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Sudden Changes in Variance and Volatility Persistence in Asian Foreign Exchange Markets*

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This paper has investigated sudden changes in volatility and examined the persistence of volatility in four Asian exchange rates during the period between 1990-2008. Using the iterated cumulative sums of squares (ICSS) algorithm, the identification of sudden changes is generally associated with global financial events, specifically the 1997 Asian currency crisis and recent US financial crisis of 2008. This paper has also demonstrated that controlling sudden changes effectively reduces the persistence of volatility, and that incorporating information regarding sudden changes in variance improves the accuracy of estimating exchange rate volatility dynamics and forecasting future volatility for researchers and investors.

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1. INTRODUCTION

The volatility of foreign exchange rate series experienced occasional shocks or multiple breaks, corresponding to central bank interventions, monetary policy changes and exchange regime changes. In particular, most of the South and East countries have suffered from large sudden changes of their exchange rate volatility caused by the 1997 Asian currency crisis. These sudden changes lead to exaggerate persistence in the volatility of foreign exchange rate series (Lastrapes, 1989; Lamoureux and Lastrapes, 1990). Such a persistent feature is a crucial component for accurately predicting future exchange rate volatility, and consequently its effects on international trade, capital flows and the economy (Malik, 2003).

The volatility persistence of foreign exchange rate series has been extensively documented and modeled by a popular GARCH model and various extensions (Bollerslev and Engle, 1993; Baillie, Bollerslev, and Mikkelsen, 1996; Tse, 1998; Beine, Laurent, and Lecourt, 2002; Beine and Laurent, 2003; Han, 2003). However, it is well known that the GARCH class models are unable to include with sudden changes which are largely explained by global, domestic, economic and political events. Lastrapes (1989) and Lamoureux and Lastrapes (1990) have argued that volatility persistence might be overestimated by ignoring deterministic regime shifts in the GARCH estimation.

In order to avoid the impact of sudden changes in volatility, Inclan and Tiao (1994) designed the iterated cumulative sums of squares (ICSS) algorithms, which identify time points at which sudden changes in variances occur. Since then, extensive studies have detected the time points of sudden changes, and then directly incorporated the sudden change dummies into the GARCH model (Aggarwal, Inclan, and Leal, 1999; Ewing and Malik, 2005; Malik, Ewing, and Payne, 2005; Wang and Moore, 2009; Hammoudeh and Li, 2008). In particular, Malik (2003) detected time periods of sudden changes in the volatility of five major exchange rates, and volatility persistence is overstated by those sudden changes.

This study examines the impacts of sudden changes on the volatility persistence of four Asian foreign exchange rates, namely Singaporean dollar, Korean won, New Taiwan dollar and Thai baht. In doing so, the ICSS algorithm of Inclan and Tiao (1994) is used to identify the time points of sudden changes and then the GARCH model incorporate this information to measure the effect of a shock on volatility persistence. Most Asian foreign exchange markets experienced large sudden changes, caused by corresponding to the 1997 Asian currency crisis and the recent US financial crisis of 2008. For investors and policy makers, examining the impact of sudden changes in volatility provides a better understanding of how major economic events will affect volatility over time. It may be appropriate to evaluate the accuracy of volatility persistence, accounting for sudden changes in conditional variances.

The reminder of the paper is organized as follows. Section 2 describes the characteristics of the sample data. Section 3 briefly presents the methodology for the ICSS algorithm and for the GARCH model. Section 4 provides the estimation results of the ICSS algorithm and the GARCH model. The final section, section 5, provides some concluding remarks.

2. MODEL FRAMEWORK

Some econometric studies have introduced several types of methodologies on the test of structural breaks or sudden change in economic variables (Bai and Perron, 1998, 2003; McConnell and Perez-Quiros, 2000; Qu and Perron, 2007). However, those approaches consider the break points in only the return series of economic variables and econometrically impose any restrictive assumptions on the coefficients of break points. In accordance with the work of Inclan and Tiao (1994), this study identifies the points of sudden changes in volatility by means of the ICSS algorithm, and then estimates the GARCH (1, 1) model with and without sudden change dummies.

2.1. Detecting Points of Sudden Change in Variance

The ICSS algorithm is utilized to identify discrete sub-periods of changing volatility of exchange rate returns. It assumes that the variance of a time series is stationary over an initial period of time, until a sudden change occurs as the result of a sequence of financial events; the variance then reverts to stationary until another market shock occurs. This process is repeated over time, generating a time series of observations with an unknown number of changes in the variance.

Let $\{\varepsilon_t\}$ denote a independent time series with a zero mean and unconditional variance σ_t^2. The variance in each interval is given by σ_t^2, $j = 0, 1, \ldots, N_T$, where N_T is the total number of variance changes in T observations and $1 < K_1 < K_2 < \ldots < K_{N_T} < T$ are the set of change points. Then, the variance over the N_T intervals is defined as follows:

$$\sigma_t^2 = \begin{cases} \sigma_0^2, & 1 < t < K_1 \\ \sigma_1^2, & K_1 < t < K_2 \\ \vdots & \\ \sigma_{N_T}^2, & K_{N_T} < t < T \end{cases} . \tag{1}$$

A cumulative sum of squares is utilized to determine the number of changes in variance and the point in time at which each variance shift occurs. The cumulative sum of squares from the first observation to the k-th point in time is expressed as follows:

$$C_k = \sum_{t=1}^{k} \varepsilon_t^2, \quad \text{where } k = 1, \ \ldots, \ T. \tag{2}$$

Define the statistic D_k as follows:

$$D_k = \left(\frac{C_k}{C_T} \right) - \frac{k}{T}, \quad \text{where } D_0 = D_T = 0, \tag{3}$$

in which C_T is the sum of the squared residuals from the whole sample period. Note that if there are no changes in variance, the D_k statistic will oscillate around zero (if D_k is plotted against *k*, it will resemble a horizontal line). However, if there are one or more changes in variance, then the statistic values drift up or down from zero. In this context, significant changes in variance are detected using the critical values obtained from the distribution of D_k under the null hypothesis of constant variance. If the maximum absolute value of D_k is greater than the critical value, the null hypothesis of homogeneity can be rejected. Define k^* to be the value at which $\max_k |D_k|$ is reached, and if $\max_k \sqrt{(T/2)}|D_k|$ exceeds the critical value, then k^* is used as the time point at which a variance change in the series occurs. The term $\sqrt{(T/2)}$ is required for the standardization of the distribution.

In accordance with the study of Inclan and Tiao (1994), the critical value of 1.358 is the 95th percentile of the asymptotic distribution of $\max_k \sqrt{(T/2)}|D_k|$. Therefore, upper and lower boundaries can be established at ± 1.358 in the D_k plot. A change point in variance is identified if it exceeds these boundaries. However, if the series harbors multiple change points, the D_k function alone is not sufficiently powerful to detect the change points at different intervals. In this point, Inclan and Tiao (1994) modified an algorithm that employs the D_k function to search systematically for change points at different points in the series. The algorithm works by evaluating the D_k function over different time periods, and those different periods are determined by breakpoints, which are identified by the D_k plot.

2.2. GARCH Model with Sudden Change Dummies

Following the seminar work of Engle (1982), consider the return series of foreign exchange rate y_t and the associated prediction error $\varepsilon_t = y_t - E_{t-1}[y_t]$, in which $E_{t-1}[\cdot]$ is the expectation of the conditional mean on the information set at time *t*–1. The AR (1)-GARCH (1, 1) model of

Bollerslev (1986) is as follows[1]:

$$y_t = \mu + \phi y_{t-1} + \varepsilon_t, \quad \varepsilon_t = z_t \sqrt{h_t}, \quad z_t \sim N(0,\ 1), \tag{4}$$

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1}, \tag{5}$$

where $\omega > 0$, $\alpha \geq 0$, $\beta \geq 0$, which ensure the unconditional variance (h_t) is positive, and $(\alpha + \beta) < 1$ are introduced for covariance stationarity. In the GARCH model, the sum of α and β quantifies the persistence of shocks to unconditional variance. A comon empirical finding is that the sum of α and β is very close to one, implying that shocks are infinitely persistent corresponding to an inegarated GARCH (IGARCH) process.

Lastrapes (1989) and Lamoureux and Lastrapes (1990) have argued that the GARCH model tend to overestimate volatility persistence when sudden changes or regime shifts are prevalent and ignored in unconditional variance. In an effort to calculate accurate estimates of the model parameters, sudden changes should be incorporated into the GARCH model. From equation (5), we modify the GARCH (1, 1) model with multiple sudden changes that were identified via the ICSS algorithms, as follows:

$$h_t = \omega + d_1 D_1 + \cdots + d_n D_n + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1}, \tag{6}$$

in which $D_1, \ \ldots, \ D_n$ are dummy variables that take a value of one from each point of sudden change of variance onwards, and take a value of zero elsewhere.

3. DATA

The data sets consist of monthly nominal spot exchange rates (against US

[1] An first order of autoregressive AR(1) process is used to correct the autocorrelation of exchange rate return series.

dollar) for Singaporean dollar, Korean won, New Taiwan dollar, and Thai baht from January, 1990 to December, 2008.[2)] These markets have adopted different exchange regimes. Since 1985, the Singapore dollar has adopted a more market-oriented exchange regime, classified as a Monitoring Band. The Korean won was allowed to a floating rate system on December 24, 1997. The New Taiwan dollar was set free to a float rate system on 3 April, 1989. The Thai baht adopted the managed-float exchange rate regime on 2 July 1997. During the 1997 Asian currency crisis, the monetary authorities in this reign allowed to their own exchange rates to deprecate by more than 20%.

The price series are then converted into the nominal percentage return series for all exchange rate series, i.e., $y_t = 100(P_t / P_{t-1})$ for $t = 1, 2, \ldots, T$, in which y_t is the return for each index at time *t*, P_t is the current price, and P_{t-1} is the price from the previous day. Table 1 shows the descriptive statistics and the results of the unit root test for four exchange rate returns. In Panel A of table 1, (i) the mean of sample returns is positive expect for Singaporean dollar. (ii) The standard deviation of Korean won and Thai baht returns is substantially higher than others. (iii) The distribution of all return series is not distributed normally, as indicated by the skewness, kurtosis, and the Jarque-Bera test. (iv) The null hypothesis of no serial correlation is rejected by the Ljung-Box *Q* statistic, $Q(12)$, with a lag of 12 for the level of all exchange rate return series and thus the AR(1) specification will be used in the mean equation.

In addition, Panel B of table 1 provides the results of three unit root tests: the augmented Dickey-Fuller (ADF), Phillips-Peron (PP), and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS). Large negative values for the ADF and PP test statistics reject the null hypothesis of a unit root, whereas the KPSS test statistic does not reject the null hypothesis of stationarity at a significance level of 1%. Thus, all exchange rate returns are stationary processes.

[2)] All sample exchange rates are obtained from the database of the Federal Reserve Bank of St. Louis.

Table 1 Descriptive Statistics and Unit Root Tests

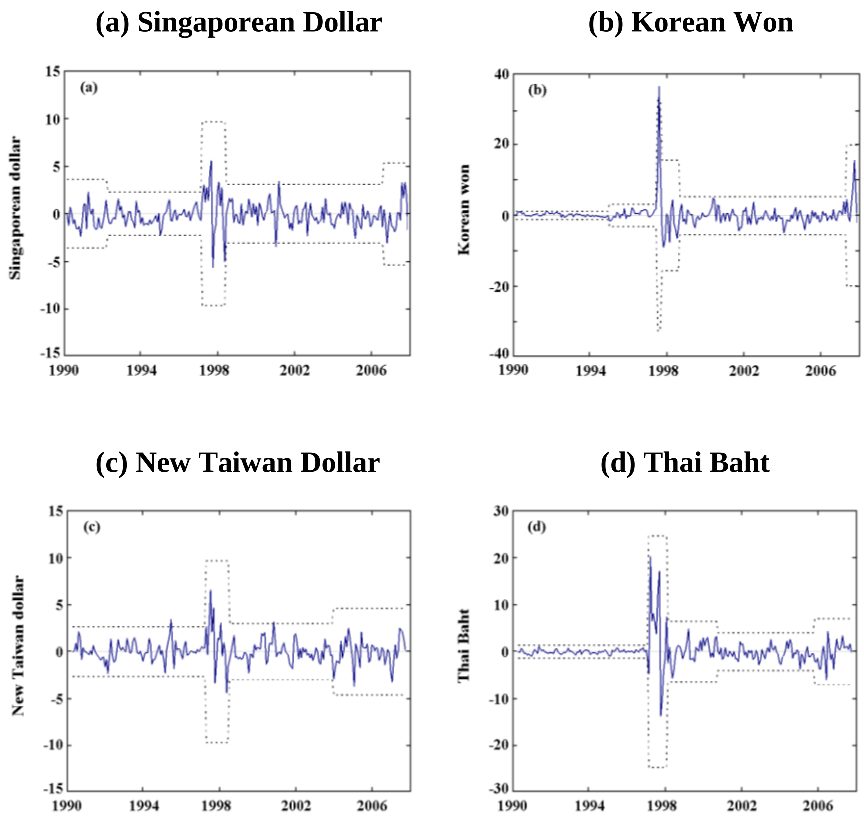
	Singaporean Dollar	Korean Won	New Taiwan Dollar	Thai Baht
Panel A: Descriptive Statistics				
Mean	–0.107	0.300	0.105	0.134
Standard Deviation	1.355	3.464	1.322	2.951
Maximum	5.643	36.87	6.826	21.02
Minimum	–5.698	–8.927	–4.501	–14.16
Skewness	0.283	5.743	0.579	2.276
Kurtosis	6.093	58.77	6.890	22.58
Jarque-Bera	93.94***	30799***	156.54***	3840***
Q(12)	25.27***	68.85***	45.97***	36.44***
Panel B: Unit Root Tests				
ADF	–11.21***	–10.55***	–10.37***	–11.40***
PP	–11.05***	–8.031***	–10.25***	–11.45***
KPSS	0.198	0.072	0.084	0.137

Notes: The Jarque-Bera corresponds to the test statistic for the null hypothesis of normality in sample returns distribution. The Ljung-Box statistic, *Q*(12), check for the serial correlation of the return series up to the 12th order. Mackinnon's 1% critical value is –3.435 for the ADF and PP tests. The critical value for the KPSS test is 0.739 at the 1% significance level. *** indicates a rejection of the null hypothesis at the 1% significance level.

4. EMPIRICAL RESULTS

Figure 1 illustrates the returns for four exchange rate returns with the points of sudden change and ±3 standard deviations. The time points of sudden change in volatility are correlated to a moderate degree with global economic events.

Figure 1 Monthly Returns of Exchange Rates



Note: Bands (dot lines) mean ±3 standard deviations, where change points are estimated by ICSS algorithms.

Table 2 indicates the time periods of sudden changes in volatility, as identified by the ICSS algorithm. The results show that the time points of sudden changes in volatility range from five to three shifts for these exchange rate series. According to the values of standard deviation in table 2, the biggest sudden change was observed immediately after the breakout of the 1997 Asian currency crisis and the second biggest sudden change is corresponding to the recent US financial crisis of 2008.

Table 2 Sudden Changes in Volatility

Series	Number of Change Points Detected	Time Period	Standard Deviation
Singaporean Dollar	4	1990. 1-1992. 3	1.161
		1992. 4-1997. 6	0.773
		1997. 7-1998. 10	**3.214**
		1998. 11-2007. 7	1.052
		2007. 8-2008. 12	1.847
Korean Won	5	1990. 1-1995. 2	0.458
		1995. 3-1997. 10	1.003
		1997. 11-1998. 1	**14.43**
		1998. 2-1999. 1	4.089
		1999. 2-2008. 4	1.796
		2008. 5-2008. 12	6.017
New Taiwan Dollar	3	1990. 1-1997. 7	0.929
		1997. 8-1998. 11	**2.900**
		1998. 12-2004. 10	1.030
		2004. 11-2008. 12	1.440
Thai Baht	4	1990. 1-1997. 5	0.457
		1997. 6-1998. 6	**10.47**
		1998. 7-2001. 4	2.341
		2001. 5-2006. 10	1.342
		2006. 11-2008. 12	2.451

Note: The bold types indicate the largest value of standard deviation among the time period for sudden changes in volatility.

Table 3 reports the estimation results from the GARCH (1, 1) model, with and without sudden change dummy variables in all four cases. In Panel A, the GARCH model without the dummy variables evidences highly significant α and β, and the sum of the parameters $(\alpha+\beta)$ are close to 1 or unity. Specifically, the sums of parameters are even over unity for both Korean won (1.457) and Thai baht (1.271), which is corresponding to an integrated GARCH (IGARCH) process, i.e., shocks have a permanent impact on the variance of returns. As for $(\alpha+\beta)>1$, the GARCH model is mis-specified in measuring the persistence in variance because the GARCH

Table 3 GARCH (1, 1) Parameters with and without Dummy Variables for Sudden Changes in Variance

Panel A: GARCH (1, 1) Model without Dummies

Series	Singaporean Dollar	Korean Won	New Taiwan Dollar	Thai Baht
α	0.237 (0.076)***	0.889 (0.078)***	0.26 (0.057)***	0.639 (0.043)***
β	0.651 (0.106)***	0.568 (0.028)***	0.599 (0.059)***	0.632 (0.020)***
$\alpha+\beta$	0.888	1.457	0.859	1.271
Log-likelihood	–360.61	–443.21	–364.99	–404.26
Skewness	0.176	0.393	–0.026	0.103
Kurtosis	3.549	9.324	4.77	7.854
Jarque-Bera	4.039 [0.132]	385.87 [0.000]***	29.79 [0.000]***	224.23 [0.000]***
LM ARCH (10)	2.041 [0.031]**	0.881 [0.551]	0.3 [0.981]	2.959 [0.001]***
$Q_s(12)$	19.92 [0.090]	10.24 [0.593]	4.458 [0.974]	26 [0.011]**

Panel B: GARCH (1, 1) Model with Dummies

Series	Singaporean Dollar	Korean Won	New Taiwan Dollar	Thai Baht
α	0.073 (–0.088)	0.172 (–0.11)	0.237 (0.118)**	0.117 (–0.124)
β	0.353 (–0.4)	0.211 (–0.18)	0.039 (–0.196)	0.029 (–0.303)
$\alpha+\beta$	0.426	0.383	0.276	0.146
Log-likelihood	–344.17	–387.9	–346.63	–355.25
Skewness	0.062	0.271	0.15	–0.056
Kurtosis	3.173	3.559	3.792	3.022
Jarque-Bera	0.433 [0.805]	5.771 [0.060]	6.816 [0.033]**	0.124 [0.940]
LM ARCH (10)	1.363 [0.199]	0.313 [0.997]	0.575 [0.832]	0.613 [0.802]
$Q_s(12)$	14.77 [0.254]	5.044 [0.956]	9.181[0.687]	7.412 [0.829]

Notes: *P*-values in brackets and standard errors in parenthesis. LM ARCH (10) test statistic checks the remaining ARCH effects in estimated residuals. $Q_s(12)$ is the Ljung-Box test statistic for the serial correlation of squared residual series. ** and *** indicate the statistics are significant at the 5% and 1% levels, respectively.

model strictly impose the restriction of $(\alpha+\beta)<1$ (Bollerslev, Engle, and Nelson, 1994). Lamoureux and Lastrapes (1990) agued that when ignoring structural breaks (sudden changes), the GARCH model produces high persistence in variance.

As mentioned above, we examine the GARCH model accounting for sudden changes in variance in order to analyze the impact of sudden changes on persistence in variance. The inclusion of dummy variables in Panel B of this table dramatically reduces the sums of the parameters $(\alpha + \beta)$ for all four exchange rate returns which are in the range 0.146-0.426. This evidence is consistent with the study of Malik (2003), which has argued that ignoring sudden changes generates volatility persistence in major foreign exchange markets. It is concluded that sudden changes generate persistence in the variance of Asian foreign exchange rates.

Finally, we evaluated the accuracy of the model specifications, using several diagnostic tests. The insignificance of LM ARCH(10) and Ljung-Box $Q_s(12)$ tests shows that no ARCH effect or serial correlation can be observed in the residual series. In addition, the estimated residuals from the model with dummy variables evidence a normal distribution due to the insignificance of skewness, kurtosis, and Jarque-Bera test.[3)] This finding indicates that the GARCH model with dummy variables is well specified for examinations of the volatility persistence in four foreign exchange markets.

5. CONCLUSIONS

In this study, we have investigated sudden changes of volatility and re-examined the volatility persistence for four exchange rate return series, namely Singaporean dollar, Korean won, New Taiwan dollar and Thai baht. In an effort to assess the impact of sudden changes in volatility persistence, we identify the time points of sudden changes based on the ICSS algorithms,

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[3)] This finding is consistent with that of Baillie and Bollerslev (1990), which found that excess kurtosis in the weekly exchange rate residuals, estimated from the GARCH model and advocated the use of Student-t distribution to capture the excess kurtosis in the residuals. However, our finding in this study suggests a new insight on the kurtosis of residuals when considering sudden changes in the GARCH model.

and then incorporate this information into the GARCH model.

Using the ICSS algorithm, the identification of sudden changes is largely associated with global financial events, specifically the 1997 Asian currency crisis and recent US financial crisis of 2008. In addition, when sudden changes are incorporated into GARCH model, the persistence of volatility has been vanished in all foreign exchange markets. Thus, incorporating information on sudden changes in variance improves the accuracy of estimating exchange rate volatility dynamics for researchers and investors.

REFERENCES

Aggarwal, R., C. Inclan, and R. Leal, "Volatility in Emerging Stock Markets," *Journal of Financial and Quantitative Analysis*, 34(1), 1999, pp. 33-55.

Bai, J. and P. Perron, "Estimating and Testing Linear Models with Multiple Structural Changes," *Econometrica*, 66(1), 1998, pp. 47-68.

____________, "Computation and Analysis of Multiple Structural Change Models," *Journal of Applied Econometrics*, 18(1), 2003, pp. 1-22.

Baillie, R. T. and T. Bollerslev, "The Message in Daily Exchange Rates: A Conditional-Variance Tale," *Journal of Business & Economic Statistics*, 7(3), 1989, pp. 297-305.

Baillie, R. T., T. Bollerslev, and H. O. Mikkelsen, "Fractionally Integrated Generalized Autoregressive Conditional Heteroskedasticity," *Journal of Econometrics*, 74(1), 1996, pp. 3-30.

Beine, M. and S. Laurent, "Central Bank Interventions and Jump in Double Long Memory Models of Daily Exchange Rates," *Journal of Empirical Finance*, 10(5), 2003, pp. 641-660.

Beine, M., S. Laurent, and C. Lecourt, "Accounting for Conditional Leptokurtosis and Closing Days Effects in FIGARCH Models of Daily Exchange Rates," *Applied Financial Economics*, 12(8), 2002, pp. 589-600.

Bollerslev, T., “Generalized Autoregressive Conditional Hetroskedastisticity,” *Journal of Econometrics*, 31(3), 1986, pp. 307-327.

Bollerslev, T. and R. F. Engle, “Common Persistence in Conditional Variances,” *Econometrica*, 61(1), 1993, pp. 167-186.

Bollerslev, T., R. F. Engle, and D. B. Nelson, “ARCH Models,” Chapter 49, in R. F. Engle and D. L. McFadden, eds., *Handbook of Econometrics IV*, Elsevier Science, 1994, pp. 2959-3038.

Engle, R. F., “Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation,” *Econometrica*, 50(4), 1982, pp. 987-1007.

Ewing, B. T. and F. Malik, “Re-examining the Asymmetric Predictability of Conditional Variances: The Role of Sudden Changes in Variance,” *Journal of Banking & Finance*, 29(10), 2005, pp. 2655-2673.

Hammoudeh, S. and H. Li, “Sudden Changes in Volatility in Emerging Markets: The Case of Gulf Arab Stock Markets,” *International Review of Financial Analysis*, 17(1), 2008, pp. 47-63.

Han, Y. W., “Long Memory Property and Central Bank Intervention During Currency Crisis in the Daily Korean won-US dollar Exchange Rates,” *The Journal of the Korean Economy*, 4(1), 2003, pp. 93-116.

Inclán C. and G. C. Tiao, “Use of Cumulative Sums of Squares for Retrospective Detection of Changes of Variance,” *Journal of American Statistical Association*, 89(427), 1994, pp. 913-923.

Lamoureux, C. G. and W. D. Lastrapes, “Persistence in Variance, Structural Change, and the GARCH Model,” *Journal of Business & Economic Statistics*, 8(2), 1990, pp. 225-234.

Lastrapes, W. D., “Exchange Rate Volatility and U.S. Monetary Policy: An ARCH Application,” *Journal of Money, Credit and Banking*, 21(1), 1989, pp. 66-77.

Malik, F., “Sudden Changes in Variance and Volatility Persistence in Foreign Exchange Markets,” *Journal of Multinational Financial Management*, 13(3), 2003, pp. 217-230.

Malik, F., B. T. Ewing, and J. E. Payne, “Measuring Volatility Persistence in the Presence of Sudden Changes in the Variance of Canadian Stock Returns," *Canadian Journal of Economics*, 38(3), 2005, pp. 1037-1056.

McConell, M. M. and G. Perez-Quiros, "Output Fluctuations in the United States: What Has Changed since the Early 1980's?," *American Economic Review*, 19(5), 2000, pp. 1464-1476.

Qu, Z. and P. Perron, "Estimating and Testing Structural Changes in Multivariate Regressions," *Econometrica*, 75(2), 2007, pp. 459-502.

Tse, Y. K., "The Conditional Heteroscedasticity of the Yen-dollar Exchange Rate," *Journal of Applied Econometrics*, 13(1), 1998, pp. 49-55.

Wang, P. and T. Moore, "Sudden Changes in Volatility: The Case of Five Central European Stock Markets," *Journal of International Financial Markets, Institutions & Money*, 19(1), 2009, pp. 33-46.