Stock Returns and Volatility: an empirical study of Chinese stock markets

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ABSTRACT *This paper uses GARCH models to analyse the relationship between returns and volatility on the Shanghai and Shenzhen Stock Exchanges in China. Empirical estimates using the sample data from 21 May 1992 to 2 February 1996 suggest that the variances of the returns in the two markets are best modelled by the GARCH-M (1,1) specification. Volatility transmission between the two markets (the volatility spill-over effect) is also found to exist. The results of one month ahead ex ante forecasts show that the conditional variances of the returns of the two stock markets exhibit a similar pattern.*

1. Introduction

Although there is extensive recent literature on the dynamic characteristics of financial markets in industrialised nations (US, UK, Japan and Germany), there is a lack of similar studies for developing countries, particularly in the quantification of market characteristics of the emerging Chinese stock markets.

As the only two official stock markets in mainland China, the Shanghai and Shenzhen Stock Exchanges began their operations in December 1990 and July 1991 respectively. Both markets have expanded dramatically since. By the end of 1995 there were 188 companies listed in Shanghai and 135 in Shenzhen. The number of shares traded in the two markets in 1995 reached 458 with a total trade volume of 6402.40 billion yuan ($776.7 billion). The listed companies were from the retail, real estate, public, chemical and manufacturing sectors, with 78% of these companies among the largest ten companies in their respective sectors. In addition, economic reforms have recently transformed 3000 state-owned or collective-owned medium and large sized companies into share holding companies. This will create a huge potential for further development of the Chinese stock markets. By means of channelling scarce resources to the most productive sectors, the Chinese stock markets have fuelled rapid economic growth. The purpose of this paper is to provide a quantitative analysis of the dynamic characteristics of these stocks and thereby promote an understanding of the functioning of the Chinese financial sector.

Using augmented Dickey–Fuller type statistics Liu, Song & Romilly (LSR hereafter) (1997), found that the random walk (weak sense) hypothesis may be

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accepted for both the Shanghai and Shenzhen stock markets. This implies that economic agents cannot predict movements in stock returns, and that the markets are efficient individually. LSR also apply the Granger (1988) error correction causality test and cointegration analysis to the two markets and conclude that they are cointegrated with a bi-directional causality relationship. This finding suggests that the Chinese stock markets are inefficient collectively. This paper is intended to extend LSR's study by further examining the dynamic properties of the Chinese stocks in terms of their return volatilities (risks), leverage and spill-over effects.

This paper is organised as follows: in Section 2, previous studies in the area of stock volatility are reviewed and the methodology used in this paper is discussed. Section 3 presents empirical results on the dynamic characteristics of the two Chinese stock markets. In Section 4, forecasts based on the models developed in Section 3 are generated and discussed. Section 5 contains a summary and conclusions.

2. Methodology

Although they have experienced rapid development, the Chinese stock markets have a considerably smaller capitalisation than such well developed financial markets as New York, London and Tokyo. The Chinese markets are also characterised by a very small number of listed companies. Moreover, economic reform has brought about many changes in the nature and structure of the Chinese economy, particularly the relationship between the macroeconomy and the financial markets. These factors may contribute to greater instability and volatility in the Chinese stock markets.

The Autoregressive Conditional Heteroscedasticity (ARCH) model first introduced by Engle (1982) and later generalised by Bollerslev (1986) as GARCH (p,q) has been successfully used in modelling the volatility in financial time series. In this paper these models are used to examine the dynamic characteristics of the Shanghai and Shenzhen stock markets. The GARCH (p,q) model consists of Equations (1) and (2):

$$R_t = \eta + \sum_{i=1}^{m} \theta_i R_{t-i} + \varepsilon_t + \sum_{j=1}^{n} \vartheta_j \varepsilon_{t-j} \tag{1}$$

where R_t is an index of daily stock returns in logarithms as defined by Equation (6) in Section 3, $\varepsilon_t|\Omega_{t-1} \sim N(0,h_t)$, and the conditional variance of returns, R_t, is specified as:

$$h_t = \alpha + \sum_{i=1}^{p} \beta_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \phi_j h_{t-j} \tag{2}$$

The parameters in Equation (2) should satisfy: $\alpha > 0$, β_i, $\phi_j > 0$, $i = 1, \dots p$, $j = 1, \dots q$. The GARCH process allows the current conditional variance to be a function of past conditional variance as well as the past squared error terms derived from the stock returns model. As suggested by Akgiray (1989), allowing the conditional variances to depend on past realised variances is particularly consistent with the actual volatility pattern of the US stock markets where there are both stable and unstable periods.

Engle *et al.* (1987) found that an increase in risks (variances) tends to result in higher expected returns in share prices. Therefore, the GARCH in mean or GARCH-M model is a natural extension of the GARCH model, since it introduces a conditional variance (or standard deviation) term in Equation (1):

$$R_t = \eta + \lambda h_t + \sum_{i=1}^{m} \theta_i R_{t-i} + \varepsilon_t + \sum_{j=1}^{n} \vartheta_j \varepsilon_{t-j} \tag{3}$$

The combination of Equations (2) and (3) is called GARCH-M (*p*,*q*). Parameter λ is the contemporaneous response to the change of the conditional variance. This indicates that higher risks (variance) may lead to a higher level of expected returns.

In their study of the Chinese stock markets, LSR (1996) found a common stochastic trend existing between the Shanghai and Shenzhen share prices, i.e. they are cointegrated. The causal relationships between the two markets are also indentified by LSR. In this paper we use GARCH models to examine the possible volatility transmission between the Shanghai and Shenzhen markets in order to determine whether volatility in one market will influence the other and vice versa.

The idea of volatility spill-over is proposed by Hamao *et al.* (1990) to examine the short-run interdependence of price volatility across the New York, Tokyo and London stock markets. To model the spill-over effect of volatility in market B on market A, a lagged squared error term from the mean equation of the GARCH model for market B may be introduced into the GARCH model for market A as an explanatory variable in the conditional variance equation. The estimate of the coefficient of the lagged squared error term is then examined, and a significant estimate would suggest a spill-over effect.

The spill-over effect from market B to market A may be captured by the following specification:

$$h_t = \alpha + \sum_{i=1}^{p} \beta_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \phi_j h_{t-j} + \sum_{\gamma=1}^{w} \zeta_\gamma \varepsilon_{Bt-\gamma}^2 \tag{4}$$

where the $\varepsilon^2{}_{Bt-\gamma}$s are previous shocks to market B. Equations (3) and (4) may be termed the GARCH-spill-over model. The coefficients ζ_γ measure the impact of past shocks to the returns of market B on the conditional volatility of market A.

Kim & Rogers (1995) investigate the effects of return volatility in the US and Japanese financial markets on the Korean market, and Chelley-Steeley & Steeley (1996) examine the transmission of volatility between and within capitalisation-ranked portfolios in the UK. Both studies confirm the existence of a spill-over effect.

The relationship between stock return volatility and the sign of stock returns is also of interest. It is argued by Engle & Ng (1993) that the relationship has a negative sign, i.e. when stock returns decrease, the volatility increases and vice versa. This phenomenon is termed the leverage effect. It may be modelled by the asymmetric volatility model or threshold ARCH (or TARCH) model in which a multiplicative 'indicator' dummy variable is introduced to capture the influence of the sign of stock returns on the conditional variance:

$$h_t = \alpha + \sum_{i=1}^{p} \beta_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \phi_j h_{t-j} + \omega S_{t-1}^{-1} \varepsilon_{t-1}^2 \tag{5}$$

where $S_{t-1}^{-1} = 1$ if $\varepsilon_{t-1} < 0$, and $S_{t-1}^{-1} = 0$ otherwise. This allows the impact of the squared errors on conditional volatility to be different according to the sign of the lagged error terms. If the coefficient of ω is positive and significant then a negative shock in the return series will have a greater effect on future volatility than a positive shock.

Many researchers, such as French *et al.* (1987), Chou (1988), Akgiray (1989), Baillie & DeGennaro (1990) and Kim & Kon (1994), have found that GARCH specifications are able to model stock returns that display volatility clustering in some international stock markets. Bollerslev *et al.* (1992) provide a detailed survey of GARCH modelling. There is, however, a need to extend this type of study to the emerging financial markets and to the Chinese financial market in particular.

3. The Data and Empirical Results

The data used in this study are the time series of daily closing prices on the Shanghai and Shenzhen Stock Exchanges obtained from the databases of the two markets. The sample period starts from 21 May 1992 through to 2 February 1996, with a total of 967 observations for each of the two markets. When the stock exchanges were closed because of national holidays, the index level was assumed to be the same as that on the previous trading day. Stock prices on the Shanghai market were strictly regulated before 21 May 1992, and therefore prices on both markets before this date are not included in the sample.

The daily returns were calculated as the change in the logarithm of closing prices of successive days:

$$R_t = \text{In}(P_t) - \ln(P_{t-1}) \tag{6}$$

Akgiray (1989) notes that if a return series represented by Equation (6) can be regarded as a 'white noise' process (with the implication that the share price is a pure random walk), the series should be identically and independently distributed with zero mean and constant variance, i.e. $R_t \sim$ i.i.d $(0, \sigma^2)$. Moreover the absolute and squared values of R_t, should also lack dependency. Although LSR (1996) found that the two Chinese return series follow a 'random walk' process, the evidence below suggests that the returns of the two shares are not pure 'white noise' since the null hypothesis of independence in $R_{t,}|R_t|$ and R_t^2 for both series is rejected. This implies that the Shanghai and Shenzhen share price time series can at most be regarded as a martingale process and the corresponding return series as martingale differences. According to LeRoy (1989) and Harvey (1993, p. 268), a white noise is an i.i.d $(0, \sigma^2)$ sequence which suggests that past observations of the series cannot be utilised to predict the future values of the expected mean and variance of the series. In a martingale difference process past observations contain no information for prediction, but it may be possible to construct a non-linear model in which the non-linearity is reflected in higher order moments such as variance, and hence this has implications for assessing the return volatilities of share prices in a financial market.

Some earlier studies on daily stock returns, such as Mandelbrot (1963, 1967) and Fama (1965), discovered that the distribution of stock returns exhibit the following features: leptokurtosis, skewness and volatility clustering, all in contrast to the properties of an identical Gaussian distribution. The statistical evidence below indicates that Chinese stock returns also have similar features.

The return, absolute return and squared return series for the two Chinese stock markets are plotted in Figs 1–3 and some of the descriptive statistics of the two series are presented in Table 1.

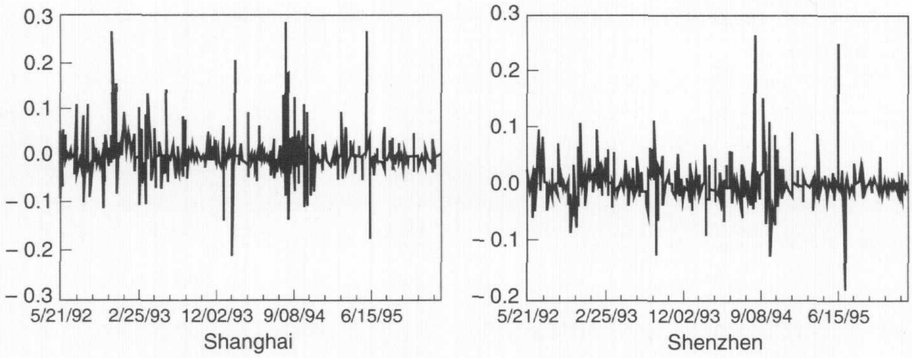

Fig. 1. Returns of the Shanghai and Shenzhen stock exchanges.

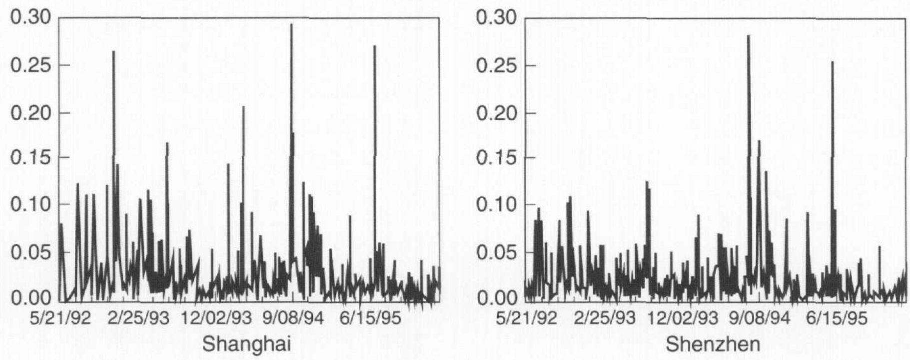

Fig. 2. Absolute returns of the Shanghai and Shenzhen stock exchanges.

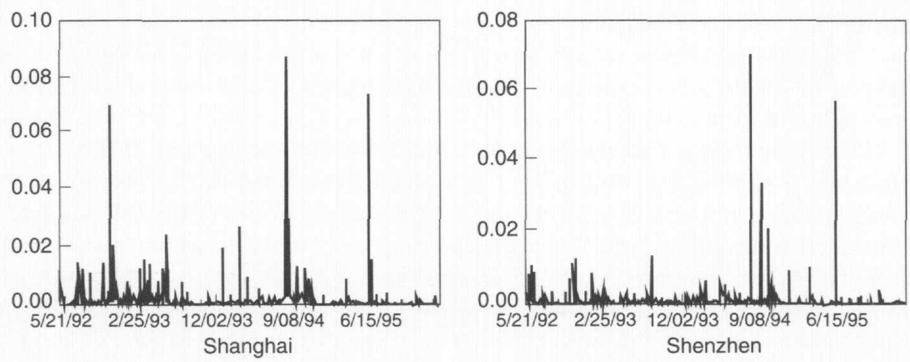

Fig. 3. Squared returns of the Shanghai and Shenzhen stock exchanges.

The spikes in Fig. 1 indicate that the two return series are not random walk processes, and this is confirmed by Figs 2 and 3 which imply significant volatility clustering. The lack of independence which is one of the conditions of a white noise process is also statistically rejected by the Ljung–Box Q-statistics and the autocorrelation functions, as can be seen from Table 1.

The descriptive statistics for the two stock returns are the mean, standard

Table 1. Descriptive statistics for the stock returns

Statistics	R_1	R_2	$\|R_1\|$	$\|R_2\|$	R_1^2	R_2^2
Mean	− 0.00095	− 0.0011	0.0247	0.0203	0.0016	0.0010
SD	0.04020	0.0315	0.0316	0.0242	0.0056	0.0039
ρ_1	− 0.004	− 0.006	0.279	0.203	0.152	0.068
ρ_2	− 0.042	0.066	0.287	0.286	0.244	0.184
ρ_3	0.055	− 0.051	0.223	0.237	0.168	0.200
ρ_4	0.046	0.084	0.208	0.192	0.149	0.074
ρ_5	0.041	0.015	0.124	0.199	0.039	0.055
ρ_6	− 0.073	− 0.077	0.165	0.143	0.089	0.041
ρ_7	0.009	0.012	0.131	0.111	0.086	0.055
ρ_8	− 0.022	0.001	0.083	0.090	0.009	0.005
ρ_9	0.080	0.062	0.079	0.090	0.009	0.000
ρ_{10}	− 0.042	− 0.100	0.140	0.100	0.034	0.012
ρ_{11}	− 0.051	− 0.06	0.102	0.064	0.019	− 0.005
ρ_{12}	0.033	0.028	0.141	0.054	0.054	− 0.006
Skewness	1.332	1.395	—	—	—	—
Kurtosis	13.30	16.24	—	—	—	—
$Q(12)$	25.76	34.32	366.14	312.72	149.83	89.53
Jarque–Bera	4553.6	7367.8	—	—	—	—

Note: R_1 and R_2 are the log returns of the Shanghai and Shenzhen markets respectively.

deviation, first to twelfth order autocorrelation coefficients, skewness, excess kurtosis, the Ljung–Box statistic for testing the hypothesis that all autocorrelations up to lag 12 are jointly equal to zero, and the Jarque–Bera normality statistic. For the absolute and squared returns series, the skewness, kurtosis and normality statistics are not applicable.

The kurtosis, skewness and Jarque–Bera normality statistics in the first two columns of Table 1 indicate that the null hypothesis of a normal distribution is rejected for both series.

The independence assumption for the T observations in each of the series is tested by calculating the first to twelfth order autocorrelation coefficients. Using the usual approximation of $1\sqrt{T}$ as the standard error of the estimated autocorrelation coefficients, first-order autocorrelation is not found in either return series but higher order autocorrelation appears to exist. The Ljung–Box $Q(12)$ statistics for the cumulative autocorrelation up to twelfth-order autocorrelation in the two return series are both greater than 21.02 (the 5% critical value from a χ^2 distribution with 12 degrees of freedom), suggesting that the hypothesis of independence (lack of autocorrelation) in daily returns should be rejected. Furthermore, the autocorrelation coefficients and Ljung–Box statistic for the absolute and squared return series also indicate very strong autocorrelation. Overall, these results clearly reject the independence assumption for the two Chinese time series of daily stock returns and justify the use of the GARCH specification in modelling the variance (volatility) of the Chinese stock markets.

In the estimation of the GARCH type models, we start with a general specification of the mean equation (1) and the variance equation (2). The orders of the AR and MA process in the mean equation (1) are determined by the partial autocorrelation function (PACF) and the autocorrelation function (ACF) of the return series of Shanghai and Zhenzhen respectively. The final GARCH specification is decided by looking at the properties of standardised residuals, which are the conventional residuals divided by their one step ahead conditional standard deviation. If the model is correctly specified, these should be independent and identically distributed with mean zero and variance one. The best specification for both Shanghai and Shenzhen is the GARCH (1,1) with the mean equations of ARMA (6,6) for Shanghai and ARMA(10,10) for Shenzhen. Other models such as GARCH(p,q) for $p = 1,2, \ldots, 6$ and $q = 1, 2, \ldots, 6$ were also tried, but there were no significant improvements in goodness of fit based on likelihood-ratio tests and other statistics such as the standard deviation of the regression, the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC).

We then examine the effect of risk on returns using the GARCH (1,1)-M model in which returns are assumed to be related to the standard deviation $\sqrt{h_t}$ as well as the ARMA terms. The variance spill-over and leverage effects are also investigated via Equations (4) and (5). Table 2 presents the estimation results of various GARCH specifications, where Equations (1)–(4) in Table 2 are GARCH (1,1), GARCH-M (1,1), GARCH (1,1) Spill-over and TARCH models respectively.

The estimates of the GARCH (1,1) model for both Shanghai and Shenzhen show that all the parameters in the mean and variance models are statistically significant and the values of the estimated parameters α, β_1 and ϕ_1 satisfy $\alpha > 0$, β_1, $\phi_1 > 0$. The sum of $\beta_1 + \phi_1$ is less than unity. This suggests that, although it is widely accepted for well established financial markets, the hypothesis of persistent mean reversion in the conditional variance may not be confidently assumed for the Chinese markets. The Ljung–Box $Q(12)$ statistics for the standardised residuals and squared standardised residuals, however, indicate that most of the linear dependence (autocorrelation) in the mean and variance has been captured by the GARCH(1,1) specification. The GARCH-M(1,1) estimates for the two markets show that the risk of stocks as measured by the standard deviation is positively related to the level of returns. This evidence is consistent with a positive risk premium on stock indexes, i.e. higher risks result in higher returns.

The estimates of Equations (3a) and (3b) show that the coefficient of the lagged error term ζ_1 is significant. This means that shocks to the stock returns in one market are transmitted to the other, i.e. spill-over effects exist between the two Chinese stock markets. This result suggests that there may be a bi-directional causal relationship between risk in the two Chinese stock markets. The result of volatility transmission is a natural extension to the results of LSR (1996), who found a cointegration relationship between the prices of the two stocks.

The ARMA and GARCH (1,1) specifications are also estimated with the introduction of a multiplicative 'indicator' dummy variable S_{t-1}^{-1} (where $S_{t-1}^{-1} = 1$ if $\varepsilon_{st-1} < 0$, and $S_{t-1}^{-1} = 0$ otherwise) to capture the influence of the sign of the stock returns on the conditional variance (the leverage effect). However, the leverage effect is not detected for either set of stock returns since the estimated coefficient ω is not significant in Equations (4a) and (4b).

The estimation results suggest that the spill-over models with variance in mean represented by Equations (3a) and (3b) are adequate specifications for modelling the volatility of the Chinese stock markets. These two models are then used for forecasting in the next section.

Table 2. The estimates of various GARCH models

Parameter	Shanghai (1a)	(2a)	(3a)	(4a)	Shenzhen (1b)	(2b)	(3b)	(4b)
ARMA								
η	− 0.002	− 0.009	− 0.008	− 0.009	− 0.002	− 0.008	− 0.002	− 0.009
	(− 1.929)	(− 2.312)	(− 1.999)	(2.305)	(− 1.750)	(− 2.615)	(− 1.406)	(− 2.596)
θ_3	− 0.575	− 0.481	− 0.499	− 0.479	—	—	—	—
	(− 3.710)	(− 2.809)	(− 2.913)	(− 2.791)				
θ_6	− 0.361	− 0.326	− 3.556	− 0.325	0.473	− 0.598	− 0.762	− 0.592
	(− 2.449)	(− 1.860)	(− 2.053)	(− 1.851)	(4.206)	(− 15.16)	(− 15.51)	(− 15.14)
θ_{10}	—	—	—	—	0.433	0.369	0.128	0.376
				(5.099)	(8.851)	(2.564)	(8.874)	
ζ_3	0.659	0.538	0.546	0.537	—	—	—	—
	(4.125)	(3.020)	(3.080)	(2.995)				
ζ_4	—	—	—	—	0.136	0.060	0.053	0.061
				(4.961)	(1.925)	(2.018)	(1.929)	
ζ_6	0.316	0.249	0.277	0.248	− 0.519	0.562	0.746	0.559
	(2.102)	(1.355)	(1.525)	(1.345)	(− 5.179)	(15.95)	(13.91)	(16.07)
ζ_{10}	—	—	—	—	− 0.528	− 0.396	− 0.116	− 0.398
				(7.349)	(− 6.829)	(− 2.054)	(− 6.851)	
λ	—	0.221	0.204	0.22	—	− 0.231	0.029	0.248
		(1.855)	(1.631)	(1.80)		(2.141)	(0.328)	(1.997)
GARCH								
α	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.00006	0.0002
	(9.48)	(9.974)	(8.291)	(9.077)	(5.487)	(6.292)	(5.077)	(6.114)
β_1	0.318	0.335	0.245	0.334	0.224	0.302	0.251	0.301
	(11.51)	(10.95)	(7.868)	(9.510)	(5.511)	(6.166)	(7.162)	(5.142)
ϕ_1	0.564	0.556	0.530	0.556	0.623	0.570	0.436	0.578
	(15.18)	(15.41)	(12.03)	(14.83)	(10.32)	(10.027)	(11.36)	(10.16)
ω	—	—	—	0.001	—	—	—	− 0.0002
				(0.019)			(− 0.004)	
ζ_1	—	—	0.171	—	—	—	0.183	—
			(6.883)				(8.508)	
$Q(12)^{SDR}$	7.038	6.479	6.897	6.502	9.214	6.818	6.017	6.909
$Q(12)^{SDR}$	0.947	0.878	0.795	0.848	1.426	1.496	1.50′	1.510
Log-likelihood	1869.9	1871.3	1884.0	1870.3	2056.3	2062.5	2223.7	2062.7

Notes: values in brackets are *t*-statistics. $Q(12)^{SDR}$ and $Q(12)^{SQSDR}$ are Ljung–Box $Q(12)$ statistics of standardised residuals and standardised squared residuals for cumulative autocorrelation up to the 12th order.

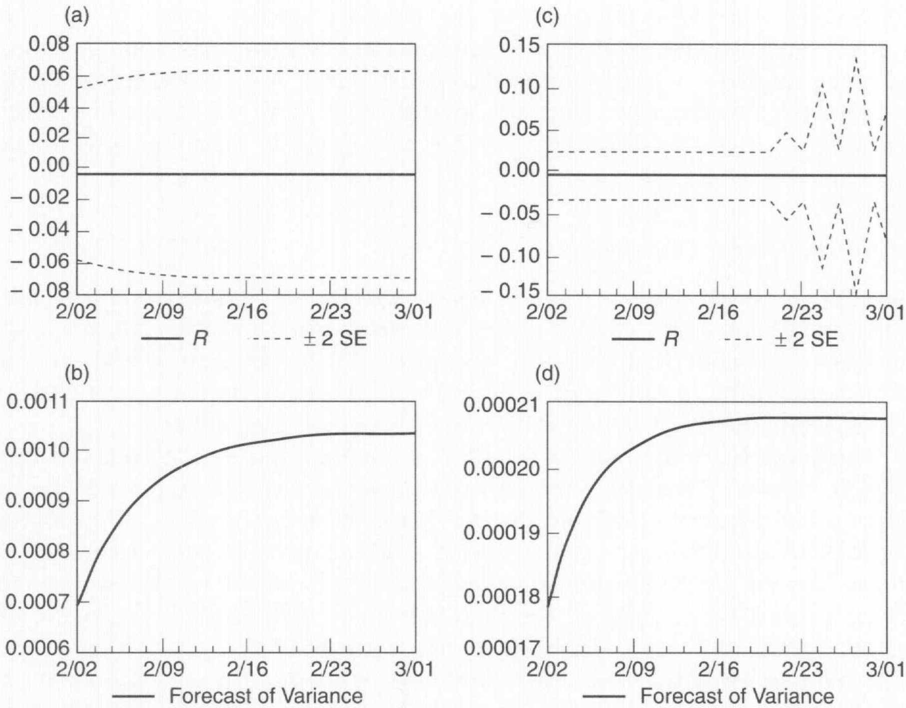

Fig. 4. Forecasts of stock returns and variances.

4. Volatility Forecasts of the Daily Returns

As suggested by Akgiray (1989), forecasting the volatility of stock returns is useful for the following two reasons. First, the forecasting capability of the GARCH models demonstrates the overall usefulness of the models as practical tools for stock market analysis. Second, good forecasts of stock volatility will help to establish pricing strategies for securities since risk is inherently related to volatility and share prices.

Equations (3a) and (3b) are used in forecasting the conditional mean and variance of the Shanghai and Shenzhen stock returns. The estimation period for both stock markets is from 21 May 1992 to 2 February 1996, and one-month-ahead forecasts are generated, i.e. the forecasts are produced for the period from 3 February 1996 to 2 March 1996. The forecasts of the daily returns with a boundary of two standard errors and the variance of the returns are plotted in Fig. 4.

Panels (a) and (b) in Fig. 4 are the forecasts of the daily returns and their variance for the Shanghai stock market, and panels (c) and (d) are the corresponding forecasts for the Shenzhen market. The forecasts of the returns are zero, a result consistent with the random walk hypothesis. However, the variance of the daily returns, as suggested by many researchers, could be forecasted using the GARCH models. The variances for both Shanghai and Shenzhen are time varying, with a steady increase in the first half of the month and then stabilisation in the second half of the month. The information contained in the general trend of the variance forecasts is very useful, since the GARCH models imply that returns will rise in response to increases in risk.

Another interesting result is that the standard forecast errors of the mean returns are very similar for both the Shenzhen and Shanghai stock markets in the first three quarters of the month, but the standard forecasting errors for the Shenzhen daily return series fluctuate towards the end of the forecasting period. This suggests that the Shenzhen market is more volatile than that of Shanghai.

5. Summary and Conclusions

The Chinese stock markets have much smaller capitalisation and fewer listed companies than the well developed financial markets such as New York, London and Tokyo. Economic reforms have changed both the structure of the economy and its relationship to the financial markets. All these factors have contributed to greater instability and volatility in the two Chinese stock markets.

This paper has examined the volatility of the two Chinese stock markets using GARCH models. The descriptive statistics show that the distributions of the two returns series are not normal and the independence assumption for the two series is rejected. The individual autocorrelation coefficients from order 1 to order 12 and the Ljung–Box $Q(12)$ cumulative autocorrelation statistic for the absolute and squared returns series suggest that there are considerable volatilities in the two markets so that the use of GARCH models is justified.

A number of GARCH (p,q) specifications are fitted to the data and the results show that both the Shanghai and Shenzhen returns series may be best explained by the GARCH-M (1,1) specification with the mean equations of ARMA (6,6) for Shanghai and ARMA (10,10) for Shenzhen. The estimated GARCH-M models are consistent with a positive risk premium on stock prices, i.e. higher risks result in higher returns. The empirical results also suggest that volatility transmission exists between the two markets, although the leverage effect which is widely associated with developed financial markets is not found for the Chinese markets.

The *ex ante* forecasts of 20 days (one month) for the two markets show that the two predicted returns variances exhibit a similar pattern and are time dependent, with a faster increase in the first half of the forecasting period and stabilisation in the second half.

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