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Measuring Asymmetry and Persistence in Conditional Volatility in Real Output: Evidence from Three East Asian Tigers Using a Multivariate GARCH approach

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Abstract

We search for evidence of conditional volatility in the quarterly real GDP growth rates of three East Asian tigers: Singapore, Hong Kong and Taiwan. The widely accepted exponential GARCH-type model is used to capture the existence of asymmetric volatility and the potential structural break points in the volatility. We find evidence of asymmetry and persistence in the volatility of GDP growth rates. It is noted that the identified structural breakpoints of volatility correspond reasonably well to the historical economic and political events in these economies. Policy implications are discussed.

Keywords: East Asia, Real Output, GARCH, structural changes, asymmetric volatility

JEL classification: F14; F31; P21

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1. INTRODUCTION

East Asia, especially the four tigers of Hong Kong, Singapore, South Korea and Taiwan, has enjoyed a remarkable record of high and sustained economic growth over three decades from 1965 to the early 1990s. Their ability to achieve speedy developments with equity has intrigued many economists who attempted to understand the drive of growth. Most of this miraculous growth is believed due to a combination of fundamentally sound development policies, tailored interventions, and an unusually rapid accumulation of physical and human capital, as well as rapid intra-regional trade integration. Studies on output co-movement and volatility dynamics of the real GDP growth across countries have important implication for regional economic integration. Yet there is no study focusing on the volatility dynamics of the real GDP growth in these economies. The closely related one is Ho and Tsui (2004) who employed the exponential GARCH model by Nelson (1991) to investigate conditional variances of GDP series of Greater China – the Mainland China, Hong Kong and Taiwan. However, the drawback of this study is that they use only a single GARCH-type model in their analysis, and their approach does not capture the possible cross effects among the economies.

In this paper, we employ a multivariate GARCH framework to investigate the asymmetric conditional volatility in the real GDP growth rates and the possible structural breaks in conditional variance in the economies of Hong Kong, Singapore and Taiwan (Korea is excluded due to lack of data). There are a few studies applying the multivariate models to macroeconomic variables. Our choice of multivariate GARCH-type models includes the constant conditional correlation (CCC) model by Bollerslev (1990) and the time-varying conditional correlation MGARCH (VC-MGARCH) by Tse and Tsui (2002). Our findings suggest that the CCC-MGARCH model is more adequate.

The rest of this paper is organized as follows. In section 2, we discuss the theoretical framework and methodology for this study along with Nelson (1991) and Tse and Tsui (2002). Section 3 describes the data used in the study and the empirical results. Diagnostic test will be conducted and discussed for model adequacy checking. Section 5 concludes the paper.

2. ARMA-EGARCH-CCC-MGARCH MODEL

Since the seminal ARCH model by Engle(1982) and later its extension to the Generalized Autoregressive conditional heteroscedasticity (GARCH) by Bollerslev (1986), there has been a growing literature of GARCH-type models. For asset returns, it is well-known that the negative shocks may have greater impacts on the volatility than the positive shocks of the same magnitudes. However, the simple GARCH(1,1) model is unable to account for this leverage effect because it assigns the same degree of importance to both negative and positive shocks. Nelson (1991) proposes the Exponential GARCH model (EGARCH) to account for such leverage effects. Under the EGARCH(p,q) model with the assumption of normal distribution, we have:

$$\ln(h_t) = \alpha_o + \sum_{h=1}^{p} \alpha_h \ln(h_{t-h}) + \sum_{h=1}^{q} \theta_h g\left(\frac{\varepsilon_{t-h}}{\sigma_{t-h}}\right) \tag{1}$$

where $g\left(\frac{\varepsilon_{t-h}}{\sigma_{t-h}}\right) = \beta_h \frac{\varepsilon_{t-h}}{\sigma_{t-h}} + \gamma_h \left[\left|\frac{\varepsilon_{t-h}}{\sigma_{t-h}}\right| - \mathrm{E}\left(\left|\frac{\varepsilon_{t-h}}{\sigma_{t-h}}\right|\right)\right]$ and $E\left(\left|\frac{\varepsilon_{t-h}}{\sigma_{t-h}}\right|\right) = \sqrt{\frac{2}{\pi}}$.

The EGARCH approach is able to capture asymmetric volatility through the parameter β. If β is less than 0, a negative shock will add more volatility. In addition, EGARCH places no restrictions on parameters β, α and γ. As Hong Kong, Singapore and Taiwan have a close economic tie and share many similarities, it is natural to apply multivariate GARCH models to study the dynamic pattern of the real output together. There are well-known multivariate GARCH-type models like the VEC model by Engle, Granger and Kraft (1984) and the BEKK model by Engel and Kroner (1995). However, there is no guarantee that these multivariate GARCG-type models could be able to secure the requirement of positive definiteness in the variance-covariance matrix and thus convergence during estimation. Moreover, the relatively fewer data points for GDP growth rate series could also cause unwanted divergence in estimation.

Applying the multivariate GARCH-type models like the CCC-MGARCH and VC-MGARCH models would be computationally efficient in the estimation as these models are more stable, especially in satisfying the positive definiteness condition and free from the curse of dimensionality as there are less number of parameters to be estimated. Under the VC-MGARCH model, the conditional correlation matrix of standardized residuals $\frac{\varepsilon_t}{\sigma_t} = (\frac{\varepsilon_{1t}}{\sigma_{1t}},\dots\dots,\frac{\varepsilon_{Kt}}{\sigma_{Kt}})'$ is assumed to be time-varying. The conditional correlation between ε_{it} and ε_{jt} evaluated at time t-1 is given by the expression $\rho_{ij} = h_{ijt} / \sqrt{(h_{iit} h_{ijt})}$. In general, both ρ_{ij} and H_t vary with time. Hence, the time-varying conditional covariance can be expressed as the product of conditional correlation and square root of the product of the corresponding two conditional variances,

$$h_{ijt} = \rho_{ij}(h_{iit} h_{jjt})^{\frac{1}{2}} \qquad j = 1,\dots\dots, K, \; i = j+1,\dots\dots,K \qquad (2)$$

The conditional variance-covariance matrix will become:

$$H_t = D_t R\, D_t \qquad \text{or}$$

$$H_t = diag(\sqrt{h_{11,t}},...,\sqrt{h_{KK,t}})\ R\ diag(\sqrt{h_{11,t}},...,\sqrt{h_{KK,t}}) \qquad (3)$$

We note in passing that each conditional variance still follows the univariate GARCH-type specifications, for example EGARCH.

Tse and Tsui (2002) propose the VC-MGARCH model to allow for time-varying conditional correlations. Specifically, the time-varying conditional correlation matrix R_t is generated from the recursive ARMA structure:

$$R_t = (1-\theta_1-\theta_2)R_0 + \theta_1 R_{t-1} + \theta_2 \varphi_{t-1}, \qquad (4)$$

The covariance-variance matrix is specified as:

$$H_t = D_t R_t D_t \qquad \text{or}$$

$$H_t = diag(\sqrt{h_{11,t}},...,\sqrt{h_{KK,t}})\ R_t diag(\sqrt{h_{11,t}},...,\sqrt{h_{KK,t}}) \qquad (5)$$

where θ_1 and θ_2 are assumed to be non-negative and $\theta_1+\theta_2 < 1$. $R_0 = \{\rho_{ij}\}$ is a time invariant K x K positive definite parameter matrix with unit diagonal elements and φ_{t-1} is a K x K matrix whose elements are functions of the lagged observations of ε_t. As R_t is a standardized measure, φ_{t-1} is thus also standardized into a correlation matrix of the lagged standardized residuals ε_i. Denoting $\varphi_{t-1} = \{\varphi_{ijt}\}$, the elements of φ_{t-1} are specified as

$$\varphi_{t-1} = \frac{\sum_{h=1}^{M} e_{i,t-h} e_{j,t-h}}{\sqrt{(\sum_{h=1}^{M} e_{i,t-h}^2)(\sum_{h=1}^{M} e_{j,t-h}^2)}},\ 1 \le i \prec j \le K \qquad (6)$$

where $e_{it} = \varepsilon_{it} / h_{it}$. When θ_1 and θ_2 are confined to zero, the VC-MGARCH model is reduced to the CCC-MGARCH model. When we apply both models to the three GDP growth series, we often find that estimates of θ_1 are so close to zero that the VC-MGARCH estimation did not converge.

Our study of the data series indicates possible presence of structure breaks. To identify the location of breakpoints, we employ the iterated cumulative sum of squares (ISCC) algorithm to identify structural breaks in volatility. This technique is developed by Inclan and Tiao (1994) and Sanso et al. (2004). The program treats the series of growth rates for the initial period to have stationary variance and then captures a change in variance when it occurs. If there is leptokurticity and conditional heteroskedasticity, the structural breaks in volatility may occur more often, generating spurious breaks. As such, Sanso et al. (2004) improve the procedure by accounting for the kurtosis and the conditional heteroskedasticity, using a nonparametric adjustment based on the Bartlett kernel. Another advantage of this modified ISCC is that it allows for multiple break points to be detected by dividing and examining different parts of the series. We then use dummy variables in the conditional variance equations to capture the structural changes in volatility:

$$\ln(h_t) = \alpha_o + \sum_{h=1}^{p} \alpha_h \ln(h_{t-h}) + \sum_{h=1}^{q} \theta_h g\left(\frac{\varepsilon_{t-h}}{\sigma_{t-h}}\right) + \sum_i \omega_i \times B_{(Country)i} \qquad (7)$$

3. DATA AND RESULTS

Our data set comprises quarterly real GDP of Singapore, Taiwan and Hong Kong taken from CEIC data manager, covering the "miracle period" in 1965-1990 and the post-miracle period till 2007Q2. The raw GDP data is seasonally adjusted by the Cencus-X11 (Multiplicative) procedure. Let r_t be the continuously compounded growth rates of the seasonally adjusted quarterly real GDP for each country, we use autoregressive (AR) specification for mean equations with lag order up to m

$$r_t = \phi_0 + \sum_{i=1}^{m} \phi_i r_i + \varepsilon_t \qquad (8)$$

We first assess the statistical features of the real growth rates series in these economies and Table 1 presents the results. It is found that Singapore enjoys the highest mean growth rates, while Hong Kong has the most volatile rates during the sample period. Singapore growth rates are negatively skewed, whereas those of Hong Kong and Taiwan are positively skewed. And all three growth series have excess kurtosis with Taiwan being the highest at 6.31. Normality checking by the Jarque-Bera test reveals that they are not normally distributed, thereby reflecting high kurtosis and non-zero skewness. As regards the Q statistics for checking possible correlation in the variance, we find that Q statistics of the squared growth rates for Singapore and Taiwan are not significant at the 5% level, and for Hong Kong it is just barely significant, which indicates the absence of autocorrelation in the variance. However, we find support for high sample kurtosis and the rejection of the null hypothesis of normal distribution by the Jarque-Bera tests. These may indicate the presence of conditional heteroskedasticity. We have employed the augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) tests to check the stationarity of the GDP growth rate series. The results show that all ADF and PP test statistics are significant at the 1% level, indicating that all are stationary.

[Insert Table 1 about here]

Applying the ISCC algorithm, two possible breaks are found for Taiwan respectively in 1987 and 1998, and two for Hong Kong and Singapore in 1997 and 2003, coinciding with the Asian Financial crisis and SARS outbreak. We then adopt correspondingly dummy variables in the conditional variance equations to capture the structural changes in volatility. We report in Table 2 the estimation results of the conditional variance both with and without the breakpoints. As it can be seen, there is a marked difference in term of persistence between cases “with breakpoints” and “without”, indicated by the estimated value of α in the variance equations. For the latter case, the persistence is higher than that of the case “with breakpoint”. For example, the estimated value of α for Taiwan is 0.8453 in the absence of breakpoints, but reduced to 0.4252 when breakpoints are present in the variance structure. The possible explanation is that, when dummy variables are included into the variance equation, they account for the excess volatility that is otherwise treated as persistence. Moreover, it is found that the degree of persistence for the growth rates is the highest for Taiwan, and the growth rates for Singapore and Hong Kong show a lesser degree of persistence.

[Insert Table 2 about here]

As discussed earlier, the signs of the estimates of β of Eq. 1 determine asymmetry in the conditional volatility. It is noted in Table 2 that the coefficients of volatility asymmetry for Singapore and Hong Kong are all negative and significant at the 5% level, while the corresponding value for Taiwan, though negative, is insignificant at the 5% level. These suggest that negative shocks have a greater impact on future volatilities than positive shocks of the same magnitude. This is consistent with the findings of Ho and Tsui (2003), who have detected significantly negative volatility asymmetry in the real GDP of the US.

It is generally believed that volatility of the GDP growth rates in particular and those of macroeconomic variables in general are higher during the time of recession (see, for instance, Brunner, 1992 and French and Sichel, 1993). Casual observation suggests that real output volatility apparently increase during economic downturns, and in particular, increases in the conditional deviation usually occur after the contractions (recessions) in the economy. According to the NBER, during or shortly after the recessions in the United States, the conditional standard deviations have been significantly higher for sectors such as the Consumer Good, Investment Good and Manufacturing sectors. Ho and Tsui (2003) also observe that in the period after the 1973/74 and 1979 oil price shocks, the world economy plunged into a global recession and the conditional standard deviation of the overall US industrial production (IIP) indices is relatively higher.

Hong Kong and Singapore are well known for being entrepot traders as well as international financial centres with few restrictions on trade and capital flows, and also both have a heavy reliance on international trade, with Hong Kong being the important intermediary serving Mainland China and Singapore being the international hub linking the East and the West. It is therefore not surprising to see a high volatility in the real output growth in these two economies. The insignificantly negative volatility asymmetry in the real growth rate provides further support.

[Insert Table 3 about here]

Table 3 reports the estimated constant conditional correlations and log-likelihood values. It is found that all the estimated values of conditional pair-wise correlation coefficients are significant at the 1% level, indicating that dynamic correlations probably exist among these three economies. It is interesting to note that the pattern of conditional correlations and the magnitude differ between the models. The magnitude is generally smaller in the estimations with the inclusion of the breakpoints than without. The possible explanation is that, when we include the dummy variables to account for the structural breaks, we might have improved the estimation of conditional standard deviations, which otherwise is absorbed in the constant conditional correlation. These differences are further presented in Figures 1-3, where the dashed lines denote estimates of conditional standard deviations without accounting for structural changes in volatility while solid lines indicate with structural breakpoints. As can be seen from the figures, the structural breaks are very visible, and consistent with the historical events in each country. It is interesting to note that the volatility decreases in 1987 for the economy of Taiwan, which could be due to the government’s anti-overheating measures implemented in the 1987 and anti-inflationary stance since the beginning of 1980s. The finding of the breakpoints for Hong Kong and Singapore is associated with the economic downturns and political uncertainty.

On the diagnostics front, we have conducted the Ljung-Box Q statistic and Jarque-Bera test for normality to check for model adequacy (the results are available upon request). It is found that the Jarque-Bera test statistics for series “with breakpoints” is smaller than those without breakpoints. As such, we cannot reject the null hypothesis of normality. Also, the Q-Statistics for squared series with the breakpoints are smaller than that without. We can conclude that it is more adequate to accommodate break points in the multivariate GARCH-type models to account for structural changes in conditional volatility. In addition, the log-likelihood values generated from models with structural breakpoints are larger than those without breakpoints. This provides further support for the inclusion of structural breakpoints in volatility estimations.

4. CONCLUSION

We have employed two multivariate GARCH-type models to investigate the volatility dynamics and persistence of the real output growth for the economies of Hong Kong, Singapore, and Taiwan. The results indicate the presence of asymmetry and persistence in volatility. It is also found that asymmetric volatility is sensitive to the structure of the conditional variance. The detection of structural breakpoints of volatility corresponds well to the historical economic and political events such as the Tiananmen event, Asian Financial crisis and SARS outbreak. Moreover, when structural breakpoints are included in estimation, the quality of the estimation results is found to be improved.

The evidence of asymmetry and persistence in volatility has important implications. With the presence of asymmetric volatility, the policy-makers need to be more pro-active in formulating their economic stimulating measures during periods of negative impacts. This is because, when negative shocks happen, investors would normally have negative sentiment and over-react to the shocks, which can make the already-sinking economy even worse. When the volatility is high at certain time, it is very likely that this volatility will persist. Thus, when negative shocks occur, there would be an additional effect caused by both asymmetry and persistence in volatility, namely asymmetry causes higher volatility which then, as a result of volatility persistence, would intensify the problem. During the time of positive impacts, the economies may face a quick overheating problem due to investors' over-reaction to their optimistic expectation. Therefore, an appropriate counter-cyclical policy measures have to be made by the government to respond to the adverse impact of negative shocks and to stabilise the macroeconomic environment. The ability to identify breakpoints would provide policy-makers with additional information to identify the causes of the volatility and help to stabilize the economy. Our findings also indicate that negative economic disturbances arising from one economy may spill over to another one through the strong economic linkages. As such, international economic policy co-ordination would become imperative to ameliorate the effect of shocks from the original source.

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Table 1 Summary Statistics of the Growth Rates 1965Q1-2007Q2

Region	Singapore	Taiwan	Hong Kong
Panel A: Moments, Maximum, Minimum			
Mean	0.0172	0.0163	0.0141
Median	0.0180	0.0165	0.0148
Maximum	0.0604	0.0705	0.0713
Minimum	-0.0281	-0.0173	-0.0409
Standard Deviation	0.0160	0.0120	0.0199
Skewness	-0.5400	0.5682	0.1240
Kurtosis	4.0604	6.3100	4.0098
Observations	169	169	169
Panel B: Jarque-Bera Test for Normality			
Test Statistic	11.36**	60.73**	5.36*
Panel C:Unit-Root Test			
ADF test-stat 12 lags	-7.933**	-8.343**	-9.803**
Phillips-Perron (PP) t-stat 4 lags	-7.971**	-8.365**	-4.599213**
Panel D: *Q-Statistics (level)*			
Q(10)	28.831**	31.311**	24.338**
Q(20)	44.781**	39.873**	31.216*
Panel E: *Q-Statistics (Squared terms)*			
Q(5)	2.1092	10.033	18.328**
Q(10)	5.1589	10.608	23.305*
Q(20)	15.814	12.164	27.891

Notes: The Jarque-Bera statistic follows the chi-square distribution with 1 degree of freedom. "*" and "**" stand for significance at the 5% and 1% level respectively.

Table 2: Estimates of Conditional Variance with and without breakpoints

	Conditional Variance with breakpoints			Conditional Variance without breakpoints		
	HK	Spore	Taiwan	HK	Spore	Taiwan
α_0	-4.2267 (1.276)	-4.5951 (1.360)	-5.0902 (2.396)	-2.8362 (1.5899)	-4.5951 (1.389)	-1.4275 (0.810)
α_h	0.5305 (0.139)	0.4994 (0.152)	0.4252 (0.274)	0.6655 (0.1862)	0.5096 (0.158)	0.8453 (0.0897)
γ_h	0.3662 (0.272)	0.1930 (0.195)	0.2232 (0.273)	0.6873 (0.1361)	0.2184 (0.201)	0.3676 (0.263)
β_h	-0.5649 (0.116)	-0.4024 (0.180)	-0.1599 (0.143)	-0.3409 (0.1398)	-0.4086 (0.174)	-0.169 (0.108)
ω_1		0.2706 (0.212)	0.0009 (0.217)			
ω_2	-0.1906 (0.276)	0.4316 (0.233)	-0.6830 (0.397)			
ω_3	-0.0037 (0.318)					

Note: The Bollerslev-Wooldridge robust, heteroskedastic-consistent standard errors are reported in parentheses. "**" and "*" indicate statistical significance at the 1% and 5% levels respectively.

Table 3: Constant conditional correlations and log-likelihoods

	Correlations			Model adequacy comparison
	Spore-Taiwan	*Spore-HK*	*Taiwan-HK*	Log-likelihood
With breakpoints	0.3045**	0.3124**	0.3306**	1223.94
	(0.0846)	(0.0927)	(0.1009)	
Without breakpoints	0.3129**	0.3380**	0.4083**	1212
	(0.0814)	(0.0897)	(0.0916)	

Figure 1: Conditional standard deviation of real GDP growth rates of Singapore

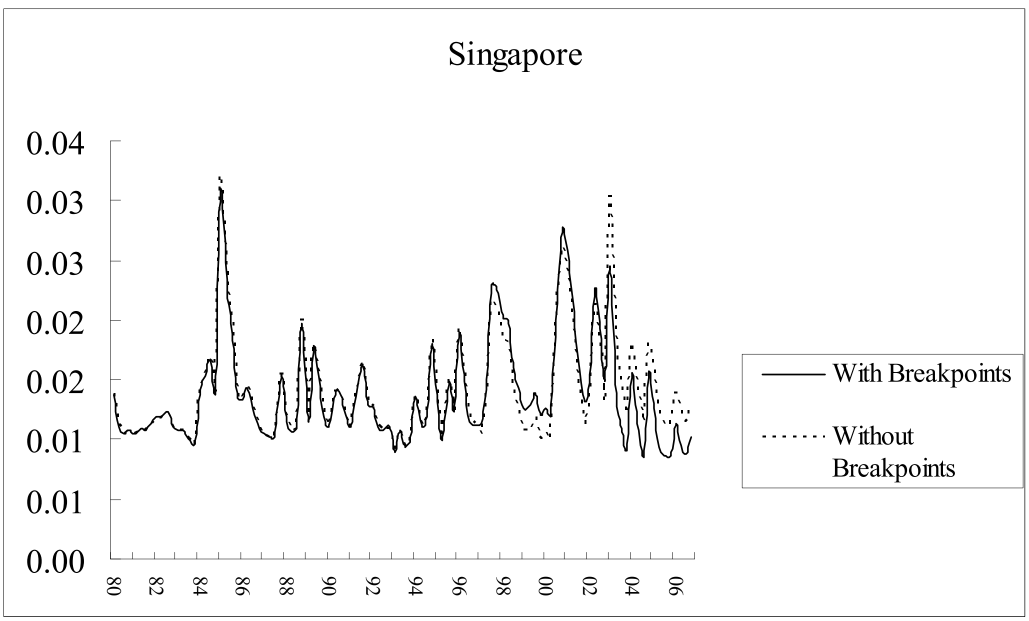

Figure 2: Conditional standard deviation of real GDP growth rates of Taiwan

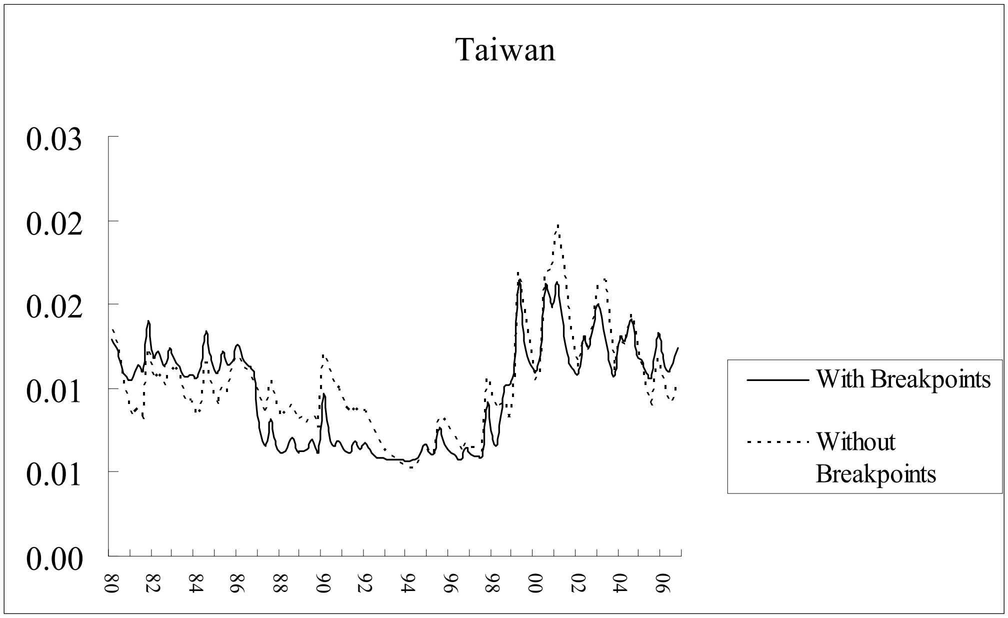

Figure 3: Conditional standard deviation of real GDP growth rates of Hong Kong