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Are exchange rate movements predictable in Asia-Pacific markets? Evidence of random walk and martingale difference processes

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ABSTRACT

This study investigates 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 Kim's (2009) Automatic Variance Ratio (AVR) test for the RW and Kuan and Lee's (2004) test for the MDS. The null of RW or MDS hypotheses is not rejected for three currencies: Australian dollar and Korean won for the post-Asian financial crisis period tested by MDS, and Malaysian ringgit for the entire test period as well as the pre-Asian financial crisis period when the currency is evaluated by the AVR. As for the post-Asian crisis, six other Asian currencies including Malaysian ringgit show no discernible improvement toward market efficiency. Our findings have broad policy implications — investors may be able to exploit time-varying movements of the returns of the five currencies which can be identified by technical trading rules for profitable trading.

1. Introduction

Since Meese and Rogoff's (1983) seminal work on the predictability of foreign exchange rates 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 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.[3]

Strong evidence in the literature indicates that nominal exchange rates generally follow a random walk process or its change follows a martingale difference sequence — the two patterns of currency movement analyzed under the two common names; the random walk hypothesis (henceforth RWH) or the martingale difference hypothesis (henceforth MDH). Under both hypotheses, markets are weak-form efficient so that future changes of foreign exchange rate are unpredictable from past prices or return. Thus, it is not possible for currency traders to consistently beat the market by "technical" or "filter" rules except for one phenomenon

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[3] 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 et al. (2007) for their exhaustive evaluation of technical trading rules and Lee, Gleason, and Mathur (2001) and Martin (2001) for emerging country currencies.

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unique to foreign exchange markets, namely opportunities associated with interventions by monetary authorities that may or may not provide predictable moves in the exchange rates.

The empirical validity of the RWH is still debated in the foreign exchange literature, and variance ratio (henceforth VR) analysis has been most widely used in testing the hypothesis. 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 employ parametric VR tests of Lo and MacKinlay (1989) or its multiple versions of Chow and Denning (1993), which are asymptotic tests, which are valid when the sample size is large. It is well known that, in small samples, these tests often erroneously reject RWH (see, for example, Lee, Kim, & Newbold, 2004).

In general, the martingale process is 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 (Dominguez & Lobato, 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 short, the key feature of MDH is that, in contrast to most previous studies of RWH, which test time series of asset returns that are assumed linearly uncorrelated, MDH tests mean-independence or conditional-mean-independence of linear or non-linear combinations of past asset returns.

In this study, we use the wild bootstrapped automatic variance ratio test of Kim (2009) and the martingale difference sequence test of Kuan and Lee (2004). Kim's (2009) test is an extension of Choi's (1999) automatic variance ratio test where the holding period is selected optimally using a fully data-dependent procedure. It is a non-parametric test in which the sampling distribution of the automatic variance ratio test is approximated using a bootstrapped procedure valid under conditional heteroskedasticity. As shown in Kim (2009), it has more desirable small sample properties than other variance ratio tests. Kuan and Lee (2004) demonstrate that their test is more powerful than several other tests of MDH, for their test is insensitive to the assumption of conditional homoskedasticity and requires a weaker moment condition.

We examine the weak-form market efficiency of the Australian dollar and seven Asian emerging markets' currencies against the three world reserve currencies: the U.S. dollar, the Japanese yen and the Euro during the period between January 1993 and December 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.

Our study is significant to not only academics, but also to government policy-makers and private investors for the following five reasons. First, following the Asian financial crisis in 1997, the seven Asian emerging economies changed their exchange rate regimes from de facto pegs to floating systems.[4] Second, there is strong evidence that the implicit reference currencies against which the currencies of these Asian countries are measured under the floating regimes have significantly shifted from the U.S. dollar to the Euro and the Japanese yen. (Patnaik, Shah, Sethy, & Balasubramaniam, 2011). Third, a strong trading bloc has recently emerged in Asia and Pacific, which is dominated by the Japanese yen and to some extent by the Australian dollar for cross-border trade and financial transactions. The movements of the seven Asian currencies are increasingly tied to the Japanese yen and the Australian dollar, especially for their financial transactions related to forward, futures, options and offshore derivative markets.[5] Fourth, the strength of the currencies of Australia 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. Fifth, there has been active discussion regarding the integration of regional currencies in East Asia (Eichengreen & Park, 2004 and Kearney & Muckley, 2008). Successful integration of regional currencies requires empirical assessments of not only the relative efficiency of individual currencies in the region, but also the sustainability of government policies related to foreign exchange markets.

The major findings of our study are: (i) Kuan-Lee's martingale and Kim's automatic VR tests, both of which are non-parametric, are useful tools in evaluating a time series of returns against a random walk or martingale difference hypothesis when the series has a conditionally heteroskedastic variance and a small sample size. (ii) Despite increasing evidence that the influence of the U.S. dollar on pegging their currencies has declined and that the influence of Japanese yen has increased, especially after the Asian financial crisis, there appears little evidence that the overall efficiency of foreign exchange markets for these currencies has markedly improved. Our findings show that only the Australian dollar and the Korean won have behaved as a random walk and a martingale difference in the post-Asian crisis period; and the other six Asian emerging currencies – the Indonesian rupiah, the Malay ringgit, the Philippine peso, the Singapore dollar, the Taiwanese dollar, and the Thai baht – have shown no discernible improvement toward weak-form efficiency in the post-Asian crisis.

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

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[4] Malaysia temporarily issued a moratorium immediately following the onset of the crisis in 1997. By most accounts, the exchange rate systems in the seven Asian emerging economies 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 (Lee, Lee, & Robinson,2004), and that Korea was under a managed floating regime until April 2002, but is now under “free floating” or “complete liberalized regimes”query, see Kim and Ryou (2001), Ryoo (2001) and Eom et al. (2008).

[5] Bowman (2005), Ma, Ho, and MaCauley (2004) and http://www.cme.com/trading/prd/fx.

2. Related literature

In the literature there are two broad econometric approaches to testing the efficiency of foreign exchange markets. The first approach is time series analysis of parity or alignment of exchange rates in models that include market variables like spot, forward and prices. In this approach, market efficiency tests are evaluations 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). Examples of this approach include the evaluation of the so called "puzzle" related to purchasing power parity and forward premium. Despite voluminous studies published over the last two decades, the efficiency of foreign exchange markets still remain unresolved.[6] The second approach includes time series examinations like Lo and MacKinlay (1989) and the Chow and Denning (1993) VR tests, and the Kuan and Lee (2004) martingale difference hypothesis tests based on moment conditions. This category also includes tests of unit root and cointegration, and ARIMA and GARCH processes.[7]

A "simple" random walk process, of which the first difference is independent within noise process, is a special case of the martingale difference process. The assumption of the first difference being independent implies that increments (or first difference) in linear or nonlinear functions are uncorrelated. But the development of literature in testing random walk has evolved by relaxing the assumption of independent and identically distributed increments. Thus, in a weak form efficiency, a sequence of increments is a martingale difference, and the distribution of increments should have zero mean and no correlation at any lag in the testing parameters (Campbell, Lo, & MacKinlay, 1997). 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 a challenge. In financial time series analyses, the common way of testing the process consists of testing that the process is uncorrelated in sample autocorrelations. In econometric studies, the property of the martingale difference sequence is known as mean-independence or conditional mean independence (Dominguez & Lobato, 2003).

In the literature, VR tests are the econometric tools of choice for studies that analyze the efficiency of emerging "stock markets." However, VR tests for examining RWH in emerging "foreign exchange markets" are quite sparse. Hoque, Kim, and Pyun (2007) report that 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 in the study of "foreign exchange markets" may be attributable to the ways in which governments intervene in "foreign exchange markets." It is a rare event for central banks of countries to intervene as buyers or sellers in "stock markets." That is not the case for foreign exchange markets. Not only do central banks intervene directly and quite frequently in foreign exchange markets, but they also actively implement other policy tools, such as money supply and interest rate targets that alter expectations on future values of their respective currencies. Moreover, as Calvo and Mishkin (2003) point out, official policy pronouncements are quite different from what central banks actually do in foreign exchange markets. For instance, an official policy of an emerging economy may state that it follows a floating regime, but its central bank may neither fully disclose its policy targets nor its intention to align its exchange values under various floating rate mechanisms.

With the Lo-MacKinlay VR test, Ajayi and Karemera (1996) reject the RWH for seven Asian emerging markets,[8] while Lee, Pan, and Liu (2001) show that many Asian and non-Asian currencies generally follow a random walk process. Lima and Tabak (2005) also report that currencies of Asian and Latin American countries are consistent with the RWH. Using the Euro, Belaire-Franch and Opong (2005), show that contradictory evidence on the RWH of foreign exchange markets may be caused by the use of the traditional VR test, which is particularly sensitive to conditional heteroskedasticity. Belaire-Franch and Opong also demonstrate that non-parametric VR tests yield a significant improvement over traditional VR tests.

Under a random walk or a martingale difference process, currency traders could find no combination of known past returns that consistently improve their forecasts of future returns. Lee, Kim, and Newbold (2004) show that a martingale difference process has added significance in testing asset returns when return time series is subject to structural breaks. Studies of MDH are mixed on balance. For example, while Fong et al. (1997) and Dominguez and Lobato (2003) report affirmative results, Hong and Lee (2003) and Yilmaz (2003) do not.

3. Data and summary statistics

The currencies under study are the Australian dollar (AUD) and seven emerging Asian currencies: the Indonesian rupiah (IDR), the Malaysian ringgit (MYR), the Philippine peso (PHP) the Singapore dollar (SGD), the South Korean won (KRW), the Taiwanese dollar (TWD), and the Thai baht (THB). Daily nominal exchange rates of these currencies are measured 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).[9] The number of daily observations of individual currencies under study is approximately 4033, with slight variations in the

[6] See Koedij, Lothian, and van Dijk (2006) for an overview, Ho (2008) for PPP and Wang and Jones (2003) on forward premium puzzle.

[7] 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 et al. (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.

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

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

sample numbers attributable to different days of market closing. The Australian dollar is included because it is fast becoming a major trading currency in the region (Bowman, 2005).[10] The Hong Kong dollar is excluded from the study as it is pegged to the U.S. dollar on a currency board regime.

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 period covers January 1993 through November 1997 for all currencies (except for the Thai baht where its first sub-sample ends in June 1997)[11]; 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.

Table 1 shows descriptive statistics for the daily exchange rates relative to the three base currencies — USD, Euro and JPY. The skewness of daily exchange rates for all currencies is positive when the USD and Euro are the base currencies 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. In fact, Jarque-Bera's statistics suggest the presence of significant non-normality in the six exchange rates.

4. Methodology

As reported by Hoque et al. (2007) and Chiang et al. (2010), variance ratio (VR) tests are most widely reported in the literature on the efficiency of stock and foreign exchange markets in emerging economies. In the literature, VR tests used range from the single period VR test of Lo and MacKinlay (1989) and multiple VR test of Chow and Denning (1993) to more powerful nonparametric sign and rank VR test of Wright (2000). Since Chiang et al. (2010) and Al-Khazali, Leduc, and Pyun (2009) have already evaluated, using Chow and Denning's multiple VR and Wright's rank and sign VR tests, the efficiency of floating exchange rate systems of Pacific-Asian countries, we test the martingale difference hypothesis (MDH) with a new nonparametric test proposed by Kuan and Lee (2004) and the RWH with Kim's (2009) automatic VR test.

It should be noted that we test a random walk process in which the assumptions of independent and identically distributed increment are relaxed. Employing the method developed by Kim (2009), however, our test of the RWH has desirable small sample properties under conditional heteroskedasticity. This attribute makes Kim's test more powerful as compared to previous VR tests discussed in Section 2 above. It should also be noted that Kuan and Lee's (2004) test for MDH assumes no conditional homoskedasticity, and requires a weak moment condition in linear or nonlinear functions of past return series of foreign exchanges. In this sense, Kuan and Lee's test of MDH and Kim's AVR test of RWH are complementary, enhancing the empirical validity of testing a weak form of market efficiency of the eight Pacific-Asian market currencies.

4.1. Kuan and Lee's test

The strength of Kuan and Lee's (2004) test in evaluating MDH is its insensitivity to the assumption of conditional homoskedasticity and it requires a weaker moment condition. A brief account of the test is as follows.

Following notation similar to that of Kuan and Lee, we define

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

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

where y_t, $t=1, 2,\ldots, T$ are a series of daily returns, β is the reciprocal of the sample standard deviation of the series y. For $k>1$ and $k<t\le T$, we define functions $\varphi_c(y, t-1, k)$ and $\varphi_s(y, t-1, k)$ recursively by

$$\varphi_c(y,t-1,k) = \varphi_c(y,t-1,k-1)\varphi_c(y_{t-k}) - \varphi_s(y,t-1,k-1)\varphi_s(y_{t-k}) \tag{3}$$

$$\varphi_s(y,t-1,k) = \varphi_c(y,t-1,k-1)\varphi_s(y_{t-k}) + \varphi_s(y,t-1,k-1)\varphi_c(y_{t-k}) \tag{4}$$

where

$$\varphi_c(y,t-1,1) = \varphi_c(y_{t-1}) \tag{5}$$

$$\varphi_s(y,t-1,1) = \varphi_s(y_{t-1}). \tag{6}$$

[10] For example, Kang and Wang (2002) report that for every 10% increase in the yen/dollar rate, Korea's export prices decline by 2.7%.

[11] The Thai baht effectively floated starting in July 1997.

Table 1
Descriptive statistics of daily data for currencies in USD, Euro and yen: Jan. 1993–Dec. 2008.

	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
Base currency: USD								
Mean	0.699903	0.000158	0.306286	0.023459	0.626460	0.000993	0.032515	0.029776
Median	0.717790	0.000111	0.268480	0.020807	0.613310	0.000972	0.031012	0.026627
Maximum	0.980240	0.000499	0.418640	0.038993	0.789390	0.001369	0.039742	0.044274
Minimum	0.483140	6.21E-05	0.214720	0.017716	0.539500	0.000512	0.028481	0.017923
Std. dev.	0.102415	0.000110	0.057371	0.006394	0.053792	0.000189	0.003311	0.006686
Skewness	−0.0149	1.9034	0.7774	1.4134	0.4330	0.1748	0.6797	0.5858
Kurtosis	2.7482	4.8098	1.8018	3.7768	1.9186	1.7926	1.9214	1.7007
Jarque-Bera	10.801	2439.184	647.481	1179.934	322.5190	265.499	506.010	514.309
Probability	0.0045	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	4033	3295	4033	3295	4033	4033	4033	4033
Base currency: Euro								
Mean	0.598722	0.000137	0.264328	0.020576	0.541383	0.000853	0.028221	0.025551
Median	0.600040	0.000104	0.256590	0.019853	0.541640	0.000837	0.028650	0.024378
Maximum	0.704290	0.000372	0.362330	0.033933	0.689420	0.001132	0.037822	0.039231
Minimum	0.484790	5.62E-05	0.192480	0.013024	0.448300	0.000460	0.020566	0.016505
Std. Dev.	0.034353	9.01E-05	0.048074	0.005713	0.052081	0.000141	0.004041	0.005008
Skewness	−0.1487	1.7602	0.2076	0.6531	0.3870	−0.0832	−0.0316	0.5216
Kurtosis	3.5676	4.4520	1.5732	2.3195	2.2580	2.1011	1.9843	1.9038
Jarque-Bera	68.750	1991.035	369.791	297.863	192.530	139.934	173.436	383.465
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	4019	3295	4019	3295	4019	4019	4019	4019
Base currency: JPY								
Mean	78.64180	0.018024	34.31571	2.701141	70.47090	0.111114	3.653129	3.326934
Median	78.41000	0.012926	32.51000	2.442500	68.90300	0.106281	3.582100	3.145150
Maximum	107.3530	0.052885	50.68800	4.817900	88.10700	0.158841	4.956629	5.016300
Minimum	55.86800	0.007768	24.89100	1.821000	58.33200	0.062473	2.695300	2.341300
Std. Dev.	11.16418	0.012307	5.593726	0.742043	6.275085	0.017856	0.332688	0.639214
Skewness	0.2050	1.8792	0.8634	1.1843	0.5160	0.1667	0.7643	0.6739
Kurtosis	2.4082	4.7391	2.8947	3.3552	2.4242	2.1354	3.9797	2.2077
Jarque-Bera	87.109	2354.635	502.909	787.558	234.672	144.284	553.926	410.675
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	4033	3295	4033	3295	4033	4033	4033	4032

Note: The sample consists of the eight currencies – the Australian dollar (AUD) and seven emerging Asian currencies: the Indonesian rupiah (IDR), the Malaysian ringgit (MYR), the Philippine peso, (PHP) the Singapore dollar (SGD), the South Korean won (KRW), the Taiwanese dollar (TWD), and the Thai baht (THB) – measured as daily nominal rates of exchange relative to the U.S. dollar (USD), the Japanese Yen (JPY), and the Euro (EUR) for the period from Jan. 1, 1993 to Dec. 31, 2008.

Further, we define

$$\psi_j(y,t,k) = y_t\varphi_j(y,t-1,k) \text{ for } j = c,s. \tag{7}$$

And for a given k,

$$\overline{\psi}_j = \frac{1}{T-k}\sum_{t=k+1}^{T} \psi_j(y,t,k) \text{ for } j = c,s \tag{8}$$

$$\hat{\sigma}_j^2 = \frac{1}{T-k}\sum_{t=k+1}^{T} \left(\psi_j(y,t,k)\right)^2 \text{ for } j = c,s \tag{9}$$

$$\hat{\sigma}_{cs} = \frac{1}{T-k}\sum_{t=k+1}^{T} \left(\psi_c(y,t,k) \times \psi_s(y,t,k)\right) \tag{10}$$

$$J = \frac{T-k}{\hat{\sigma}_c^2\hat{\sigma}_s^2 - \hat{\sigma}_{cs}^2}\left[\hat{\sigma}_s^2\overline{\psi}_c^2 + \hat{\sigma}_c^2\overline{\psi}_s^2 - 2\hat{\sigma}_{cs}\overline{\psi}_c\overline{\psi}_s\right]. \tag{11}$$

Kuan and Lee show that p-values can be derived from $J \xrightarrow{D} \chi^2(2)$.

4.2. Automatic variance ratio (AVR) test

The VR test is based on the property that, under the random walk hypothesis, the variance of k-period return is k times the variance of 1-period return. Hence, the variance ratio VR(k), defined as the ratio of variance of k-period return to k times of the variance of 1-period return, should be equal to one for all holding period k. The test requires the choice of holding period k. However, this choice is often arbitrary and selected without any statistical justifications. The AVR test, originally proposed by Choi (1999), selects the value of k using a fully data-dependent and automatic procedure. Choi's (1999) AVR test statistics take the following:

$$\mathrm{VR}(k) = 1 + 2\sum_{i=1}^{T-1} m(i/k)\hat{\rho}(i) \tag{12}$$

$$\text{where } \hat{\rho}(i) = \frac{\sum_{t=1}^{T-i}(Y_t-\hat{\mu})(Y_{t+1}-\hat{\mu})}{\sum_{t=1}^{T}(Y_t-\hat{\mu})^2} \text{ and } \hat{\mu} = T^{-1}\sum_{t=1}^{T} Y_t$$

where $\hat{\rho}(i)$ is the sample autocorrelation of order i and $\hat{\mu}$is the sample mean of x_t. Note that $m(\cdot)$ is a weighting function with positive and declining weights. We follow Choi (1999) and use the quadratic spectral kernel for the weighting function so that

$$m(x) = \frac{25}{12\pi^2x^2}\left[\frac{\sin(6\pi x/5)}{6\pi x/5} - \cos(6\pi x/5)\right]. \tag{13}$$

According to Choi (1999), VR(k) given in Eq. (12) is a consistent estimator of the normalized spectral density for Y_t at zero frequency. Under the null hypothesis that x_t is serially uncorrelated, Choi (1999) posits that

$$\mathrm{AVR}(k) = \sqrt{T/k}[\mathrm{VR}(k)-1]/\sqrt{2} \xrightarrow{d} N(0,1) \tag{14}$$

as $k\to\infty$, $T\to\infty$,$T/k\to\infty$, when Y_t is generated from a martingale difference sequence with proper moment conditions. In order to choose the value of lag truncation point (or holding period) k optimally, Choi (1999) adopts a data-dependent method of Andrews (1991) for spectral density at the zero frequency. The automatic variance ratio test statistic with the optimally chosen lag truncation point is denoted as $\mathrm{AVR}\left(\hat{k}\right)$.

To complement the $\mathrm{AVR}\left(\hat{k}\right)$ test, we use normal critical values of 1.96 and −1.96 for 5% level of significance. This is based on the asymptotic approximation based on the limiting distribution given in Eq. (14). However, this approximation can be inadequate in small samples, especially when Y_t is subject to conditional heteroskedasticity. An alternative is to use the wild bootstrap of Mammen (1993), which provides alternative critical values or p-values of the test which does not rely on asymptotic approximations. Kim (2009) proposed the use of the wild bootstrap for $\mathrm{AVR}\left(\hat{k}\right)$ is conducted in three stages as below:

(i) Form a bootstrap sample of T observations $Y_t^*=\eta_t x_t$ $(t=1,\ldots,T)$ where η_t is a random sequence with $E(\eta_t)=0$ and $E(\eta_t^2)=1$;
(ii) Calculate $\mathrm{AVR}^*\left(\hat{k}^*\right)$, the AVR statistic obtained from $\{Y_t^*\}_{t=1}^{T}$; and
(iii) Repeat (i) and (ii) B times to form a bootstrap distribution $\left\{\mathrm{AVR}^*\left(\hat{k}^*;j\right)\right\}_{j=1}^{B}$.

The two-tailed p-value of the test is obtained as the proportion of the absolute values of $\left\{\mathrm{AVR}^*\left(\hat{k}^*;j\right)\right\}_{j=1}^{B}$ greater than the absolute value of $\mathrm{AVR}\left(\hat{k}\right)$.

In summary, it should be emphasized that Kuan and Lee's methodology captures not only linear but also nonlinear relations in past returns. Thus it provides a more stringent test for MDH than those MDH tests prior to Kuan and Lee's. Since the random walk is a martingale in its return increment (i.e. the first difference) itself, Kuan and Lee's results can be compared with findings from the widely used random walk test, which relies on the first difference of return series, that is independently and identically distributed with zero mean and finite variance. In this sense, randomness in return increment is a special case of martingale difference.

More specifically, Kim's (2009) AVR test modifies Choi (1999) by relaxing the iid assumption and taking into account heteroskedastic incremental variances in return series at different lags. Kim subsequently derives the test statistics of p-values by wild bootstrapped method which is capable of handling small samples. Thus Kim's AVR test examines whether a time series has statistically significant serial correlation. Alternatively, we can employ Kuan and Lee's test of martingale difference sequence of asset returns that have no serial correlation at any lag. In this sense, Kuan and Lee's MDH test and Kim's AVR test complement but in different ways.

5. Empirical results

In this study, we have incorporated many tools of time series analysis reported in the literature. A brief background of the analytical concepts we used in this study starts from the seminal work of Meese and Rogoff (1983), which examines 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 rates by a nonlinear exponential smooth transition autoregressive model. Lee, Kim, and Newbold (2004) show the importance of a structural break in its drift term, which can be analyzed by time series models using the standard VR analysis in comparison to the martingale hypothesis test: the rejection of the martingale hypothesis by the Lo and MacKinlay (1989) VR test may be caused by ignoring the presence of structural breaks.

More recently, 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. They find the disappearance of autocorrelation as a result of the liberalization of the Korean foreign exchange market, which they interpret as an improvement in the informational efficiency of the Korean won.

5.1. Results for MDH

In financial economics it is routinely assumed that the mean of a time series does not depend on the information set built from past values. The unique property in the test of the martingale difference hypothesis is the use of information contained in the second moment of a process, that is using test statistics based on the sample autocovariance (Dominguez & Lobato, 2003). Our test is performed for multiples of 2, 5, 10, and 30 days of lagged time series. Tables 2–4 report the p-values of the MDH test suggested by Kuan and Lee (2004) obtained for each of the three base currencies in different lag periods, ks. *** represents a one percent, ** a five percent and * a 10% level of significance. Whether to reject or not reject the null for the purpose of this study, we use the 10% level of significance applicable.

We 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. The three sub-periods constitute the structural breaks *ex post* for the purpose of statistical testing of the time series we analyzed. Need it be said that the timeline of the Asian financial crisis is known and so are the public pronouncements of the central banks of the countries studied here on the shift of their foreign exchange rate systems from “pegged” to “floating” ones. The main focus of our study is to see whether or not there is a stability in the reverting pattern of intertemporal returns change against deterministic trend line of foreign exchanges during the three different sub-periods. In this respect, the structural breaks in our study are event-driven, not time series-model driven.[12]

The results we obtained for the full period (see Table 2) are not consistent with the MDH, as many of the p-values of $J(k)$ 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 VAR tests such as, the LOMAC and the Wright tests, which results are reported elsewhere.[13] In the first sub-period prior to the Asian crisis, as shown in Table 3, the MDH is rejected when the individual sample currencies are either measured in any of the three base currencies or in at least one base currency and one holding period at 10% level of significance. The results in this period are similar to that of the full period as reported in Table 2. The inference is the same over the post-Asian crisis period (see Table 4) except for the Australian dollar and the South Korean won for which the MDH is not violated when they are measured against any of the three benchmark currencies and in any holding periods. Note that during the pre-Asian crises period the MDH for AUD and MYR is not rejected relative to two benchmark currencies. Thus, one may consider that these currencies behave as weak-form efficient during that period. Our findings in this regard are consistent with at least two studies: Williamson (2001), who concludes that the Korean won and the Malaysian ringgit have followed a depreciating Japanese yen and the Singapore dollar an appreciating Japanese yen, and Eom et al. (2008), who find a significant improvement in information efficiency in the U.S. dollar price of the Korean won since the country's exchange rate systems shifted from a managed floating to an independent floating rate.

5.2. Results for the automatic variance ratio (AVR)

Variance ratio tests are based on the property that, if an asset return is purely random, the variance of k-period return is k times the variance of the one-period return. In implementing the tests, however, the holding periods of k values have been arbitrary, such as daily return for holding period k of 2, 5 and 10 days. These choices are often arbitrary with little statistical justifications. We modify Choi's (1999) automatic variance ratio (AVR) test in which the optimal value of k is automatically determined by a data-dependent procedure with a wild bootstrapped test statistics, which is designed to correct unknown conditional heteroskedasticity in the return process.

Table 5 reports the wild bootstrap p-values of the AVR test proposed by Kim (2009). The starred values indicate the p-values corresponding to the rejection of the null of random walk, all at 10% level of significance. It is evident from the table that the MYR and KRW overall follow the random walk for the entire sample period from Jan. 1993 to Dec. 2008. During the pre-Asian crisis period, none of the sample currencies follow a random walk except the MYR. In the period following the change in foreign exchange regime (i.e. the post-Asian crisis period) from a pegged to a free-floating system, only the AUD and the KRW are shown to have no rejections against the RWH. This implies that the regime change has brought about an improvement in market efficiency in those two currencies. In addition, the result of the AVR test in the post crisis period is consistent with that of the MDH test in the same period; namely, we provide evidence that corroborates a random walk and a martingale difference process for AUD and KRW. In short, as we noted above, the AVR test and the MDH test complement each other in that AUD and KRW exhibit a weak form of market efficiency in the post-crisis period, which was absent in the pre-crisis period. Both AUD and KRW have a

[12] Many academic studies used econometric models, such as univariate and vector autoregressive model (Meese & Rogoff, 1983), unit root analysis (Liu & He, 1991) and autocorrelation analysis (Eom et al., 2008). We are grateful to an anonymous referee for pointing out this important point.

[13] Al-Khazali et al. (2009).

Table 2
The *p*-values of Kuan and Lee's MDH tests for the full period: Jan. 1993–Dec. 2008.

	k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
USD	2	0.254	0.174	0.547	0.213	0.321	0.213	0.086*	0.432
	5	0.173	0.000***	0.134	0.115	0.126	0.047*	0.754	0.231
	10	0.197	0.045**	0.217	0.216	0.092*	0.000***	0.000***	0.047**
	30	0.227	0.412	0.092**	0.218	0.432	0.043**	0.213	0.143
YEN	2	0.291	0.087*	0.512	0.254	0.125	0.046*	0.043*	0.321
	5	0.085*	0.347	0.184	0.252	0.762	0.342	0.092*	0.095*
	10	0.285	0.091*	0.193	0.231	0.321	0.048**	0.087*	0.096*
	30	0.095*	0.042**	0.174	0.000***	0.265	0.213	0.654	0.086*
EUR	2	0.152	0.139	0.143	0.081*	0.086*	0.045**	0.217	0.153
	5	0.092*	0.266	0.326	0.543	0.154	0.654	0.128	0.754
	10	0.236	0.274	0.043**	0.174	0.143	0.123	0.312	0.234
	30	0.314	0.347	0.262	0.177	0.761	0.341	0.142	0.263

Note: Kuan and Lee's martingale difference hypothesis test for nominal daily returns of the eight sample currencies measured in U.S. dollar (USD), Japanese yen (YEN), and Euro (EUR), for the study period from Jan. 1, 1993 to Dec. 31, 2008. The eight currencies tested are the Indonesian rupiah (IDR), the Malaysian ringgit (MYR), the Philippine peso (PHP), the Singapore dollar (SGD), the South Korean won (KRW), the Taiwanese dollar (TWD), and the Thai baht (THB). Under the null MDH, returns of the sample currencies follow a martingale difference sequence, and the test statistics (or *J* statistics) have a Chi-square distribution with two degrees of freedom asymptotically. The *p*-values obtained in each of the three base currencies for different lag periods, *k*s are shown by *** for a 1%, ** for a 5% and * for a 10% level of significance, respectively.

Table 3
The *p*-values of Kuan and Lee's MDH tests for the pre-Asian crisis period: Jan. 1993–Nov. 1997.

	k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
USD	2	0.131	0.172	0.216	0.431	0.000***	0.432	0.044**	0.532
	5	0.342	0.278	0.185	0.036**	0.432	0.321	0.423	0.298
	10	0.234	0.167	0.342	0.198	0.189	0.047**	0.165	0.235
	30	0.182	0.000***	0.341	0.189	0.089*	0.431	0.267	0.216
YEN	2	0.096*	0.231	0.037**	0.276	0.214	0.563	0.235	0.414
	5	0.093*	0.087*	0.000***	0.321	0.047***	0.087*	0.241	0.087*
	10	0.172	0.272	0.317	0.00***	0.043**	0.231	0.000***	0.046**
	30	0.165	0.165	0.321	0.00***	0.453	0.213	0.432	0.082*
EUR	2	0.251	0.215	0.176	0.215	0.000***	0.323	0.231	0.231
	5	0.154	0.261	0.143	0.087*	0.265	0.216	0.032**	0.042**
	10	0.214	0.038**	0.176	0.452	0.231	0.252	0.264	0.264
	30	0.241	0.231	0.314	0.421	0.564	0.265	0.232	0.453

Note: Kuan and Lee's martingale difference hypothesis tests for nominal daily returns of the eight sample currencies in U.S. dollar (USD), Japanese yen (YEN), and Euro (EUR), for the pre-Asian crisis period from Jan. 1, 1993 to Nov. 30, 1997. The eight currencies tested are the Indonesian rupiah (IDR), the Malaysian ringgit (MYR), the Philippine peso (PHP), the Singapore dollar (SGD), the South Korean won (KRW), the Taiwanese dollar (TWD), and the Thai baht (THB). Under the null MDH, returns of the sample currencies follow a martingale difference sequence, and the test statistics (or *J* statistics) have a Chi-square distribution with two degrees of freedom asymptotically. The *p*-values obtained in each of the three base currencies for different lag periods, *k*s are shown by *** for a 1%, **for a 1% and * for a 10% level of significance, respectively.

Table 4
The *p*-values of Kuan and Lee's MDH tests for the post-Asian crisis period: Dec. 1998–Dec. 2008.

	k	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
USD	2	0.142	0.432	0.324	0.254	0.096*	0.342	0.564	0.376
	5	0.321	0.264	0.241	0.342	0.094*	0.278	0.041**	0.543
	10	0.283	0.038**	0.453	0.043**	0.039**	0.543	0.000***	0.042**
	30	0.352	0.321	0.039*	0.189	0.453	0.432	0.265	0.286
YEN	2	0.172	0.000***	0.267	0.215	0.453	0.189	0.089*	0.543
	5	0.263	0.000***	0.675	0.423	0.432	0.486	0.651	0.326
	10	0.421	0.000***	0.786	0.321	0.342	0.354	0.087*	0.082*
	30	0.196	0.089*	0.352	0.386	0.786	0.278	0.376	0.084*
EUR	2	0.214	0.253	0.156	0.095*	0.342	0.453	0.087*	0.432
	5	0.198	0.214	0.763	0.321	0.265	0.453	0.342	0.038**
	10	0.184	0.215	0.046**	0.045**	0.038**	0.376	0.089*	0.564
	30	0.263	0.028**	0.043*	0.276	0.089*	0.321	0.342	0.421

Note: Kuan and Lee's martingale difference hypothesis tests for nominal daily returns of the eight sample currencies in U.S. dollar (USD), Japanese yen (YEN), and Euro (EUR), for the post-Asian crisis period from Dec. 1, 1997 to Dec. 31, 2008, or. The eight currencies tested are the Indonesian rupiah (IDR), the Malaysian ringgit (MYR), the Philippine peso (PHP), the Singapore dollar (SGD), the South Korean won (KRW), the Taiwanese dollar (TWD), and the Thai baht (THB). Under the null MDH, returns of the sample currencies follow a martingale difference sequence, and the test statistics (or *J* statistics) have a Chi-square distribution with two degrees of freedom asymptotically. The *p*-values obtained in each of the three base currencies in different lag periods, *k*s are shown by *** for a 1%, **for a 5% and * for a 10% level of significance, respectively.

Table 5
The *p*-value of Kim's automatic variance ratio tests for the three study periods.

	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
The full period: Jan. 1993–Dec. 2008								
USD	0.07*	0.02**	0.56	0.13	0.08*	0.78	0.00***	0.00***
YEN	0.16	0.44	0.9	0.04**	0.17	0.73	0.02**	0.01***
EUR	0.17	0.58	0.8	0.81	0.00***	0.91	0.00***	0.37
The pre-Asian crisis period: Jan. 1993–Nov. 1997								
USD	0.01***	0.01***	0.18	0.08*	0.01***	0.15	0.00***	0.00***
YEN	0.16	0.04**	0.59	0.17	0.09*	0.04**	0.01***	0.00***
EUR	0.9	0.71	0.83	0.89	0.09*	0.17	0.19	0.04**
The post-Asian crisis period: Dec. 1998–Dec. 2008								
USD	0.28	0.01***	0.98	0.22	0.84	0.89	0.53	0.4
YEN	0.33	0.03**	0.11	0.09*	0.15	0.99	0.01***	0.27
EUR	0.35	0.67	0.06*	0.07*	0.02**	0.4	0.00***	0.09*

Note: Automatic variance ratio test of the random walk hypothesis (RWH) for nominal daily returns of the eight sample currencies in U.S. dollar (USD), Japanese yen (YEN), and Euro (EUR), for the full study period from Jan. 1, 1993 to Dec. 31, 2008 and the pre- and post-Asian crisis periods. Under the null, the variance of *k* period is equal to *k* times the variance of one period variance. *k* is chosen automatically, following Choi (1999). The two-tailed p-value for testing the hypothesis is derived from the wild bootstrap method of Kim (2009). The *p*-values obtained in each of the three base currencies for different holding periods, *k*s are shown by *** for a 1%, **for a 5% and * for a 10% level of significance, respectively.

rejection of the null hypothesis before the crisis, but show no rejection afterwards. The MYR shows no rejection before the crisis, but only one rejection afterwards.

Again, our findings on KRW is consistent with: Williamson (2001), who finds that the Korean won and the Malaysian ringgit have followed a depreciating Japanese yen and the Singapore dollar an appreciating Japanese yen, and Eom et al. (2008), who find a significant improvement in information efficiency in the U.S. dollar price of the Korean won since the Asian financial crisis in 1997. It should be noted that Cheung, Chin, and Pascual (2005) find that while the overall efficiency of KRW has improved, the currency's directional changes show an asymmetrical relationship between the U.S. dollar-based and the Japanese yen-based KRW. This means that while the market efficiency of KRW is statistically efficient when it is measured in the U.S. dollar, the Euro and the yen, there are arbitrary opportunities for traders who use technical trading rules.

The IDR and TWD exhibit strong evidence of non-random walk, since they show two rejections, both before and after the Asian crisis. The SGD and THB show marked improvement in their random walk property: both show three rejections before the crisis, but only one rejection after the crisis. In contrast, the PHP shows no evidence of such improvement.

Thus, MDH and AVR 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.

5.3. Comparisons between MDS and AVR tests

The comparisons of our findings from MDS and AVR tests are reported in Table 6. First, the MDS test, for the full period, indicates that when the Euro is the base currency, the MDS hypothesis is rejected for AUD, MYR, PHP, SGD and KRW while the AVR

Table 6
Comparisons between MDS and AVR tests.

MDH test/AVR test								
	AUD	IDR	MYR	PHP	SGD	KRW	TWD	THB
The full period: Jan. 1993–Dec. 2008								
USD	A/R	R/R	R/A	A/A	R/R	R/A	R/R	R/R
YEN	R/A	R/A	A/A	R/R	A/A	R/A	R/R	R/R
EUR	R/A	A/A	R/A	R/A	R/R	R/A	A/R	A/A
The pre-Asian crisis period: Jan. 1993–Nov. 1997								
USD	A/R	R/R	A/A	R/R	R/R	R/A	R/R	A/R
YEN	R/A	R/R	R/A	R/A	R/R	R/R	R/R	R/R
EUR	A/A	R/A	A/A	R/A	R/R	A/A	R/A	R/R
The post-Asian crises period: Dec. 1998–Dec. 2008								
USD	A/A	R/R	R/A	R/A	R/A	A/A	R/A	R/A
YEN	A/A	R/R	A/A	A/R	A/A	A/A	R/R	R/A
EUR	A/A	R/A	R/R	R/R	R/R	A/A	R/R	R/R

Note: Each cell in the table reports a result (i.e. reject or accept decision) of martingale difference hypothesis (MDH) and automatic variance ratio (AVR) test. For instance, R/A represents that the MDH is "Rejected", while the AVR is "Accepted." 10% level of significance is used as the cut off rate for both of the tests. In case of the MDH test, "R" is reported if a currency is rejected for one of the four holding period (see Tables 2 to 4 for detail).

test shows that the RWH is rejected for SGD and TWD exchanges rates only. Second, when the USD is the base currency, the MDS hypothesis is rejected for all currencies except for AUD and PHP while the RWH hypothesis is rejected for all exchange rates except for MYR, PHP and KRW. Third, when the yen is the base currency, the MDS hypothesis is rejected for all currencies except for MYR and SGD while the RWH is rejected for PHP, TWD and THB exchange rates only. In summary, the results for the entire period show that the RW and MD hypotheses are rejected for all exchange rates at least against one benchmark currency, except for MYR and KRW when AVR is used. Note that AUD, IDR and PHP exchange rates are rejected against one base currency only. Furthermore, the results of each test depend on the benchmark used.

For the pre-Asian crises period, the results of both tests show: first, when the Euro is the benchmark the MDS hypothesis is rejected for IDR, PHP, SGD, TWD and THB while the RWH is rejected only for SGD and THB exchange rates. Second, when the USD is the base currency, the MDS hypothesis is rejected for all exchange rates except for AUD, MYR and THB while the RWH is rejected for all exchange rates except for MYR and KRW. Third, when the yen is the base currency, the MDS hypothesis is rejected for all exchange rates while the AVR test show that the RWH is rejected for all exchange rates except for AUD, MYR and PHP. In summary, the results, for the pre-Asian crisis period show that the RW and MD hypotheses are rejected for all exchange rates at least against one benchmark, except for MYR when AVR test is used. Note that MDS is rejected for AUD and MYR against one benchmark while RW is rejected for AUD, PHP and KRW.

For the post-Asian crisis period, the MDS hypothesis is not rejected for AUD and KRW against the three benchmarks. However, it is rejected for the other currencies against at least two benchmarks. Furthermore, the AVR test does not reject the RWH for AUD and KRW against the three benchmarks. However, the RWH hypothesis is rejected for the other currencies against at least one benchmark. In summary, the results, for the post-Asian crises show that the RW and MD hypotheses are rejected for all exchange rates, using the three benchmarks, except for AUD and KRW. Note that MYR, SGD and THB exchange rates are rejected relative to one benchmark.

We conclude that the results of both tests show that for the sub-period following the Asian crisis, only the Australian dollar and the Korean won behave as weak-form efficient relative to three benchmark currencies while the other Asian currencies show no discernible improvement toward market efficiency. We may also consider random walk behavior for any currency behaving as weak-form efficient relative to at least two benchmark currencies.

6. Concluding remarks

This paper tests the random walk hypothesis (RWH) and the martingale difference hypothesis (MDH) 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 Kuan and Lee's (2004) test to investigate the MDH and Kim's (2009) test to examine the RWH.

Our results suggest that (i) Kuan–Lee's and Kim's tests are useful for evaluating the two hypotheses studied in this paper, (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.

These findings are consistent with the conclusions of Ahn, Lee, and Suh (2002) and Ryoo (2001), Yilmaz (2003) and Eom et al. (2008) for the Korean won in that noise trading, which may have existed, especially in the inter-bank exchange transactions, may no longer be as replicable, as the liberalization of foreign exchange rules and regulations implemented by the government of South Korea in the aftermath of the Asian financial crisis, which seems to have enhanced the overall efficiency of the won against the three world reserve currencies. Our findings in this respect are as much about the efficiency of the Korean won as they are about the countries concerted efforts in liberalizing the respective financial markets in recent years. Our findings on the Australian dollar also support those reported by Bowman (2005).

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. In particular, central bank interventions in emerging foreign exchange markets in Asia have often been pronounced. This is particularly true for the period examined in this paper during which the Euro has appreciated against the U.S. dollar, resulting in massive shifts in many Asian countries away from the U.S. 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 floating rate systems.

We have evaluated the martingale process by ascertaining mean-independence or conditional-mean-independence in the second moment of a process (Dominguez and Lobato (2003). In this sense, we have affirmed the empirical validity of the assumption implicit in the “technical” or “filter” rules that returns revert to their historical or time-varying means at least for the six Asian emerging currencies, which have been on floating rate systems since the Asian financial crisis in 1998.

For future research, the affirmation of the martingale processes in these Asian currencies lend strong support to a growing academic literature on the intertemporal stability of excess returns to technical trading rules in the foreign exchange markets — the intertemporal stability of excess returns which are consistent with the adaptive market hypothesis (AMH), not with the efficient market hypothesis (Lo, 2004; Neely, Weller, & Ulrich, 2007). Under the 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 ones.

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