.98*	-1.09	-2.11*	-0.78	-1.97*	-1.32
k=10(usd)	-1.89*	-2.11*	-1.04	-2.11*	-0.78	-1.26	-0.39	-2.29*
k=10(yen)	-0.89	-0.78	-2.01*	-0.60	-1.87*	-0.92	-2.21*	-1.14
k=30(eur)	-0.67	-1.95*	-1.87*	-2.04*	-0.78	-2.10*	-0.84	-1.90*
k=30(usd)	-1.11	-2.24*	-1.23	-1.90*	-0.90	-1.93*	-1.78*	-0.38
k=30(yen)	-1.25	-0.78	-1.92*	-1.86*	-1.84*	-0.93	-0.92	-1.98*

Notes: The table reports statistics of the Wright non-parametric VR test based on ranks (R_1 and R_2) and signs(S_1) over *k* daily lags. The designations in parentheses of the *k* column denote the base currency of the Euro, the US dollar and the yen, respectively. An * indicates significance at the 10 % level.

Table 3: Wright's VR Test Results for the RWH (The Pre-Asian Crisis Period: Jan.1993 – Nov. 1997)

R_1

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	0.60	-0.83	-1.29	-1.27	-0.90	-0.78	0.78	-0.83
k=2(usd)	1.05	-0.91	-0.94	-0.78	-1.89*	-0.38	0.59	-0.29
k=2(yen)	0.56	-1.09	-1.26	-1.31	-0.73	-0.58	0.91	-0.89
k=5(eur)	-0.75	-1.85*	-0.84	-0.45	-1.28	-2.36*	-1.23	-1.16
k=5(usd)	-0.93	-1.24	-1.93*	-0.38	-1.12	-1.29	-3.01*	-1.12
k=5(yen)	-0.72	-0.89	-1.25	-1.04	-1.04	-0.78	-0.90	-0.78
k=10(eur)	-2.11*	-0.94	-0.89	-1.89*	-2.11*	-089	-2.29*	-1.89*
k=10(usd)	-1.98*	-2.11*	-1.09	-0.67	-0.90	-1.88*	-1.09	-0.89
k=10(yen)	-0.87	-0.56	-0.67	-0.29	-0.47	-0.90	-1.95*	-2.01*
k=30(eur)	-1.12	-1.11	-1.90*	-0.97	-0.98	-0.29	-0.87	-1.13
k=30(usd)	-1.07	-093	-0.67	-1.99*	-1.28	-0.89	-0.49	-1.09
k=30(yen)	-0.89	-1.98*	-0.47	-0.67	-1.87*	-0.39	-2.23*	-0.93

R_2

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	-0.89	-0.89	-0.87	-0.47	-2.12*	0.89	0.67	-0.89
k=2(usd)	-0.46	-0.78	-0.56	-0.83	-1.89*	0.58	1.25	-0.57
k=2(yen)	-1.12	-1.23	-1.03	-0.48	-0.89	1.23	1.12	-1.89*
k=5(eur)	-1.26	-1.16	-0.89	-1.78*	-0.45	1.12	-0.78	-1.36
k=5(usd)	-1.81*	-0.78	-1.17	-0.83	-0.78	1.89*	-0.37	-1.26
k=5(yen)	-0.56	-1.89*	-1.82*	-2.03*	-0.93	0.67	-0.89	-0.76
k=10(eur)	-0.89	-2.01*	-2.06*	-0.83	-0.89	2.25*	-2.25*	-2.47*
k=10(usd)	-1.27	-0.82	-0.39	-0.39	-2.22*	1.03	-0.78	-2.89*
k=10(yen)	-1.97*	-1.87*	-0.92	-0.56	-0.98	1.11	-0.88	-0.89
k=30(eur)	-2.11*	-0.86	-1.06	-0.89	-0.89	0.89	-0.97	-0.75
k=30(usd)	-1.03	-1.92*	-2.45*	-2.23*	-0.39	1.35	-2.11*	-0.45
k=30(yen)	-0.89	-0.56	-0.82	-0.78	-1.89*	1.24	-1.98*	-0.67

S_1

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	-1.28	-0.89	-0.38	-0.78	-1.27	0.87	1.27	1.29
k=2(usd)	-0.78	-1.78*	-0.85	-0.28	-1.38	1.21	1.12	1.09
k=2(yen)	-0.73	-0.56	-0.92	-1.25	-1.13	0.78	0.78	0.89
k=5(eur)	-1.14	-0.39	-2.56*	-1.89*	-2.12*	0.96	-1.26	-1.28
k=5(usd)	-0.78	-0.81	-0.78	-0.39	-2.78*	0.29	-0.89	-0.78
k=5(yen)	-0.89	-0.90	-0.82	-1.11	-1.89*	1.02	-0.56	-0.38
k=10(eur)	-1.19	-2.29*	-1.26	-0.89	-0.89	0.68	-2.22*	-2.16*
k=10(usd)	-1.89*	-0.89	-198*	-2.23*	-0.81	1.98*	-1.90*	-0.78
k=10(yen)	-0.98	-1.94*	-0.56	-0.78	-1.27	0.78	-2.78*	-1.90*
k=30(eur)	-0.83	-0.56	-0.38	-0.67	-2.11*	1.01	-0.78	-0.67
k=30(usd)	-2.24*	-0.28	-0.78	-0.26	-1.78*	1.12	-0.90	-0.39
k=30(yen)	-0.83	-0.39	-1.99*	-0.92	-0.82	0.78	-1.20	-0.84

Note: See note to Table 2

Table 4: Wright's VR Test Results for the RWH (The Post-Asian Crisis Period: Dec.1998 – Dec. 2008)

R_1

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	0.56	-0.78	-1.38	-0.78	-0.89	-0.94	-0.89	-0.45
k=2(usd)	0.83	-0.28	-1.23	-0.38	-2.13*	-0.83	-1.26	-1.28
k=2(yen)	0.72	-1.28	-0.78	-0.59	-0.36	-0.29	-0.92	-1.35
k=5(eur)	-0.67	-0.39	-0.47	-2.11*	-0.85	-1.23	-0.73	-0.93
k=5(usd)	-0.36	-0.91	-0.78	-0.87	-1.24	-0.89	-1.89*	-0.78
k=5(yen)	-0.82	-0.39	-0.87	-2.56*	-2.13*	-0.39	-0.48	-0.82
k=10(eur)	-1.12	-2.14*	-2.67*	-0.58	-0.73	-1.42	-0.47	-2.78*
k=10(usd)	-1.29	-1.89*	-0.37	-0.48	-1.26	-1.28	-1.98*	-2.46*
k=10(yen)	-0.89	-2.37*	-0.92	-0.58	-1.42	-1.53	-0.41	-1.78*
k=30(eur)	-0.56	-0.89	-0.45	-2.78*	-3.02*	-0.37	-0.65	-1.92*
k=30(usd)	-0.89	-039	-1.89*	-0.93	-2.67*	-0.78	-0.93	-0.78
k=30(yen)	-1.27	-028	-0.82	-0.29	-1.25	-0.82	-2.01*	-0.37

R_2

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	-0.78	-0.92	-0.48	-0.48	-0.47	-1.25	-0.45	-0.57
k=2(usd)	-1.36	-0.89	-0.89	-0.38	-0.83	-1.13	-0.84	-0.83
k=2(yen)	-0.89	-1.31	-1.26	-1.28	-1.28	-1.19	-0.92	-1.93*
k=5(eur)	-0.48	-0.39	-2.56*	-3.01*	-3.13*	-0.78	-1.04	-0.78
k=5(usd)	-0.29	-0.59	-0.78	-0.89	-2.78*	-0.92	-1.07	-0.91
k=5(yen)	-1.03	-0.83	-1.89*	-0.49	-1.26	-0.67	-0.83	-0.83
k=10(eur)	-0.89	-2.11*	-0.78	-0.94	-0.48	-1.32	-2.23*	-1.92*
k=10(usd)	-1.17	-1.99*	-0.93	-0.39	-0.94	-1.27	-2.67*	-2.05*
k=10(yen)	-0.90	-0.78	-0.49	-1.89*	-2.03*	-0.93	-0.89	-2.39*
k=30(eur)	-0.48	-0.78	-2.12*	-0.93	-0.85	-0.67	-0.56	-1.02
k=30(usd)	-1.13	-1.90*	-1.90*	-1.28	-0.93	-0.72	-0.89	-1.04
k=30(yen)	-0.89	-0.39	-2.89*	-2.67*	-0.46	-0.81	-3.02*	-0.83

S_1

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2(eur)	-1.17	-1.26	-1.27	-0.59	-1.35	-1.42	-1.25	-0.67
k=2(usd)	-0.67	-1.17	-0.89	-0.89	-0.93	-1.27	-1.35	-0.73
k=2(yen)	-0.39	-0.78	-1.27	-0.49	-1.21	-1.32	-0.56	-0.93
k=5(eur)	-1.29	-0.89	-0.89	-1.34	-2.67*	-0.83	-1.03	-1.34
k=5(usd)	-0.59	-2.78*	-2.89*	-1.28	-1.28	-0.91	-0.91	-2.03*
k=5(yen)	-1.35	-1.98*	-1.88*	-2.02*	-0.49	-0.37	-0.67	-1.92*
k=10(eur)	-0.89	-0.89	-0.89	-2.78*	-3.02*	-1.22	-3.06*	-0.84
k=10(usd)	-1.26	-0.29	-0.56	-2.45*	-2.92*	-0.67	-2.07*	-1.78*
k=10(yen)	-0.89	-0.67	-0.39	-0.89	-1.98*	-0.56	-1.89*	-0.78
k=30(eur)	-1.28	-2.37*	-2.37*	-0.48	-0.85	-1.34	-0.89	-3.02*
k=30(usd)	-1.32	-2.78*	-2.11*	-0.58	-0.93	-1.26	-0.45	-0.78
k=30(yen)	-0.89	-0.94	-2.89*	-0.89	-0.78	-0.76	-0.93	-0.45

Note: See note to Table 2

Table 5: Kuan and Lee's Test Result for the MDH (The Full Period: Jan. 1993 – Dec .2008)

k	**AUD**	**IDR**	**MYR**	**PHP**	**SGD**	**KRW**	**TWD**	**THB**
k=2 (eur)	0.44	0.45	1.18	6.16**	4.75*	7.66**	1.23	1.03
k=2 (usd)	1.28	1.44	1.31	1.36	1.18	1.59	5.02*	0.75
k=2 (yen)	2.21	5.45*	0.81	1.22	1.00	6.13**	6.35**	0.78
k=5 (eur)	5.61*	0.77	1.27	1.82	1.29	0.89	1.12	0.46
k=5 (usd)	0.45	14.39***	1.19	1.18	1.25	6.81**	0.85	0.74
k=5 (yen)	5.64*	1.14	1.14	1.16	0.09	1.25	5.36*	5.23*
k=10 (eur)	1.77	1.19	8.09**	1.27	1.08	1.54	1.45	0.89
k=10 (usd)	1.22	7.40**	1.10	1.61	4.91*	17.17***	9.04**	6.66**
k=10 (yen)	1.13	4.19*	1.44	1.14	1.41	7.18**	5.12*	4.78*
k=30 (eur)	1.11	1.15	1.44	1.44	0.39	1.18	1.17	1.36
k=30 (usd)	1.19	1.02	4.81*	1.21	0.79	5.52*	1.02	1.28
k=30 (yen)	5.21*	6.55**	1.42	9.34***	0.32	1.21	0.78	5.12*

Notes: An * indicates significance at the 10% level, an ** indicates significance at the 5% level, while an *** indicates significance at the 1% level.

Table 6: Kuan and Lee's Test Result for the MDH (The Pre-Asian Crisis Period: Jan. 1993-Nov. 1997)

k	**AUD**	**IDR**	**MYR**	**PHP**	**SGD**	**KRW**	**TWD**	**THB**
k=2 (eur)	1.06	1.27	0.38	0.67	9.03**	1.28	1.13	1.23
k=2 (usd)	1.48	1.55	1.02	0.91	11.80***	1.14	6.72**	0.85
k=2 (yen)	5.13*	0.46	6.88**	0.88	0.63	0.36	1.35	0.71
k=5 (eur)	1.17	1.21	1.18	5.18*	1.03	1.01	7.12**	7.46**
k=5 (usd)	1.33	1.33	1.16	7.21**	1.45	1.14	0.65	0.84
k=5 (yen)	4.91*	5.19*	9.61**	0.81	7.10**	5.50*	0.36	5.13*
k=10 (eur)	0.81	6.35**	1.38	1.62	1.23	1.28	0.45	1.19
k=10 (usd)	1.30	1.12	1.05	1.37	1.40	7.89**	1.04	0.66
k=10 (yen)	1.37	1.26	1.25	9.39**	7.65**	1.21	12.12***	6.78**
k=30 (eur)	1.08	1.49	0.84	1.56	0.14	1.01	1.27	1.46
k=30 (usd)	1.17	9.82**	1.10	1.74	5.18*	0.39	1.32	1.18
k=30 (yen)	1.19	1.19	0.81	9.65***	0.31	1.14	0.88	5.22*

Notes: An * indicates significance at the 10% level, an ** indicates significance at the 5% level, while an *** indicates significance at the 1% level.

Table 7: Kuan and Lee's Test Result for the MDH (The Post-Asian Crisis Period: Dec. 1998 – Dec. 2008)

k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
k=2 (eur)	0.46	0.78	3.02	5.16*	0.90	1.05	5.23*	1.13
k=2 (usd)	0.80	0.51	0.84	0.88	5.20*	1.08	1.02	0.65
k=2 (yen)	1.43	10.30***	0.16	0.78	0.53	1.46	5.35*	0.88
k=5 (eur)	1.18	1.10	0.03	1.24	1.13	0.16	1.22	6.46**
k=5 (usd)	0.51	0.78	1.44	1.13	5.65*	1.21	7.85**	0.64
k=5 (yen)	1.34	14.26***	0.30	0.68	0.91	1.31	0.36	0.93
k=10 (eur)	1.09	1.13	8.70**	7.59**	6.43**	1.00	5.45*	0.89
k=10 (usd)	1.19	7.20**	0.73	8.79**	6.16*	0.77	13.04***	7.66**
k=10 (yen)	1.08	11.08***	0.35	1.17	0.66	1.15	5.32*	5.18*
k=30 (eur)	0.70	8.35**	6.16**	1.05	5.13*	1.15	1.07	1.16
k=30 (usd)	0.48	0.98	6.66**	0.60	0.45	1.10	1.22	1.38
k=30 (yen)	1.36	5.45*	3.46	0.73	0.09	0.65	0.88	5.22*

Notes: An * indicates significance at the 10% level, an ** indicates significance at the 5% level, while an *** indicates significance at the 1% level.