Working Paper Series: 19 Jan/2015

Testing for Martingale Difference Hypothesis with Structural Breaks: Evidence from Asia-Pacific Foreign Exchange Markets

Afees A. Salisu and Tirimisiyu F. Oloko

Centre for Econometric and Allied Research (CEAR), University of Ibadan, Nigeria.
www.cear.org.ng

Testing for Martingale Difference Hypothesis with Structural Breaks: Evidence from Asia-Pacific Foreign Exchange Markets

Afees A. Salisu[a,b,c] **and Tirimisiyu F. Oloko**[b]

[a] Department of Economics, University of Ibadan, Nigeria.
[b] Centre for Econometric and Allied Research (CEAR), University of Ibadan, Nigeria.
Email: olokotrimicy@yahoo.com; tf.oloko@cear.org.ng
[c] Corresponding author: Department of Economics and Centre for Econometric and Allied Research, University of Ibadan, Oyo State, Nigeria.
Email: aa.salisu@mail.ui.edu.ng; aa.salisu@cear.org.ng
Mobile: (+234) 8034711769

Abstract

This study tests for martingale difference hypothesis (MDH) in nine selected Foreign Exchange (FX) markets from Asia-Pacific countries. Its main contributions to the literature include: (i) it adopts most recent techniques in both the Autocorrelation based and Spectrum based tests for MDH, namely; the Wild Bootstrap Automatic Variance Ratio test by Kim (2009) and Wild Bootstrap Generalized Spectral test by Escanciano and Velasco (2006); (ii) it determines structural breaks endogenously for all the returns series using Perron (2006) unit root test with structural break, and (iii) based on the Perron results, it obtains two sub-samples and thereafter tests for MDH. Empirical result from this study shows that FX markets of the Asia-Pacific are martingale under the full sample period. Meanwhile, after accounting for structural break, the result shows that South Korean FX market is non-martingale before the structural break while China FX market is non-martingale after the structural break. Thus, a preliminary test for structural break may be necessary before any meaningful generalization can be made on financial series when testing for MDH.

JEL Codes: C12, F31

Key words: Martingale Difference Hypothesis (MDH), Structural breaks, Asia-Pacific, FX market

Testing for Martingale Difference Hypothesis with Structural Breaks: Evidence from Asia-Pacific Foreign Exchange Markets

1.0 Introduction

The main objective of this study is to investigate whether Asia-Pacific Foreign exchange (FX) markets satisfy martingale difference hypothesis (MDH) and to also verify whether accounting for structural breaks matters. The MDH plays a central role in economic models where expectations are assumed to be rational (Escanciano and Lobato, 2009). Given the current information set, the martingale hypothesis implies that the best predictor of future values of a time series, in the sense of least mean squared error, is simply the current value of the time series (Escanciano and Lobato, 2009). Empirical literature testing the MDH have adopted different methodology ranging from the linear measures to the non-linear ones. Examples of the linear measures are the portmanteau test by Ljung and Box (1978) and variance ratio test by Lo and MacKinlay (1988, 1989). Recently however, more sophisticated techniques have been developed with better power and size properties under each category. Prominent among these new linear measures are automatic portmanteau (AQ) test of Escanciano and Lobato (2009);and the automatic variance ratio (AVR) test of Kim (2009) which extends the earlier work of Choi (1999). For the non-linear measures, the notable recent tests are the generalized spectral (GS) test of Escanciano and Velasco (2006) and the consistent tests of Dominguez and Lobato (2003).Charles et al.(2011) provide for a review of the recent tests while a survey of their applications on foreign exchange markets is detailed in a related paper by Azad (2009).

With the increasing proliferation of tests, Charles et al. (2011) conduct a Monte Carlo experiment to compare power properties of alternative tests for the MDH. Overall, they find that the wild bootstrap AVR test shows the highest power against linear dependence; while the GS test performs most desirably under nonlinear dependence. Thus, in this study, we adopt both the wild bootstrap AVR and wild bootstrap GS tests for the MDH. Our study covers nine Asia-Pacific FX markets in China, Hong Kong, Indonesia, Japan, Malaysia, Philippine, Singapore, South Korea and Thailand. Their currencies are among the thirty (30) most traded exchange rates in the world. Unlike Al-Khazali et al. (2012) that conducted a similar study, we also account for structural breaks in the MDH tests using the Perron (2006) generalized structure for analyzing structural breaks with unit roots. Consequently, we obtain two sub-samples based on the break point and thereafter test for MDH. The resulting statistics are compared with the full sample in order to ascertain the possibility of any significant changes as a result of structural breaks. All these analyses combined distinguish this paper from the previous works.

Section 2 describes the data and also provides some preliminary analyses. Section 3 presents the econometric methodology implemented in the study. Section 4 discusses the empirical results while Section 5 concludes the study.

2.0 Preliminary analyses

This section describes data and provides some preliminary information about the FX markets of the nine Asia-Pacific countries earlier mentioned. To start with, we examine the weak form efficiency of these FX markets by testing for the significance of martingale difference hypothesis (MDH). Exchange rate measure used here expresses the domestic currencies of the selected countries relative to Euro due to the large volume of transactions recorded between these countries and Europe. Also, the increasing economic integration between the Asia-Pacific and Europe which has continued to foster economic ties including trade relations between them justifies the need for an efficient FX market in terms of the demand for and supply of their currencies. For convenience, we use CNY for Chinese Yuan Renminbi, HKD for Hong Kong Dollar, IDR for Indonesian Rupiah, JPY for Japanese Yen, KRW for South Korean Won, MYR for Malaysian Ringgit, PHP for Philippine Peso, SGD for Singaporean Dollar and THB for Thai Baht relative to Euro. Therefore, an increase in exchange rate will mean depreciation in the domestic currency relative to Euro while a decrease will mean appreciation. Weekly data for the period from April 1, 2005 to September 12, 2014 were obtained from the database of the Central Bank of Ireland. Exchange rate return is described as the continuously compounded exchange rate percentage returns at time t calculated as below:

$$R_t^i = 100 * \ln(E_t^i / E_{t-1}^i) \qquad (1)$$

where R_t^i is the exchange rate returns of a given country i at time t, E_t^i is the exchange rate of that country at time t, while E_{t-1}^i represents one period lag in exchange rate of a chosen country. We carry out preliminary analyses on both level and returns series to examine the statistical features for martingale hypothesis (MH) and martingale difference hypothesis (MDH) respectively in the exchange rate of the Asia-Pacific countries. Meanwhile, empirical analysis is done using the returns series to circumvent the problem of non-stationarity usually encountered with the level series (see Escanciano and Lobato, 2009). Thus, we test the weak form efficiency of the selected FX markets by examining whether the exchange rate returns of these countries are Martingale Difference Sequence (MDS).

Table 1 presents the descriptive statistics of the series under two panels A and B. Panel A describes the level series while Panel B describes the return series. The mean value under both panels shows the average value for the exchange rate and exchange rate returns respectively for the countries under study. As expected, Panel A shows that all the exchange rates have positive mean values with the highest positive value being that of the IDR and the least positive value being for SGD. This implies that the SGD is the strongest currency relative to Euro while the IDR is the weakest among the currencies under consideration. This seems to be explained by the degree of exchange rate volatility in each FX market. As observed, IDR has the highest standard deviation while the SGD has the lowest. This implies that IDR is the most volatile currency while SGD is the least volatile. Similarly, CNY, HKD, IDR, JPY, KRW and THB exhibit positive skewness which suggests higher possibility of depreciation for these currencies relative the Euro. Whereas, negative skewness in MYR, PHP and SGD suggest they have higher probability of appreciation. On the other hand, kurtosis statistic shows that with the exception of HKD which has fairly normal excess kurtosis, exchange rates of all other countries are platykurtic or thin tailed.

Table 1: Descriptive statistics

Panel A: Level series

	FX	Obs	Mean	Std. Dev.	Skewness	Kurtosis	JB	LB-Q(10)	LB-Q^2(10)	ARCH LM(5)	ARCH LM(10)
China	CNY	494	9.291	0.918	0.110	1.722	34.589*	9.944	133.16*	51.18*	83.98*
Hong Kong	HKD	494	10.436	0.692	0.566	3.173	27.025*	5.229	88.425*	119.64*	121.32*
Indonesia	IDR	494	13018.630	1432.648	0.832	2.594	60.392*	10.914	251.64*	94.70*	97.98*
Japan	JPY	494	132.302	19.395	0.038	2.065	18.100*	10.917	79.810*	42.23*	58.05*
Malaysia	MYR	494	4.480	0.339	-0.019	1.987	21.126*	8.84	78.917*	56.53*	70.23*
Philippine	PHP	494	61.606	4.686	-0.103	2.386	8.644**	14.381	90.064*	46.19*	74.40*
Singapore	SGD	494	1.874	0.183	-0.146	1.517	47.014*	12.792	78.83*	43.89*	59.15*
South Korea	KRW	494	1455.419	178.039	0.354	2.618	13.317*	20.014**	214.69*	112.20*	127.65*
Thailand	THB	494	44.617	3.66	0.146	1.985	22.962*	18.201**	99.108*	66.85*	73.73*

Panel B: Return series

	FX	Obs	Mean	Std.Dev.	Skewness	Kurtosis	JB	LB-Q(10)	LB-Q^2(10)	ARCH LM(5)	ARCH LM(10)
China	CNY_R	493	-0.061	1.286	-0.274	5.089	95.791*	9.367	127.48*	46.92*	79.57*
Hong Kong	HKD_R	493	-0.002	1.486	0.162	15.747	3339.729*	6.613	90.85*	123.79*	126.15*
Indonesia	IDR_R	493	0.045	1.512	0.258	5.283	112.523*	9.132	154.42*	66.66*	69.12*
Japan	JPY_R	493	-0.001	1.782	-1.394	12.325	1945.914*	10.088	60.17*	32.94*	42.45*
Malaysia	MYR_R	493	-0.036	1.177	-0.205	4.223	34.181*	8.716	81.83*	58.21*	68.39*
Philippine	PHP_R	493	-0.045	1.274	-0.010	3.750	11.557*	13.77	79.49*	47.55*	73.66*
Singapore	SGD_R	493	-0.056	0.986	-0.210	4.060	26.721*	11.95	73.51*	38.18*	53.92*
South Korea	KRW_R	493	0.005	1.516	0.119	8.630	652.344*	17.68**	167.20*	94.87*	104.98*
Thailand	THB_R	493	-0.040	1.365	-0.017	5.016	83.518*	19.20**	94.55*	67.65*	73.75*

Note: *, ** and *** represent rejection of null hypotheses at 1%, 5% and 10% respectively. Both level and return series are assumed to follow AR(1) process and accordingly, Ljung-Box Q-statistic and ARCH LM tests are performed on the residual series generated from the process.Also, nR^2 statistic is reported for ARCH LM test as against the F-statistic alternative.

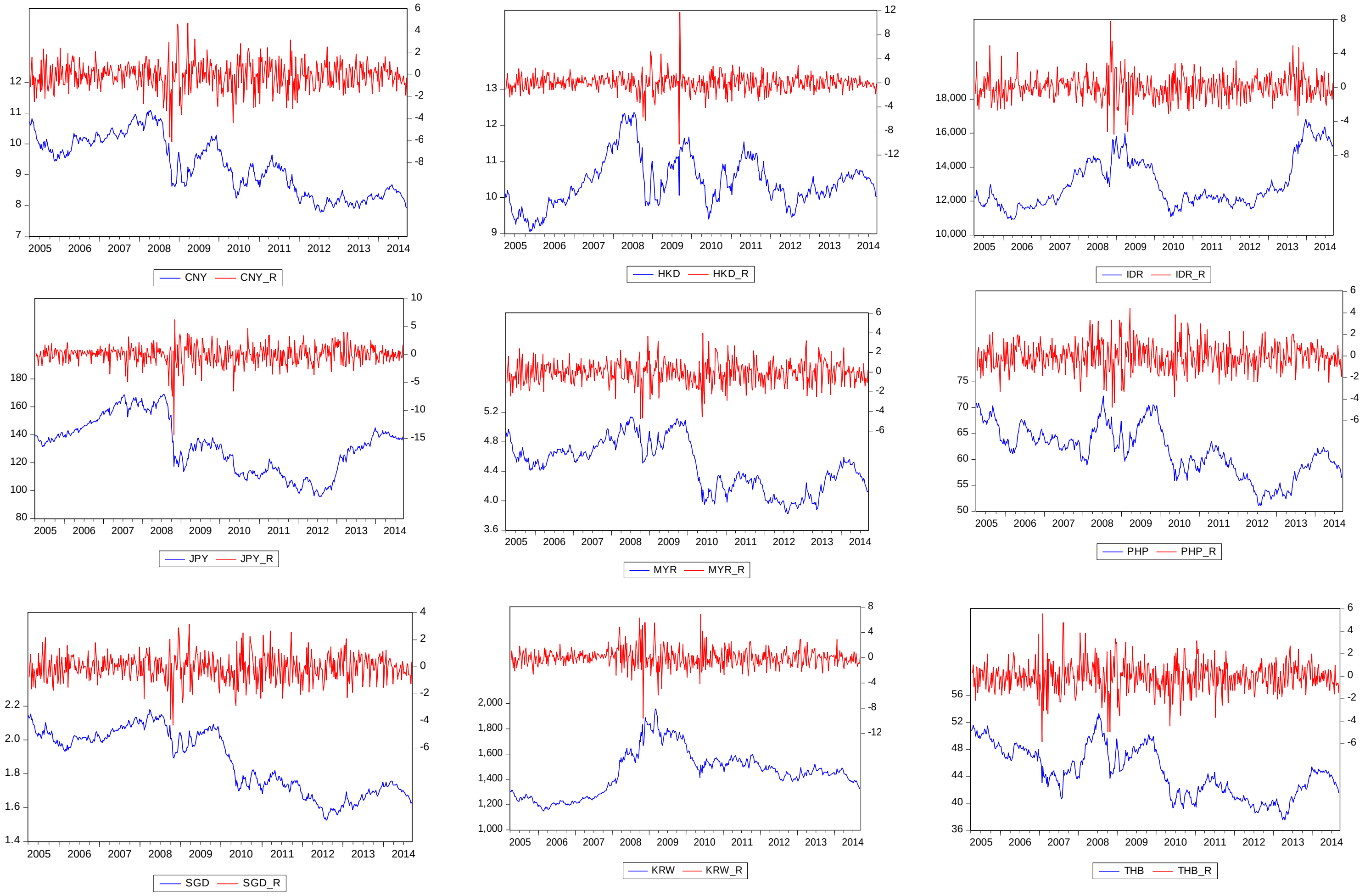
Meanwhile, the Jarque-Bera statistic determined with the combination of skewness and kurtosis statistics reveals that exchange rates of these countries are not normally distributed at 5% level of significance. Furthermore, the Ljung Box Q-statistic for squared residual shows that higher order serial correlation is significant, while ARCH LM test at both lags 5 and 10 reveals that the null hypothesis of no Autoregressive Conditional Heteroscedasticity (No ARCH) effects is strongly rejected. The joint statistical properties of non normality, higher order serial correlation and conditional heteroscedasticity in financial time series such as exchange rate suggest the presence of conditional mean dependence which could be validated under the assumption of martingale hypothesis MH or MDH.

On the other hand, Panel B reveals that most of the currencies have negative average return with the exception of Indonesian rupiah (IDR_R) and South Korean won (KRW_R) returns. This implies that exchange rate returns of seven out of the selected countries appreciated on the average over the period under consideration with the Chinese Yuan Renminbi (CNY_R) being the currency with the highest rate of exchange rate returns appreciation. This may partly be attributable to the increasing trend in Chinese exports to the Euro zone in addition to change in exchange rate regime from fixed to managed floating in 2005. Meanwhile, positive mean values for IDR_R and KRW_R imply that both currencies depreciate on the average over the period under consideration. Also, considering exchange rate returns volatility as depicted by the standard deviations of the returns series, Japanese Yen returns (JPY_R) appears to be the most volatile exchange rate returns and eventually it becomes the one with the least average rate of appreciation as implied by -0.001% mean value. Conversely, SGD_R is the least volatile exchange rate returns as explained by its smallest standard deviation; this enables it to generate another high average rate of appreciation after the Chinese Yuan. The fact that Chinese Yuan has the highest returns despite a fairly high volatility implies efficient management of the FX market by the People's Bank of China.

Furthermore, the skewness statistic shows that all exchange rate returns are skewed while the kurtosis statistic shows that they are all leptokurtic (highly peaked and fat tailed). The Jarque-Bera statistic also reveals that they are not normally distributed. The Q-statistic for squared residual shows that there is significant higher order serial correlation while ARCH LM test shows that we can strongly reject the null hypothesis of no ARCH for all the exchange rate returns. Therefore, evidence of non normality, autocorrelation and ARCH effects is also inherent in exchange rate returns of these countries suggesting the test for MDH. As previously discussed, we employ the wild bootstrapping procedure for Automatic Variance Ratio (AVR) and Generalized Spectral (GS) tests. And as demonstrated by Charles et al. (2011), these techniques have high size and power advantages over others in determining linear and nonlinear dependence in conditional mean of the financial returns.

Meanwhile, evidence from table 1 has revealed the presence of ARCH effects in exchange rate returns which are further buttressed graphically in figure 1, thus justifying the choice of wild bootstrap AVR and GS tests. In addition, evidence from the respective graphs for exchange rate returns of these countries reveals the presence of notable spikes or structural changes which may suggest the presence of structural break. Furthermore, studies have shown that predictability of financial returns is inconsistent over time. In other words, structural changes in financial markets play a significant role in determining the weak form efficiency of the markets (see for example, Charles et al., 2011 and Lazăr et al., 2012).

Figure 1: Graph of level and return series



Thus, this study accounts for the possibility of inconsistency in the weak form efficiency of the FX markets being examined by determining periods of structural change endogenously. As noted earlier, we employ unit root test with structural break by Perron (2006) to determine the break points/dates as well as the stationarity or otherwise of both the level and returns series. The author provides the framework for the implementation of the general structure of the structural break with unit root (see Perron, 1997; 2006). The generalized test regression can be expressed as:

$$y_t = \mu + \theta DU_t + \beta t + \gamma DT_t^* + \delta D(T_1)_t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \; ; \; e_t \sim i.i.d. \;\; (0, \sigma_e^2) \qquad (2)$$

where $DU_t = 1$; $DT_t^* = t - T_1$ if $t > T_1$ and 0 otherwise; $D(T_1)_t = 1$ if $t = T_1 + 1$ and 0 otherwise. The test considered is the minimal value of the t-statistic for testing that $\alpha = 1$ versus the alternative hypothesis that $|\alpha| < 1$ over all possible break dates in some pre-specified range for the break fraction $[\epsilon, 1-\epsilon]$. The implementation of the test regression follows the Innovational Outlier (IO) framework as it allows the change to the new trend function to be gradual rather than being instantaneous as assumed by the Additive Outlier (AO) framework. The result is presented in table 2 below:

Table 2: Unit root with structural break

Countries	FX	Level series			Returns series		
		Break dates	**Coeffs**	**T-stats**	**Break dates**	**Coeffs**	**T-stats**
China	CNY	11/06/2008	-0.057	-4.239	24/10/2008	-0.949	-21.447
Hong Kong	HKD	20/10/2006	-0.046	-3.592	04/09/2009	-1.047	-24.322
Indonesia	IDR	04/12/2009	-0.041	-3.977	17/04/2009	-1.010	-22.341
Japan	JPY	09/11/2012	-0.027	-3.410	24/10/2008	-1.020	-24.108
Malaysia	MYR	04/12/2009	-0.053	-4.687	14/05/2010	-1.012	-22.663

Philippine	PHP	27/11/2009	-0.040	-3.688	20/03/2009	-0.967	-21.623
Singapore	SGD	27/11/2009	-0.043	-4.148	24/10/2008	-0.988	-22.167
South Korea	KRW	02/11/2007	-0.043	-3.851	21/11/2008	-1.093	-24.261
Thailand	THB	04/12/2009	-0.045	-3.854	26/01/2007	-1.029	-23.108

Source: Authors Computations
Note: We extract appropriate Critical values from Table 1(e) model 2 in Perron (1997), which are -5.28 and -4.62 for 1% and 5% level of significance respectively.

From the above table, all level series are not significant but with the exception of MYR which is significant at 5 per cent level of significance. Meanwhile, FX returns series for all the currencies are strongly significant, thus making it impossible to reject the null hypothesis of unit root with structural break. The corresponding break dates for all the returns series are also indicated in table 1. Hence, empirical result is presented for testing the MDH under three folds, namely; the full sample period, the period before structural break and the period after structural break.

3.0 The Methodology

We describe below the underlying methodological procedure for the Wild Bootstrap Automatic Variance Ratio test and the Generalized Spectral tests.

3.1 Wild Bootstrap Automatic Variance Ratio (WBAVR) Test

This methodology is a recent technique developed by Kim (2009) in determining market efficiency using variance ratio (VR) test. The VR test is based on linear dependence with the assumption that a martingale series is serially uncorrelated. The test was first introduced by Campbell and Mankiw (1987) and later developed by Cochrane (1988), Lo and MacKinlay (1988), Chow and Denning (1993), Choi (1999), Wright (2000), Belaire-Franch and Contreras (2004), Kim (2006, 2009), among others. It proposes that for a random (unpredictable) process, the variance for observations taken with an interval of length k must be k times the variance of observations taken with an interval of length 1 (Veka, 2013).Thus, the variance ratio for R_t (which is previously defined as our returns and therefore differenced series)can be expressed as:

$$\mathrm{VR}_k = \frac{\mathrm{Var}\left(R_t - R_{t-k}\right)}{k\mathrm{Var}\left(R_t - R_{t-1}\right)} = 1 + 2\sum_{i=1}^{k-1}\left(1 - \frac{i}{k}\right)\widehat{\rho}_i \tag{3}$$

Where $\widehat{\rho}_i = \frac{\sum_{t=1}^{T-i}\left(R_{t+i} - \hat{\mu}\right)\left(R_t - \hat{\mu}\right)}{\sum_{t=1}^{T}\left(R_t - \mu\right)^2}$ and $\hat{\mu} = T^{-1}\sum_{t=1}^{T} R_t$

Thus, $\widehat{\rho}_i$ denotes the autocorrelation coefficient at the *i*th lag and $\hat{\mu}$ is the mean value of R_t. Meanwhile, the choice of optimal value of k has been the major concern of various VR tests. Before Choi (1999), optimal value of k was largely determined arbitrarily. Choi (1999) was the first to determine the optimal value of holding period k automatically which led to the origin of Automatic Variance Ratio (AVR) test. According to Choi (1999), AVR test is based on a VR estimator related to the normalized spectral density estimator at zero frequency expressed as below:

$$\mathrm{AVR}_k = 1 + 2\sum_{i=1}^{T-1} h\left(\frac{i}{k}\right)\widehat{\rho}_i \tag{4}$$

Where $h\left(\alpha\right)$ is the quadratic spectral kernel, defined as:

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

k_c is thus the optimal bandwidth parameter determined according to the methodology outlined by Andrews (1991). Hence, if x_t is generated from an MDS with proper moment conditions and as $k \to \infty$ and $T \to \infty$, then

$$AVR\left(k_c\right) = \sqrt{\frac{T}{k_c}}\frac{AVR(k_c)-1}{\sqrt{2}} \xrightarrow{d} N(0,1)\,(6)$$

However, Kim (2009) recommends wild bootstrap of Mammen (1993) to strengthen AVR against small sample properties especially when x_t is subject to conditional heteroscedasticity. Kim's (2009) wild bootstrap AVR test employed in this study follows three stages:

1. Form a boostrap sample of size T as $x_t^* = \eta_t x_t$ for $t = 1,...,T,$ with η_t being a random sequence with zero mean and unit variance.
2. Calculate $AVR^*(\hat{k}_c^*)$ with x^*.
3. Repeat items (1) and (2) B times to form a bootstrap distribution $\left\{AVR^*(\hat{k}_c^*; j)\right\}_{j=1}^{B}$.

The two-tailed *p*-value of the test can be obtained by dividing the number of absolute values of $\left\{AVR^*(\hat{k}_c^*; j)\right\}_{j=1}^{B}$ greater than the absolute value of $AVR(\hat{k}_c)$ by the total number of bootstrap samples B:

$$p - value = \frac{\sum_{j=1}^{B} I\left(\left|AVR^*(\hat{k}_c^*; j)\right| > AVR(\hat{k}_c)\right)}{B} \tag{7}$$

We consider both 300 and 500 bootstrap iterations for the purpose of robustness. The asymptotic properties of $AVR(k_c)$ then depend on x_t having a finite fourth moment.

3.2 Generalized Spectral (GS) Test

The GS test of Escanciano and Velasco (2006) is an extension of the generalized spectral density function introduced by Hong (1999) to capture both linear and non-linear dependence in asset returns. The technique has been proven to have high power against non-linear dependence compared to various alternatives such as Deo (2000), Domínguez and Lobato (2003), Hong and Lee (2003) and Kuan and Lee (2004). Hence, this test is employed in this study to capture non-linear dependence in the conditional mean of the exchange rate returns of the selected countries, which would not have otherwise been captured by the AVR test.

The null hypothesis for the GS martingale test is defined as $H_0^* : \{R_t\}$ is an MDS, which implies that $E[R_t | R_{t-1}, R_{t-2}, ...] = \mu$, where μ is a real number. Escanciano and Velasco (2006) considered pairwise approach that makes use of available data in the sample and at the same time avoids high dimensional integration. Thus, they present null hypothesis for testing MDH as:

$H_0 : m_j(r) = 0, \forall j \geq 1,$ as surely (a.s),

where $m_j(r) = E(R_t - \mu | R_{t-j} = r)$ a.s. are the pairwise regression functions. This implies that no matter what value a previous realization of r has taken, the expected future value of r remains the same.

The alternative hypothesis is the negation of the null defined as below:

$H_A :$ there exists a $j \geq 1$ such that $P(m_j(R_{t-j}) \neq 0) > 0$

Thus, the conditional mean dependence measures $\gamma_j(x) = E[(R_t - \mu)e^{ixR_{t-j}}]$, can be viewed as a generalization of the usual autocovariances to measure the conditional mean dependence in a nonlinear time series framework.

On the basis of Theorem 1 in Bierens (1982), the following characterization is used to represent the null hypothesis (8):

$H_0 \Leftrightarrow \gamma_j(x) = 0 \ \forall j \geq 1$ almost everywhere (a.e.).

It follows that under the null hypothesis, $\hat{H}(\lambda, x) = \gamma_0(x)\lambda \equiv \hat{H}_0(\lambda, x)$ and the process for testing the null hypothesis is proposed by the authors as

$$S_n(\lambda, x) = \left[\frac{n}{2}\right]^{1/2} \{\hat{H}(\lambda, x) - \hat{H}_0(\lambda, x)\} = \sum_{j=1}^{n-1} (n-j)^{1/2} \gamma_j(x) \frac{\sqrt{2}\sin(j\pi\lambda)}{j\pi} \tag{8}$$

In order to evaluate the distance between $S_n(\lambda, x)$ and zero for all possible values of λ and x a norm has to be chosen. Escanciano and Velasco (2006) suggest the appropriateness of Cramer von Mises norm:

$$D_n^2 = \int_{\square}\int_0^1 \left|S_n(\lambda, x)\right|^2 W(dx)d\lambda = \sum_{j=1}^{n-1}(n-j)\frac{1}{j\pi^2}\int_{\square}\left|\hat{\gamma}_j(x)\right|^2 W(dx) \tag{9}$$

where $W(.)$ is a weighting function. Furthermore, they suggest the use of either the normal or exponential cumulative distribution function (CDF) as the weighting function. In this study, we employ normal CDF and the test statistic for computing D_n^2 is thus defined as:

$$D_n^2 = \sum_{j=1}^{n-1}(n-j)\frac{1}{(j\pi)^2}\sum_{t=j+1}^{n}\sum_{s=j+1}^{n}(R_t - \bar{R}_{t-j})(R_s - \bar{R}_{s-j})\exp[-0.5(R_{t-j} - R_{s-j})^2] \tag{10}$$

The null hypothesis of MDH is rejected when D_n^2 becomes sufficiently large. As the distribution of D_n^2 under the null depends on the data-generating process, wild bootstrapping procedure is employed to generate p-values as suggested by Escanciano and Velasco (2006).

4.0 Discussion of Results

Table 3 presents the results of the wild bootstrap AVR and GS tests. Figures in the table represent the probability values for rejection of MDH. Higher *p* value above and inclusive of0.10 indicates impossibility of rejection of the null hypothesis. This would imply that the conditional mean of the financial returns is not linearly or nonlinearly dependent; hence, it is martingale, or it is weak form efficient. The higher the *p* value of an FX market the more weak form efficient it becomes. Economic implication of this is that it is impossible to make abnormal profit in such an efficient market through speculations.

Meanwhile, MDH result under the full sample period shows that exchange rate returns of virtually all the countries under study are MDS process. This implies that we cannot reject the martingale difference hypothesis for all the FX markets. In other words, there is no evidence of linear and nonlinear dependence in the conditional mean of the exchange rate returns of the nine selected Asia-Pacific countries under study as evident from the result of the AVR and GS tests respectively. Therefore, FX markets of these countries are adjudged to be weak form efficient. In essence, it is not possible to make abnormal profit in these FX markets through speculations since the markets are very difficult to predict.

Table 3: Probabilities of rejection of null hypothesis

Full Sample						
			GS Test (*p* value)		AVR Test (*p* value)	
Countries	*FX*	*Period covered*	B=300	B=500	B=300	B=500
China	CNY	01/04/2005 - 12/09/2014	0.563	0.576	0.240	0.232
Hong Kong	HKD	01/04/2005 - 12/09/2014	0.623	0.622	0.547	0.564
Indonesia	IDR	01/04/2005 - 12/09/2014	0.743	0.726	0.797	0.770
Japan	JPY	01/04/2005 - 12/09/2014	0.550	0.546	0.673	0.652
Malaysia	MYR	01/04/2005 - 12/09/2014	0.577	0.558	0.947	0.940
Philippine	PHP	01/04/2005 - 12/09/2014	0.550	0.550	0.510	0.500
Singapore	SGD	01/04/2005 - 12/09/2014	0.577	0.560	0.603	0.618

South Korea	KRW	01/04/2005 - 12/09/2014	0.303	0.272	0.437	0.434
Thailand	THB	01/04/2005 - 12/09/2014	0.927	0.912	0.757	0.738
Before break						
China	CNY	01/04/2005 - 17/10/2008	0.333	0.346	0.973	0.978
Hong Kong	HKD	01/04/2005 - 28/08/2009	0.323	0.312	0.113	0.114
Indonesia	IDR	01/04/2005 - 10/04/2009	0.577	0.606	0.587	0.588
Japan	JPY	01/04/2005 - 17/10/2008	0.173	0.174	0.690	0.704
Malaysia	MYR	01/04/2005 - 07/05/2010	0.387	0.388	0.687	0.706
Philippine	PHP	01/04/2005 - 13/03/2009	0.580	0.588	0.570	0.576
Singapore	SGD	01/04/2005 - 17/10/2008	0.380	0.368	0.340	0.342
South Korea	KRW	01/04/2005 - 14/11/2008	0.060	0.076	0.243	0.246
Thailand	THB	01/04/2005 - 19/01/2007	0.883	0.878	0.137	0.118
After break						
China	CNY	31/10/2008 - 12/09/2014	0.450	0.434	0.080	0.086
Hong Kong	HKD	11/09/2009 - 12/09/2014	0.530	0.518	0.853	0.872
Indonesia	IDR	24/04/2009 - 12/09/2014	0.317	0.344	0.690	0.674
Japan	JPY	31/10/2008 - 12/09/2014	0.593	0.584	0.370	0.404
Malaysia	MYR	21/05/2010 - 12/09/2014	0.407	0.430	0.697	0.692
Philippine	PHP	27/03/2009 - 12/09/2014	0.417	0.436	0.650	0.632
Singapore	SGD	31/10/2008 - 12/09/2014	0.183	0.180	0.483	0.486
South Korea	KRW	28/11/2008 - 12/09/2014	0.870	0.884	0.977	0.982
Thailand	THB	02/02/2007 - 12/09/2014	0.503	0.464	0.333	0.332

Source: Authors' Computations
Note: B represents the number of bootstraps

On the comparative note, notwithstanding the variations in the *p* values of the AVR test, Thailand FX market appears to be the weakest form efficient market with the *p* value of 0.927 and 0.912 obtained after 300 and 500 bootstrap iterations respectively while South Korea FX market is the least weak form efficient market with the *p* value of 0.303 and 0.272 obtained after 300 and 500 bootstrap iterations respectively.

After 300 bootstraps, SGD and MYR are on the same level of weak form efficiency shown by 0.577 *p* value for both FX markets; although linear dependence as shown by the AVR test is more pronounced for SGD (0.603) than MYR (0.947). In any case, the degree of linear dependency is not significant in the two markets, thus confirming their weak form efficiency. Similar evidence is also observed between Japanese yen (JPY) and Philippine peso (PHP), but with higher linear dependence observed in the case PHP (0.510) compared to JPY (0.673). But similarly, the degree of linear dependency is as well not significant enough to undermine the weak form efficiency of both markets.

Acknowledging the significance of structural break in the exchange rate returns for these markets as shown in table 2, we divide the full sample period into two sub periods, namely; the period before structural break and the period after structural break and further analysis is carried out in respect of the two sub periods.

Under the period before structural break, it was discovered that the exchange rate returns for South Korean won (KRW) is non-martingale at 10 per cent level of significance. This implies that the FX market of South Korea was predictable before the break date and as such it was possible to make abnormal profit in the market through speculations. Meanwhile, this result was concealed under the full sample period as it concludes that the market was martingale. Thus, empirical analysis under the full sample period may be thought of as over aggregating the weak form efficiency of the FX markets. Although all other markets remained weak form efficient, it is highly imperative to account for structural break to avert the problem of over aggregation of weak form efficiency of financial markets.

Similarly, CNY was found to be non-martingale after the structural break due to significant linear dependence as evident in the AVR results. It must however be noted that for a market to be weak form efficient it must be devoid of either linear or nonlinear dependence in conditional mean, the fact linear dependence in CNY returns increased significantly after the structural break implies that the necessary condition for MDH is not satisfied and as such the market is not weak form efficient. Whereas, the fact that a financial market is not weak form efficient does not implies possibility of any loss in investment returns rather it implies that the current rate does not fully reflect all the available information in the market, thus creating avenue for speculators to exploit market information and make abnormal profit. The observed change in trending pattern of the CNY returns may be due to systematic exchange rate revaluation policy adopted by the People's Bank of China in 2008 as part of the economic recovery measures advocated by the United States on the perception that undervalued Yuan is exacerbating the plight of the global economic and financial recession.

Meanwhile, further results show that other FX markets remained martingale even after the structural break, meaning that they are still weak form efficient. Similarly, it implies that the future exchange rate returns is not predictable from the past experience or information about markets, thus making it very difficult for speculators to make abnormal profit.

5.0 Conclusion

This study tests MDH in nine selected Asia-Pacific countries being the fastest growing FX markets in the world. It examines the statistical properties of both the level and returns series for exchange rate of these countries relative to Euro. It also determines structural break endogenously from the data stream using Perron (2006) unit root test with structural break. Furthermore, it employs recent technique in variance ratio and spectrum based tests which involves wild bootstrapping procedure. Thus, WBAVR test by Kim (2009) and WBGS test by Escanciano and Velasco (2006) are employed, particularly as both are confirmed to be consistent against autoregressive conditional heteroscedasticity (ARCH) in the financial returns and as they have high power and size advantage in determining linear and nonlinear dependence in the conditional mean of financial returns respectively. Empirical result from this study shows that FX markets of all countries are martingale under the full sample period. Meanwhile, dividing the full sample into before and after structural breaks, the result shows that South Korea FX market is non-martingale before the structural break while China FX market is non-martingale after the structural break.

References

Andrews, D. W. K. (1991). Heteroscedasticity and autocorrelation consistent covariance matrix estimation. *Econometrica* 59, 817-858.

Al-Khazali, O.M., Pyun, C.S. and Kim, D. (2012). Are exchange rate movements predictable in Asia-Pacific markets? Evidence of random walk and martingale difference processes. International Review of Economics and Finance, 21: 221–231.

Azad, A.S.M.S. (2009). Random walk and efficiency tests in the Asia-Pacific foreign exchange markets: Evidence from the post-Asian currency crisis data. Research in International Business and Finance 23, 322-338.

Belaire-Franch, J., and Contreras, D. (2004).Ranks and signs-based multiple variance ratio tests. Working Paper, University of Valencia.

Bierens, H. J. (1982). Consistent model specification tests. *Journal of Econometrics* 20, 105-134.

Campbell, J. Y., and Mankiw, N. G. (1987). Permanent and transitory components in macro-economic fluctuations. *American Economic Review* 77, 111-117.

Charles, A., Darnѐ, O., and Kim, J. H.(2011). Small sample properties of alternative tests for martingale difference hypothesis. *Economics Letters* 110, 151-154.

Choi, I. (1999). Testing the random walk hypothesis for real exchange rates. *Journal of Applied Economics* 14, 293-308.

Chow, K. V., and Denning, K. C. (1993). A simple multiple variance ratio test. *Journal of Econometrics* 58, 385-401.

Cochrane, J. H. (1988). How big is the random walk in GNP? *Journal of Political Economy* 96, 893-920.

Deo, R. S. (2000). Spectral tests of the martingale hypothesis under conditional heteroscedasticity. *Journal of Econometrics* 99, 291-315.

Domínguez, M., and Lobato, I. N. (2003). A consistent test for the martingale difference hypothesis. *Econometric Reviews* 22, 351-377.

Escanciano, C. J., and Lobato, I. N.(2009).Testing the martingale hypothesis. In: Patterson K., Mills, T. C. (Eds.), Palgrave Hand-book of Econometrics. Palgrave, MacMillan.

Escanciano, C. J., and Velasco, C. (2006). Generalized spectral tests for the martingale difference hypothesis. Journal of Econometrics 134, 151-185.

Hong, Y. (1999). Hypothesis testing in time series via the empirical characteristic function: A generalized spectral density approach. *Journal of the American Statistical Association* 94, 1201-1220.

Hong, Y. and Lee, Y. J. (2003). Inference on predictability of foreign exchange rate changes via generalized spectrum and nonlinear time series models. *Review of Economics and Statistics* 85, 1048-1062.

Kim, J. H. (2006). Wild bootstrapping variance ratio tests. Economics Letters 92, 38-43.

Kim, J. H. (2009). Automatic variance ratio test under conditional heteroscedasticity. Finance Research Letters 6, 179-185.

Kuan, C.-M.and Lee, W. (2004). A new test of the martingale difference hypothesis. *Studies in Nonlinear Dynamics and Econometrics,* 8, 1-24.

Lazăr, D., Todea, A., and Filip, D. (2012). Matingale difference hypothesis and financial crisis: Empirical evidence from European emerging foreign exchange markets. *Economic Systems* 36, 338-350.

Ljung, G. M. and Box, G. E. P. (1978). On a Measure of a Lack of Fit Time Series Models. *Biometrika*65, 297-303.

Lo, A. W., and MacKinlay, A. C. (1988). Stock market prices do not follow random walks: evidence from a single specification test. *Review of Financial Studies* 1, 41-66.

Lo, A. W., and MacKinlay, A. C. (1989). The size and power of the variance ratio test in finite samples: a Monte Carlo investigation. *Journal of Econometrics* 40, 203-238.

Mammen, E. (1993). Bootstrap and wild bootstrap for high dimensional linear models. *Annals of Statistics* 21, 255-285.

Perron, P. (1997). Further evidence on breaking trend functions in macroeconomic variables. *Journal of Econometrics* 80, 355-385.

Perron, P. (2006). Dealing with Structural Breaks. In Palgrave Handbook of Econometrics, 1, 278-352.

Veka, S. (2013). Testing the martingale difference hypothesis for the Nordic power derivatives market. *Journal of Energy Markets*. 6, 141-157.

Wright, J. H. (2000). Alternative variance-ratio tests using ranks and signs. *Journal of Business and Economic Statistics* 18, 1-9.

Appendix

****R Program for Generalized Spectral Test*****

```
hkd <- read.table("C://Users//beads_synergy//Desktop//EMH//hkd.csv", header=TRUE, sep=",")
cny <- read.table("C://Users//beads_synergy//Desktop//EMH//cny.csv", header=TRUE, sep=",")
jpy <- read.table("C://Users//beads_synergy//Desktop//EMH//jpy.csv", header=TRUE, sep=",")
idr <- read.table("C://Users//beads_synergy//Desktop//EMH//idr.csv", header=TRUE, sep=",")
krw <- read.table("C://Users//beads_synergy//Desktop//EMH//krw.csv", header=TRUE, sep=",")
myr <- read.table("C://Users//beads_synergy//Desktop//EMH//myr.csv", header=TRUE, sep=",")
php <- read.table("C://Users//beads_synergy//Desktop//EMH//php.csv", header=TRUE, sep=",")
sgd <- read.table("C://Users//beads_synergy//Desktop//EMH//sgd.csv", header=TRUE, sep=",")
thb <- read.table("C://Users//beads_synergy//Desktop//EMH//thb.csv", header=TRUE, sep=",")

y <- hkd$HKD
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)

y <- cny$CNY
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)

y <- jpy$JPY
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)

y <- idr$IDR
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)

y <- krw$KRW
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)

y <- myr$MYR
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
```

```
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)

y <- php$PHP
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)

y <- sgd$SGD
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)

y <- thb$THB
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
Gen.Spec.Test(r)
Gen.Spec.Test(r,B=500)
```

**** R Program for Wild Bootstrapping of Automatic Variance Ratio Test*****

```
hkd <- read.table("C://Users//oyaronbi//Desktop//MDH//hkd.csv", header=TRUE, sep=",")
cny <- read.table("C://Users//oyaronbi//Desktop//MDH//cny.csv", header=TRUE, sep=",")
idr <- read.table("C://Users//oyaronbi//Desktop//MDH//idr.csv", header=TRUE, sep=",")
myr <- read.table("C://Users//oyaronbi//Desktop//MDH//myr.csv", header=TRUE, sep=",")
php <- read.table("C://Users//oyaronbi//Desktop//MDH//php.csv", header=TRUE, sep=",")
sgd <- read.table("C://Users//oyaronbi//Desktop//MDH//sgd.csv", header=TRUE, sep=",")
thb <- read.table("C://Users//oyaronbi//Desktop//MDH//thb.csv", header=TRUE, sep=",")
krw <- read.table("C://Users//oyaronbi//Desktop//MDH//krw.csv", header=TRUE, sep=",")

y <- hkd$HKD
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
AutoBoot.test(r, nboot=300, wild="Normal",prob=c(0.025,0.975))
AutoBoot.test(r, nboot=500, wild="Normal",prob=c(0.025,0.975))

y <- cny$CNY
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
AutoBoot.test(r, nboot=300, wild="Normal",prob=c(0.025,0.975))
AutoBoot.test(r, nboot=500, wild="Normal",prob=c(0.025,0.975))

y <- idr$IDR
nob <- length(y)
```

```
r <- log(y[2:nob])-log(y[1:(nob-1)])
AutoBoot.test(r, nboot=300, wild="Normal",prob=c(0.025,0.975))
AutoBoot.test(r, nboot=500, wild="Normal",prob=c(0.025,0.975))

y <- myr$MYR
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
AutoBoot.test(r, nboot=300, wild="Normal",prob=c(0.025,0.975))
AutoBoot.test(r, nboot=500, wild="Normal",prob=c(0.025,0.975))

y <- php$PHP
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
AutoBoot.test(r, nboot=300, wild="Normal",prob=c(0.025,0.975))
AutoBoot.test(r, nboot=500, wild="Normal",prob=c(0.025,0.975))

y <- sgd$SGD
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
AutoBoot.test(r, nboot=300, wild="Normal",prob=c(0.025,0.975))
AutoBoot.test(r, nboot=500, wild="Normal",prob=c(0.025,0.975))

y <- thb$THB
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
AutoBoot.test(r, nboot=300, wild="Normal",prob=c(0.025,0.975))
AutoBoot.test(r, nboot=500, wild="Normal",prob=c(0.025,0.975))

y <- krw$KRW
nob <- length(y)
r <- log(y[2:nob])-log(y[1:(nob-1)])
AutoBoot.test(r, nboot=300, wild="Normal",prob=c(0.025,0.975))
AutoBoot.test(r, nboot=500, wild="Normal",prob=c(0.025,0.975))
```