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Modeling the Conditional Heteroscedasticity and Leverage Effect in the Chinese Stock Markets

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Abstract: The Chinese stock market has experienced an astonishing growth and unprecedented development since its inception in the early 1990s, emerged to be the world's second-largest by market value by the end of 2009. The Chinese stock market is also one of the most volatile markets, which has been called by many observers a "casino". In the recent years there are several far-reaching events that have reshaped the Chinese stock markets. The most notable events include the "dot-com bubble" in 2000, China's non-tradable shares reform in 2005 and the global financial crisis in 2008. It is noted that the "dot-com bubble" has caused the Chinese stock markets a sharp oscillation since 2000. With a short-lived bull, the Chinese stock markets experienced a nearly five years long bear market until June 2005 when the reform of non-tradable shares was implemented, which increased the liquidity and brought the markets back to a long-term bull run. Since the US sub-prime mortgage crisis the Chinese stock markets have shown extreme instability and severe volatility, which has become the major concern to the policy-makers and investors.

Many existing studies have revealed that the financial time series data exhibit linear dependence in volatility, which indicates the presence of heteroskedasticity, implying the existence of volatility clustering. Although direct generalizations from the univariate GARCH models are straightforward, their applications are limited by practical issues associated with cumbersome computation and strong restrictions on parameters to guarantee positive definiteness of variance matrixes. This study intends to examine the presence of heteroskedasticity and the leverage effect in the two Chinese stock markets, and to capture the dynamics of conditional correlation between returns of China's stock markets and those of the U.S. in a bivariate VC-MGARCH framework. The results show that that the leverage effect is significant in both Shanghai and Shenzhen markets during the sample period in 2000-2008, and the conditional correlation between mainland China's and the U.S. stock markets is quite low and highly volatile. The results indicate that that uncertainty derived from time-varying relationship between Shanghai and the U.S. stock markets is more significant than that between Shenzhen and the U.S. stock markets. In addition, the Chinese stock markets are found to be highly regimes persistent, thereby reducing potential benefits induced by actively trading. These findings have important implication for investors seeking opportunity of portfolio diversification.

Keywords: *Chinese stock market, heteroskedasticity, leverage effect, VC-MGARCH models*

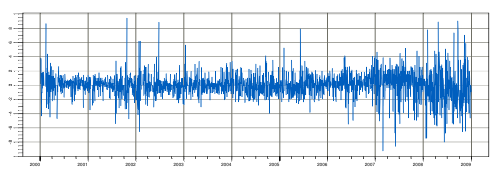
1. INTRODUCTION

Ever since its inception in the early 1990s, the Chinese stock market has experienced an astonishing growth and unprecedented development, emerged to be the world's second-largest by market value by the end of 2009. Thanks to the last decade's intensive and extensive reforms in China's securities market, which has improved substantially the regulatory system and the market-oriented appraisal system for initial public offering (IPO) as well as expanded capital supply to the market. However, the Chinese stock market is also one of the most volatile markets, which has been called by many observers a "casino". In the recent years there are several far-reaching events that have reshaped the Chinese stock markets. The most notable events include the "dot-com bubble" in 2000, China's non-tradable shares reform in 2005 and the global financial crisis in 2008. The impacts of these events on the daily returns of the Shanghai and Shenzhen markets can be clearly viewed in Figure 1. It is noted that the "dot-com bubble" has caused the Chinese stock markets a sharp oscillation since 2000. With a short-lived bull, the Chinese stock markets experienced a nearly five years long bear market until June 2005 when the reform of non-tradable shares was implemented, which increased the liquidity and brought the markets back to a long-term bull run. Since the US sub-prime mortgage crisis the Chinese stock markets have shown extreme instability and severe volatility, which has become the major concern to the policy-makers and investors.

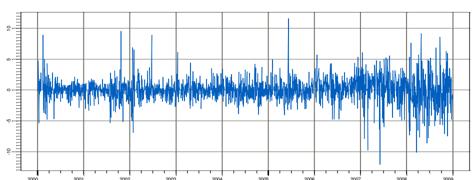
Many existing studies have revealed that the financial time series data exhibit linear dependence in volatility, which indicates the presence of heteroskedasticity, implying the existence of volatility clustering. Engle (1982) proposed the ARCH (Autoregressive conditional heteroskedasticity) model, which assumes time-varying variances are conditional on past information and unconditional variances are constant. Bollerslev (1986) late extended it to the Generalized Autoregressive conditional heteroscedasticity (GARCH). The GARCH(1,1) model is often sufficient for most of financial series, thereby has effectively reduced the lag length in the ARCH model that may induce cumbersome computation. Nelson (1991) proposes the EGARCH (Exponential GARCH) model to capture the asymmetric response to "good news" and "bad news" through interpolating absolute residuals into the conditional variances equation and relax the non-negativity constraints by taking the log form. The GJR-GARCH model developed by Glosten et al. (1993) treats asymmetric effect as a dummy variable and is also capable of capturing leverage effect.

Figure 1: Daily Returns of the Stock Exchange Composite Index

(a) Shanghai



(b) Shenzhen



Although direct generalizations from the univariate GARCH models are straightforward, their applications are limited by practical issues associated with cumbersome computation and strong restrictions on parameters to guarantee positive definiteness of variance matrixes. To tackle the computational complexities associated with the direct generalizations, Bollerslev (1990) introduces the constant conditional correlation (CCC)-MGARCH model. In particular, the univariate GARCH models are used to capture each returns series and then linked together by the conditional correlation matrix. It allows for more flexibility, and also is easier to interpret. Tse and Tsui (2002) develop a varying-correlation MGARCH (VC-MGARCH) model. They assume that the time-varying conditional-correlation matrix follows an ARMA(1,1) structure, which is similar to a dynamic conditional correlation (DCC-MGARCH) model proposed by Engle (2002).

In this study we intend to investigate the presence of heteroskedasticity and the leverage effect in the Chinese stock market. The presence of heteroskedasticity in stock returns affirm that investment decisions in the current period are affected by the unexpected volatility in the previous period. There have been a few studies on modelling and forecasting stock market volatility in China. Xu (1999) studies the volatility for daily spot returns of Shanghai composite stock index in 1992-1995, and found that the GARCH model is superior to that of either EGARCH or GJR-GARCH models, indicating that there is almost no so-called leverage effect in the Shanghai stock market since volatility is mainly caused by the changes in governmental policy. Lee et al. (2001) examine the time-series features of stock returns and volatility in four of China's stock exchanges and found strong evidence of time-varying volatility, indicating volatility is highly persistent and predictable. Copeland and Zhang (2003) also find no evidence of leverage effect in mainland China's stock markets when they adopt the EGARCH model to capture the volatility during the period in 1994-2001. Based on the four-variable asymmetric GARCH fitted in the BEKK structure developed by Engle and Kroner (1995), Li (2007) concludes that no direct linkage exists between mainland China's stock markets and the U.S. market, thereby furnishing portfolio investors with diversification benefits. Tsui and Yu (1999) apply this model to capture conditional correlation between Shanghai and Shenzhen stock markets and conclude the constancy is rejected by the information matrix test. However, the assumption of constant conditional correlations seems unrealistic for most of financial series. In this study, we identify two discrete regimes for each stock market, relatively stable state and highly volatile state, and make probabilistic inference on the persistence of each state, following the methodology of Hamilton (1989). In addition, we capture the dynamics of conditional correlation between returns of China's stock markets and those of the U.S. in a bivariate VC-MGARCH framework to shed some light in how the two markets are correlated and whether they can bring diversification to investors. The time-varying-parameter models with Markov-switching heteroskedasticity proposed by Kim (1993) is adopted to capture the changing relationship between returns of China's stock markets and those of the U.S.

The rest of our thesis is organized as follows. Section 2 describes the methodology used for this study, and Section 3 analyzes the data sets and the estimation results. The last section concludes with implication drawn from our findings on equity investment.

2. METHODOLOGY AND THE MODEL

It has been well documented that for a wide range of financial data series, time-varying conditional variances can be explained empirically through the autoregressive conditional heteroskedasticity (ARCH) model of Engle (1982). When the time-varying conditional variance has both autoregressive and moving average components, this leads to the generalized ARCH(*p,q*) (GARCH(*p,q*)) model of Bollerslev (1986). In the selected conditional volatility model, the residual series should follow a white noise process. Li et al. (2002) provide an extensive review of recent theoretical results for univariate and multivariate time series models with conditional volatility errors. McAleer (2005) reviews a wide range of univariate and multivariate, conditional and stochastic, models of financial volatility. McAleer et al. (2007) discuss recent developments in modeling univariate asymmetric volatility and McAleer et al. (2008) develop the regularity conditions and establish the asymptotic properties of a general model of time-varying conditional correlations.

The purpose of this section is to brief a bivariate VC-MGARCH framework employed in this study. We first define the GARCH framework for modelling conditional heteroskedasticity and time-varying conditional correlations, and then discuss the time-varying-parameter models with Markov-switching heteroskedasticity proposed by Kim (1993) to capture the changing relationship between returns of China's stock markets and those of the U.S. Let r_{it} be the daily returns of the Shanghai Stock Exchange Composite Index/the Shenzhen Stock Exchange Component Index. The conditional mean equation for each variable is effectively captured by an ARMA(1,1) structure specified as follows:

$$r_{it} = c_i + \phi_i r_{i,t-1} + \theta_i \varepsilon_{i,t-1} + \varepsilon_{it} \tag{1}$$

where ε_{it} is the identically and independently distributed error term. The GARCH(1,1) proposed by Bollerslev (1986) is used for the conditional variance equation:

$$\varepsilon_{it} = \eta_{it}\sigma_{it}, \;\; \eta_{it} \sim i.i.d.(0,1) \tag{2}$$

$$\sigma_{it}^2 = \alpha_{i0} + \alpha_{i1}\varepsilon_{i,t-1}^2 + \beta_{i1}\sigma_{i,t-1}^2 \tag{3}$$

where $\alpha_{i0} > 0$, $\alpha_{i1} \ge 0$, $\beta_{i1} \ge 0$ and $\alpha_{i1} + \beta_{i1} < 1$. Parameters in the above equations are typically estimated by the maximum likelihood method to obtain Quasi-Maximum Likelihood Estimators (QMLE) in the absence of normality of the conditional shocks (η_t).

To capture the asymmetric feature, we introduce three types of asymmetric GARCH models, i.e., the EGARCH, GJR-GARCH(1,1) and A-PARCH(1,d,1). The latter imposes Box-Cox power transformation on the conditional volatility function, thus allowing for more flexibility, which can be specified as follows:

$$\sigma_{it}^d = \alpha_{i0} + \alpha_{i1}(\left|\varepsilon_{i,t-1}\right| + \gamma_{i1}\varepsilon_{i,t-1})^d + \beta_{i1}\sigma_{i,t-1}^d \tag{4}$$

Where negative γ_{i1} denotes leverage effect. We have conducted quasi-maximum likelihood estimation on d and found the model with $d = 1$ is more robust to extreme values than with other value The restriction,

$\alpha_{i1}(1+\gamma_{i1}^2)+\beta_{i1}<1$, is required for the A-PARCH(1,2,1) to ensure covariance stationary. Similarly, with A-PARCH(1,1,1), $E(\sigma_t)$ and $E(|\varepsilon_t|)$ are guaranteed for existence, providing $\sqrt{2/\pi}*\alpha_{i1}+\beta_{i1}<1$.

In order to capture conditional correlations between returns of the Shanghai Stock Exchange Composite Index/the Shenzhen Stock Exchange Component Index and returns of the S&P 500 Index, we follows the methodology of Tse and Tsui (2002) to model time-varying conditional correlations in a bivariate GARCH(1,1) framework. In particular, the conditional correlations formulation in a bivariate VC-MGARCH model is

$$\rho_t = (1-\theta_1-\theta_2)\rho + \theta_1\rho_{t-1} + \theta_2\psi_{t-1} \quad (5)$$

where $(1-\theta_1-\theta_2)\rho$ is the time-invariant conditional correlation coefficient, θ_1 and θ_2 are assumed to be nonnegative and sum up to less than 1, and ψ_{t-1} is specified as

$$\psi_{t-1} = \frac{\sum_{n=1}^{2} e_{1,t-n}e_{2,t-n}}{\sqrt{(\sum_{n=1}^{2} e_{1,t-n}^2)(\sum_{n=1}^{2} e_{2,t-n}^2)}} \quad (6)$$

Ignoring the constant term and assuming normality, the conditional log likelihood function of sample size n is,

$$L = -\frac{1}{2}\sum_t\left(\log(1-\rho_t^2)+\frac{e_{1,t}^2+e_{2,t}^2-2\rho_t e_{1,t}e_{2,t}}{(1-\rho_t^2)}\right)$$

The total number of parameters is 11 for a bivariate asymmetric GARCH model with varying correlations, and this number always exceeds that of Bollerslev's (1990) constant-correlation model by 2. In fact, the CC-MGARCH model is nested within the VC-MGARCH model by restricting θ_1 and θ_2 to zero.

We employ the Markov-switching variance models (equation 7) to study the regimes switching and the time-varying-parameter models with Markov-switching heteroskedasticity (equation 8) to assess the conditional heteroskedasticity of r_{sht} and r_{szt}. The oscillatory behavior of time-varying volatility can be categorized into two distinct regimes: relatively stable state and highly volatile state. Markov-switching variance models can be specified as

$$\begin{aligned} & r_{it} = c_i + \phi_i r_{i,t-1} + \theta_i\varepsilon_{i,t-1} + a_i r_{sp,t-1} + \varepsilon_{it}, \\ & \varepsilon_{it} \sim N(0,\sigma_{is_t}^2), \\ & \sigma_{is_t}^2 = \sigma_{i0}^2 + (\sigma_{i1}^2-\sigma_{i0}^2)S_{t,} \\ & \Pr[S_t=1|S_{t-1}=1]=p_{11}, \Pr[S_t=0|S_{t-1}=0]=p_{00} \end{aligned} \quad (7)$$

And the time-varying-parameter models with Markov-switching heteroskedasticity is

$$\begin{aligned} & r_{it} = c_i + \phi_i r_{i,t-1} + \theta_i\varepsilon_{i,t-1} + \beta_{it} r_{sp,t-1} + \varepsilon_{it}, \\ & \beta_{it} = \alpha_i\beta_{i,t-1} + v_{it}, \\ & v_{it} \sim N(0,\sigma_{v_i}^2), \\ & \varepsilon_{it} \sim N(0,\sigma_{is_t}^2), \\ & \sigma_{is_t}^2 = \sigma_{i0}^2 + (\sigma_{i1}^2-\sigma_{i0}^2)S_{t,} \\ & \Pr[S_t=1|S_{t-1}=1]=p_{11}, \Pr[S_t=0|S_{t-1}=0]=p_{00} \end{aligned} \quad (8)$$

where $i = sh, sz$, ε_{it} is assumed to follow normal distribution, σ_{i0}^2 denotes the variances when China's stock markets are relatively stable, and σ_{i1}^2 represents the variances when they are suffering from huge shocks. In particular, σ_{i0}^2 is assumed to be smaller than σ_{i1}^2. $r_{sz,t-1}$ is not included in the conditional mean equation because of its insignificant value in the estimation results. Further, we conducted several tests by employing the efficient algorithm a la Bai and Perron (2002) to identify the existence of multiple structural changes and corresponding number of breaks associated with interpolating full sample of $r_{sp,t-1}$ into the conditional mean equation, The LM and Ljung-Box tests are applied to assess the appropriateness of the two Markov-switching models.

3. EMPIRICAL ANALYSIS

3.1 Data Description

We collected our data sets from Yahoo.Finance spanning from January 5, 2000 to December 31, 2008. The Shanghai Stock Exchange Composite Index launched on July 15, 1991 is a whole market index, including all listed A-shares and B-shares traded at the Exchange. A-shares are traded in RMB, while B-shares are traded in U.S. dollars at the Shanghai Stock Exchange and in Hong Kong dollars at the Shenzhen Stock Exchange. The index is compiled using Paasche weighted formula. Differing from the Shanghai Exchange, the Shenzhen Component Index only selects 40 representative listing companies' tradable shares to track the market's performance, thereby minimizing the inaccuracy induced by non-tradable shares. The S&P 500 Index, initially published in 1957, is one of the most widely quoted and tracked market-value weighted indices, representing prices of 500 stocks actively traded in either New York Stock Exchange or NASDAQ. Since March 2005, it has implemented the policy that only actively traded public shares (float weighted) are considered for the calculation of market capitalization.

In subsequent sections, the Shanghai Stock Exchange Composite Index, the Shenzhen Stock Exchange Component Index and the S&P 500 Index are abbreviated by *sh*, *sz* and *sp*, respectively. The daily returns of those indices, r_{it}, are computed as:

$$r_{it} = \ln(\frac{P_{it}}{P_{it-1}})*100 \qquad (9)$$

where $i = sh, sz, sp$, P_{it} stands for the close price of each index adjusted for dividends and splits at date t.

Table 1 displays the summary statistics of the daily returns of the three indices. As can be seen from Table 1, all the series are left-skewed and highly leptokurtic. In particular, r_{spt} has the highest kurtosis and also the skewness, indicating that negative returns are more prevalent. Such non-normal properties are also captured by the highly significant Jarque-Bera test statistics. The high Lagrange multiplier test statistics also indicate strong ARCH effects of these series. As such, appropriate GARCH models seem adequate to accommodate the statistical feature of leptokurtosis.

Before proceeding to the specific models, we employ the augmented Dickey-Fuller (ADF) and the Efficient Modified Phillips-Perron (PP) tests to check the stationarity of all the series. Our findings, available upon request, show that all ADF and PP test statistics are significant at the 1% level, thereby indicating that all the return series are stationary.

3.2 Empirical Results

The estimates of conditional correlations between returns in the Chinese and the U.S. stock markets based on estimating bivariate VC-MGARCH(1,1) and CC-MGARCH(1,1) model are reported in Table 2. It is found that both VC-MGARCH(1,1) and CC-MGARCH(1,1) models satisfy the restrictions imposed on the GARCH(1,1) model, i.e. $\alpha_1 > 0$, $0 < \beta_1 < 1$ and $\alpha_1 + \beta_1 < 1$. The insignificant constant term in the conditional correlation equation in the VC-MGARCH(1,1) is consistent with the insignificant correlation in the CC-MGARCH(1,1) where the correlation is assumed to be time-invariant. That implies there is no significant linkage between both the Shanghai/Shenzhen markets and the U.S. stock market when assuming the correlation is time-invariant. However, this assumption is quite unreasonable. From Table 2, it is noted that the conditional correlation significantly follows an AR(1) process. The LM and Ljung-Box tests statistics for the VC-MGARCH(1,1) and

Table 1: Summary Statistics for r_{it}, $i = sh, sz, sp$

	r_{sht}	r_{szt}	r_{spt}
(A) Descriptive statistics			
Mean	0.0111	0.0275	-0.0194
Std. dev	1.6520	1.8340	1.3590
Minimum	-9.2562	-12.1000	-9.4700
Maximum	9.4010	11.6300	10.9600
Skewness	-0.0102	-0.0952	-0.1220
Kurtosis	7.9360	8.2210	11.9600
No. of obs.	2337	2244	2261
(B) Jarque-Bera test for normality			
Jarque-Bera	2372.4928*	2552.0874*	7568.8045*
(C) LM test for ARCH effect			
LM(10)	155.7168*	134.2592*	673.7485*

(*: at the 1% significance level)

the CC-MGARCH(1,1) (not reported due to space limitation, but available upon request) indicate no evidence of ARCH effect or serial correlation in both the standardized residuals and the standardized squared residuals. However, the large likelihood ratio test statistic demonstrates the VC-MGARCH(1,1) model indeed outperforms the CC-MGARCH(1,1) one at any conventional level of significance.

Figure 2 displays the conditional correlation between Shanghai/ Shenzhen and the U.S. stock markets, respectively. Although the linkage between the two markets is quite low, there is still some connection between the two markets, attributed to the integration of global financial markets. Additionally, the correlation varies remarkably, with the presence of an upward or downward tendency even during a short period. That phenomenon can be explained by the immaturity of the Chinese stock markets and governmental influence on the markets. The low and highly volatile connection may bring diversification benefits to equity portfolio.

We have conducted several tests by employing the efficient algorithm a la Bai and Perron (2002) to identify the existence of multiple structural changes and corresponding number of breaks associated with interpolating full sample of into the conditional mean equation. All the test statistics are insignificant at the 5% level for both specifications, indicating that no break has been introduced when $r_{sp,t-1}$ is interpolated. This finding is confirmed by the statistic value of BIC, modified Schwarz criterion (LWZ) and sequential method with all selecting zero break.

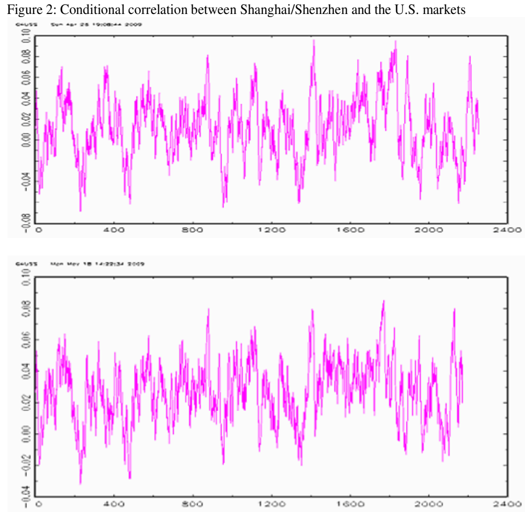
Table 2: VC-MGARCH(1,1) and CC-MGARCH(1,1)

	α_0	α_1	β_1	θ_1	θ_2	ρ
Panel A: VC-MGARCH(1,1) model for ε_{sht} and ε_{spt}						
SH	0.0233* (0.0122)	0.0681** (0.0192)	0.9261** (0.0209)	0.9383** (0.0705)	0.0102 (0.0090)	0.0109 (0.0286)
SP	0.0114* (0.0059)	0.0792** (0.0127)	0.9146** (0.0141)			
CC-MGARCH(1,1) model for ε_{sht} and ε_{spt}						
SH	0.0247** (0.0038)	0.0709** (0.0042)	0.9227** (0.0036)	N.A.	N.A.	0.0022 (0.0213)
SP	0.0119** (0.0025)	0.0810** (0.0091)	0.9119** (0.0098)			
Panel B: VC-MGARCH(1,1) model for ε_{szt} and ε_{spt}						
SZ	0.0339** (0.0168)	0.0817*** (0.0241)	0.9124*** (0.0244)	0.9185*** (0.0825)	0.0264 (0.0253)	0.0078 (0.0099)
SP	0.0115* (0.0060)	0.0843*** (0.0138)	0.9104*** (0.0151)			
CC-MGARCH(1,1) model for ε_{szt} and ε_{spt}						
SZ	0.0381*** (0.0063)	0.0890*** (0.0051)	0.9044*** (0.0044)	N.A.	N.A.	0.0231 (0.0216)
SP	0.0119*** (0.0026)	0.0860*** (0.0098)	0.9084*** (0.0101)			

Note: Standard errors are in parentheses. * indicates the 10% significance level; ** the 5% significance level; and *** the 1% significance level.

We then estimate the Markov-switching variance models (equation 7) and the time-varying-parameter models with Markov-switching heteroskedasticity (equation 8), and the results are available upon request. It is found that all the estimates are statistically significant at the 5% or 1% level, which indicates the existence of two discrete regimes and Markov-switching heteroskedasticity. Both models show a very similar result concerning the volatility. It is found that both p_{00} and p_{11} have a value close to unity, implying regimes persistence. This finding is consistent with the observation that in 2008 the Chinese market experienced persistently high level of volatility, while in 2006 it was quite stable. The duration of high volatility is about 25 days on average, while the low volatility state lasts for 33 days on average. It is also seen that, in contrast to our expectation, the estimates of ϕ and θ are quite small, far less than unity. Although it is found positive and statistically also significant, the value of the estimate a is relatively small, implying there is still a weak linkage between the Chinese and the US markets and hence low diversification benefits for portfolio investment. This finding is consistent with our casual observation.

Figure 2: Conditional correlation between Shanghai/Shenzhen and the U.S. markets



4. CONCLUDING REMARKS

This study intends to examine the presence of heteroskedasticity and the leverage effect in the two Chinese stock markets, and to capture the dynamics of conditional correlation between returns of China's stock markets and those of the U.S. in a bivariate VC-MGARCH framework. We employed the time-varying-parameter models with Markov-switching heteroskedasticity proposed by Kim (1993) to capture the dynamic relationship. The results show that that the leverage effect is significant in both markets during the sample period in 2000-2008. The ARMA(1,1)-A-PARCH(1,1) model fitted with the generalized error distribution is found to be more suitable for capturing conditional volatility in mainland China's stock markets. The conditional correlation between the Chinese and the U.S. stock markets is found to be quite low and highly volatile. It is also found that uncertainty derived from time-varying relationship between Shanghai and the U.S. stock markets is more significant than that between Shenzhen and the U.S. stock markets. In addition, the Chinese stock markets are found to be highly regimes persistent, thereby reducing potential benefits induced by actively trading. These findings have important implication for investors seeking opportunity of portfolio diversification.

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