China and the World Equity Markets: A Review of the First Decade

Kuan-Pin Lin[a] Albert J. Menkveld[b] Zhishu Yang[c]

January 13, 2005

Abstract

With more than a decade of Chinese equity markets, we study how variance, covariance, and correlations have developed for these markets and relative to world markets based on the Dynamic Conditional Correlation (DCC) model of Engle (2002). Chinese markets trade A-shares for domestic investors and otherwise identical B-shares for foreign investors. For A-shares, we find that volatility declined over the decade. Relative to world markets, we find no asymmetric volatility in China and less volatility persistence for B-shares. And, contrary to the global trend of increasing cross-country correlations, we find stationary correlations for China. A-share indices never correlated with world markets and B-share indices exhibit low correlation with Western markets and Japan (0-5%) and slightly higher correlation with the other Australasian markets (10-20%). We interpret these findings using Gordon's growth model.

[a]Portland State University
[b]Vrije Universiteit Amsterdam
[c]Tsinghua University Beijing

Contact details of the authors: KuanPin Lin, link@pdx.edu, Department of Economics, Portland State University, 241 Cramer Hall, 1721 SW Broadway, P. O. Box 751, Portland, OR 97207, USA, phone: +1 503 7253915, fax: +1 503 7253945; Albert J. Menkveld, ajmenkveld@feweb.vu.nl, Vrije Universiteit Amsterdam, FEWEB, De Boelelaan 1105, 1081 HV Amsterdam, Netherlands, phone: +31 20 5986130, fax: +31 20 5986020; Zhishu Yang, yangzhsh@em.tsinghua.edu.cn, School of Economics and Management, Tsinghua University, Beijing, 100084, P.R. China, phone: +86 10 62771769, fax: +86 10 62785562. This research was supported by grants from NSFC (Project Number: 70103002) and the School Basic Research Fund, School of Economics and Management,Tsinghua University. For research assistance, we are grateful to Qi Zhang. The usual disclaimer applies.

China and the World Equity Markets: A Review of the First Decade

Abstract

With more than a decade of Chinese equity markets, we study how variance, covariance, and correlations have developed for these markets and relative to world markets based on the Dynamic Conditional Correlation (DCC) model of Engle (2002). Chinese markets trade A-shares for domestic investors and otherwise identical B-shares for foreign investors. For A-shares, we find that volatility declined over the decade. Relative to world markets, we find no asymmetric volatility in China and less volatility persistence for B-shares. And, contrary to the global trend of increasing cross-country correlations, we find stationary correlations for China. A-share indices never correlated with world markets and B-share indices exhibit low correlation with Western markets and Japan (0-5%) and slightly higher correlation with the other Australasian markets (10-20%). We interpret these findings using Gordon's growth model.

As China celebrates ten years of modern stock market history, we look back and study how the Chinese markets developed vis-à-vis world markets. On a global level, the Chinese markets currently rank ninth in terms of market capitalization, \$512 million at the end of 2003. More importantly, the capitalization growth is unrivalled and bound to continue given that the Chinese economy appears to be on a path of strong growth, in spite of weakness in the global economy and turmoil in various economies around the world. It appears resistant to potential contagious effects, as is evidenced through its continued growth during the period of the "Asian Flu" that hit the continent early 1997.

The current literature on Chinese markets has primarily focused on its market segmentation with A-shares for domestic investors and otherwise identical B-shares for foreign investors. B-shares have traded at a discount relative to A-shares, which is a puzzle as foreign investors can diversify country risk and B-shares should therefore, as they do in other markets, trade at a premium (see Bailey, Chung, and Kang (1999)). This motivated studies on a potential information advantage of domestic investors, the illiquidity of the B-share market, and a speculation premium for A-share markets (see, e.g., Chakravarty, Sarkar, and Wu (1998),Fernald and Rogers (2002), Mei, Scheinkman, and Xiong (2003), Karolyi and Li (2003), Chan, Menkveld, and Yang (2003a, 2003b).[1]

In this paper, we study how variance, covariance, and correlations changed through time for the two Chinese equity markets—Shanghai and Shenzhen—and the world markets. For the Chinese markets, we distinguish between the A- and B-share market and we, therefore, study four markets: Shanghai-A, Shanghai-B, Shenzhen-A, and Shenzhen-B. Inspired by Fernald and Rogers (2002), we interpret our findings in terms of Gordon's (1962) standard dividend discount model that explains price changes in terms of either changes in dividend growth rates or changes in the equity risk premium. For the B-share market, we, therefore, expect a positive correlation with world markets as changes in the (world) equity risk premium impact price levels in all markets that are available for the international investor, thus

[1]We should also mention Sun and Tong (2003) , which deals with the issue of corporate governance in China. We did not include it as a separate strand of literature, as this is, to the best of our knowledge, the only study on the subject.

including the B-share market. The dividend growth argument, on the other hand, pertains to both the A- and the B-share market. We expect correlations with foreign markets to increase over time, as China has grown to be the "world's factory," which makes the fortunes of its companies, and, therefore their dividend growth, increasingly depend on the state of the world economy. More specifically, this implies that the correlation of the Chinese market with a particular foreign market depends on the extent that the Chinese firms and foreign firms depend on shocks in the global economy. And, in addition to economic interpretation, knowledge of volatility and market interrelationships is crucial for portfolio selection, risk management, and the pricing of primary and derivative securities. Finally, knowledge on the correlations among A- and B-share markets allows the Chinese government to judge to what extent the dual-share policy deprives domestic investors of diversification opportunities.

We estimate a generalized form of dynamic conditional correlation (DCC) model proposed by Engle (2002) to accommodate changing variance, covariance, and correlations.[2] This model is essentially a two-step approach to capture the dynamics. First, we identify and estimate univariate ARMA/GARCH models and, second, we capture the changing market interdependencies through a multivariate GARCH structure for the correlation matrix of the standardized returns. The standardization uses the conditional variance retrieved from the univariate GARCH model estimates. This approach appeals to us as it has the flexibility of univariate GARCH, but not the complexity of conventional multivariate GARCH, which is numerically demanding to estimate for a large set of markets. We allow for asymmetric effects in both stages, as changes to variance, covariance, and correlation might depend on whether the previous return was positive or negative. We know, for example, that correlation among equity returns increases in bear markets and decreases in bull markets (see, e.g., Erb, Harvey, and Viskanta (1994), Santis and Gerard (1997), Longin and Solnik (2001), Ang and Bekaert (2002), and Das and Uppal (2004))

We estimate the model on weekly index returns from January 1, 1993, through

[2]Cappiello, Engle, and Sheppard (2003) are the first to apply this model to world equity markets with a focus on asymmetric dynamics and the introduction of the euro. The Chinese markets, however, are not included in their sample.

December 31, 2003, for the main Chinese markets, the five largest Asian markets, the U.S. market, and the three main European markets.

For the A-share market, we find that the market has matured as volatility levels have come down to levels comparable to world markets. Contrary to world markets, however, we do not find evidence of asymmetric volatility. That is, market downturns do not seem to cause disproportionate volatility. Surprisingly, A-share returns still do not correlate with world markets, in spite of China's growing importance in the world economy.

For the B-share market, we find less persistent volatility shocks and, again, no asymmetric volatility effect. More importantly, correlation with the A-share market hovers around 50%. Based on Gordon's growth model, we interpret the common factor as stemming from innovations in the dividend process. The idiosyncratic part of A- and B-share market returns must then be due to changes in the equity risk premium, which do not have to correlate as the A- and B-share market are fully segmented. It is then surprising, however, that we find very low correlation of the B-share market with Western markets and Japan (0-5%) and slightly higher correlation with the remaining Australasian markets (10-20%). In a perfect world, changes in the world equity risk premium should lead to positive correlation. In addition, we expect it to be positive due to commonality in dividend innovations of Chinese and world companies, due to China's role as "world supplier. It is, therefore, perhaps more surprising that correlations do not increase over time, which runs counter to the upward trend in correlation among the main world equity markets (see, e.g., Cappiello, Engle, and Sheppard (2003)).

The remainder of the paper is organized as follows. Section 1 introduces the Chinese markets and reviews Gordons growth model. Section 2 presents the econometric methodology: the DCC model. Section 3 introduces the data, presents summary statistics and the model estimates. Section 4 summarizes our main findings.

1 Chinese Equity Markets

In this section, we first introduce the Chinese equity markets and then discuss Gordon's growth model to develop intuition for why Chinese and world market might be correlated.

Equity Trading in China

China's two securities markets, the Shanghai Securities Exchange (SHSE) and the Shenzhen Stock Exchange (SZSE), were established in November 1990 and July 1991, respectively. The shares initially listed on the SHSE and SZSE were called A-shares and could only be traded by Chinese citizens. Starting early 1992, another category of shares, known as B-shares, was introduced exclusively for foreign investors. Panel A of Table 1 shows how both markets have developed since then. The number of listed companies grew from 53 in 1992 to 1,287 in 2003. Total market capitalization grew from \$13 to \$513 billion in this period, which amounts to an average annual growth rate of 40%.[3]

The free float steadily grew from 24% in the early days to 31% in 2003. The total money raised in the market was on average \$9.5 billion, primarily collected from domestic investors. Panel B of Table 1 shows that the strong growth makes the Chinese markets rank ninth in the world in 2003 based on market capitalization. Among the top ten exchanges, the Chinese markets are characterized by low concentration—the top 5% firms making up least of total market capitalization—and normal turnover velocity.

The A-shares are domestic ordinary shares denominated and traded in Yuan—more formally Renminbi—by Chinese citizens. The majority of A-shares is issued by state-owned enterprises and can be classified as: (i) state shares that are held by the government through a designated government agency; (ii) legal shares, which are held by "legal persons," i.e. enterprises or other economic entities, but not individuals; and, (iii) public shares, which are owned by ordinary Chinese citizens. According to Chinese securities rules, only public shares can be traded at the exchanges. The state and legal shares are issued at the time the

[3]We refer to Chen and Shih (2002) for an elaborate description of Chinese stock market development.

company is incorporated, but cannot be traded at the exchanges. These special regulations ensure that the government maintains control over listed companies. In the remainder of the paper, whenever we refer to A-shares, we mean the public A-shares.

The B-shares are ordinary shares offered to foreign investors, denominated in Yuan, but traded in foreign currency. They are legally identical to A-shares with the same voting rights and dividends. The main difference is that all transactions, dividend payments, trades, and quotes, are in foreign currency-US dollars for the Shanghai B-shares and Hong Kong dollars for the Shenzhen B-shares. Individual investors are allowed to hold up to 25% of a firm's B-shares, but total foreign ownership cannot exceed 49%.

The trading process for A- and B-shares at the Shanghai and Shenzhen exchanges is similar. Both exchanges run order-driven, automated markets. They maintain their own systems for trusteeship, clearing, and settlement. Companies cannot be cross-listed on both exchanges. Only members have the right to enter orders directly into the trading system. Off-exchange trading as well as insiders' trading is forbidden, but not tightly monitored.

Gordon's Growth Model and Intermarket Correlations

We develop intuition for intermarket correlations using Gordon's (1962) simple asset pricing model. The model is sufficiently general that we need not specify why required returns differ, yet it remains simple enough to provide insights.

The price of a stock equals the discounted value of future dividends. Suppose dividend, D_t, are expected to grow at constant rate, g, and are discounted using required return, r. Then,

$$P_t = D_t \int_0^\infty e^{gs} e^{-rs} ds = \frac{D_t}{r - g} \tag{1}$$

Uncertainty is implicitly incorporated as an equity risk premium in the required return r. As we are interest in price changes at a relatively short horizon—weekly returns—we assume the latest dividend, D_t, has not changed and all dynamics comes from dividend growth expectations and changes in the risk premium. We use a Taylor expansion around current expectations for dividend growth and risk premiums to get, for markets A and B,

$$corr(r_A, r_B) = corr(\Delta ln P_A, \Delta ln P_B) = corr(\Delta r_A + \Delta g_A, \Delta r_B + \Delta g_B) \quad (2)$$

We assume that inter-market correlation is primarily driven by covariance of risk premiums and covariance of dividend growth rates.[4] For the A- and B-share market we, therefore, expect the correlation to be positive as future dividends for B-shares are the same as their counterparts listed on the A-share market. We do not expect any contribution from changes in the risk premium as markets are perfectly segmented.[5] For the B-share market and world equity markets, however, we expect the correlation to be positive, because changes in the world equity risk premium affect both markets. And, to the extent that dividend growth reflects the state of the world economy, changes in dividend growth will further increase this correlation. In fact, the latter argument also pertains to the A-share market and world equity markets, but such return correlations should be smaller as the risk premium does not contribute. Finally, we want to emphasize that we will use Gordon's model only as a tool to interpret our findings and, by no means, do these expectations have the status of formal hypotheses.

2 Econometric Model

Following Cappiello, Engle, and Sheppard (2003) closely, we use a generalized form of the "diagonal asymmetric" DCC model proposed by Engle (2002) to estimate the dynamic variance, covariance, and correlation for the four Chinese equity markets and the nine main foreign markets.[6]

[4]We, therefore, neglect the cross term of covariance of the premium in one market with the dividend growth rate of the other market, as we expect it to be small.

[5]As of March 2001, domestic investors are allowed to trade in the B-share market and perfect segmentation, therefore, no longer holds. Some degree of segmentation persists as foreign shares are traded in foreign currency, which restricts many Chinese investors from trading in the B-share market. The fact that B-share discounts vis-á-vis A-share counterparts shrink, but do not completely disappear is evidence of this friction.

[6]For each market, this model offers the flexibility of time-varying volatility and correlation with the other markets. It generalizes from the Constant Conditional Correlation (CCC) model of Bollerslev (1990)

Model Description

We present a concise description of the model in this paragraph. The index returns for week t are stacked in vector:

$$\underline{r}_t = [r_{1,t} \dots r_{n,t}]' \tag{3}$$

where n is the number of markets. We underline r to indicate that it is a vector. We assume the conditonal means of all returns follow an ARMA(p, q) process and use the standard information criteria and diagnostic checking statistics to select appropriate lag lengths p and q:

$$r_{i,t} = c_i + \phi_i^1 r_{i,t-1} + \dots + \phi_i^p r_{i,t-p} + \varepsilon_{i,t} + \theta_i^1 \varepsilon_{i,t-1} + \dots + \theta_i^q \varepsilon_{i,t-q} \tag{4}$$

We assume the error $\underline{\varepsilon}_t$ is conditionally normal with mean zero and covariance matrix H_t:

$$\underline{\varepsilon}_t | \zeta_{t-1} \sim \mathrm{N}(0, H_t) \tag{5}$$

where ζ_{t-1} is the information set containing all historic returns. The DCC model assumes H_t can be decomposed as:

$$H_t = D_t R_t D_t \tag{6}$$

where D_t is a nxn diagonal matrix with time-varying standard deviation, i.e. $\sqrt{h_{i,t}}$, from univariate GARCH models on the diagonal and R_t is the time-varying correlation matrix:

$$D_t = \begin{bmatrix} \sqrt{h_{1,t}} & 0 & \dots & 0 \\ 0 & \sqrt{h_{2,t}} & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \dots & \sqrt{h_{n,t}} \end{bmatrix} \quad R_t = \begin{bmatrix} r_{1,1,t} & r_{2,1,t} & \dots & r_{1,n,t} \\ r_{2,1,t} & r_{2,2,t} & & r_{2,n,t} \\ \vdots & & \ddots & \vdots \\ r_{n,1,t} & r_{n,2,t} & \dots & r_{n,n,t} \end{bmatrix} \tag{7}$$

For the univariate GARCH models, we allow for asymmetry by considering the GJR-GARCH(1,1)

and scalar DCC model of Engle (2002) to consider market-specific asymmetry and correlations. Of course, this model is not the most general version of multivariate GARCH model which is notorious for its high dimensional parameter space and computational complexity.

specification, first suggested in Glosten, Jagannathan, and Runkle (1993):

$$h_{i,t}^2 = \omega_i + k_i \underline{\varepsilon}_{i,t-1}^2 + \gamma_i 1_{[\varepsilon_{i,t-1}<0]} \varepsilon_{i,t-1}^2 + \lambda_i h_{i,t-1}^2 \tag{8}$$

where $1_{[...]}$ is the indicator function. Note that for γ_i equal to zero, the model reduces to a standard GARCH(1,1). We test for this on a market by market basis and choose the appropriate model. After estimation of the GARCH models, we standardize the residuals as:

$$u_{i,t} = \frac{\varepsilon_{i,t}}{\sqrt{h_{i,t}}} \quad \text{or} \quad \underline{u}_t = D_t^{-1} \underline{\varepsilon}_t \tag{9}$$

where $\underline{u}_t$ indicates the standardized residuals. With these residuals we define the aymmetric diagonal DCC model:

$$\begin{aligned} Q_t &= (\overline{\mathrm{Q}} - \mathrm{A}'\overline{\mathrm{Q}}\mathrm{A} - \mathrm{B}'\overline{\mathrm{Q}}\mathrm{B} - \mathrm{C}'\overline{\mathrm{N}}\mathrm{C}) + \\ &\quad \mathrm{A}'\underline{u}_{t-1}\underline{u}_{t-1}'\mathrm{A} + \mathrm{B}'Q_{t-1}\mathrm{B} + \mathrm{C}'\underline{n}_{t-1}\underline{n}_{t-1}'\mathrm{C} \end{aligned} \tag{10}$$

$$\overline{\mathrm{Q}} = \mathrm{T}^{-1} \sum_{t=1}^{\mathrm{T}} \underline{u}_t \underline{u}_t' \tag{11}$$

$$\overline{\mathrm{N}} = \mathrm{T}^{-1} \sum_{t=1}^{\mathrm{T}} \underline{n}_t \underline{n}_t' \quad \text{with} \quad n_{i,t} = 1_{[u_{i,t}<0]} u_{i,t} \tag{12}$$

$$\mathrm{A} = \begin{bmatrix} a_1 & 0 & \dots & 0 \\ 0 & a_2 & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \dots & a_n \end{bmatrix} \mathrm{B} = \begin{bmatrix} b_1 & 0 & \dots & 0 \\ 0 & b_2 & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \dots & b_n \end{bmatrix} \mathrm{C} = \begin{bmatrix} c_1 & 0 & \dots & 0 \\ 0 & c_2 & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \dots & c_n \end{bmatrix}$$

where T is the number of observations. As Q_t does not generally have ones on the diagonal, we scale it to get a proper correlation matrix R_t:

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1}, \tag{13}$$

$$Q_t^{*-1} = \begin{bmatrix} \sqrt{q_{1,1,t}} & 0 & \dots & 0 \\ 0 & \sqrt{q_{2,2,t}} & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \dots & \sqrt{q_{n,n,t}} \end{bmatrix}$$

The definition of Q_t (see equation (10)) implies that it is positive definite and since scaling does not change that, we get a proper correlation matrix with ones on the diagonal and off-diagonal elements smaller or equal to one in absolute value. A typical element of R_t is of the form $r_{i,j,t} = q_{i,j,t}/\sqrt{q_{i,i,t}q_{j,j,t}}$.

Model Estimation

Following Engle (2002), we estimate the model using a two-step approach to maximimize the likelihood. As $\underline{\varepsilon}_t|\zeta_{t-1}$ is normally distributed, the log likelihood can be expressed as:

$$\begin{aligned} L &= -\frac{1}{2}\sum_{t=1}^{T}(n\log(2\pi) + \log|H_t| + \underline{\varepsilon}_t' H_t^{-1}\underline{\varepsilon}_t) \\ &= -\frac{1}{2}\sum_{t=1}^{T}(n\log(2\pi) + 2\log|D_t| + \underline{\varepsilon}_t' D_t^{-1} D_t^{-1}\underline{\varepsilon}_t - \underline{u}_t'\underline{u}_t + \\ &\qquad \log|R_t| + \underline{u}_t' R_t^{-1}\underline{u}_t) \end{aligned} \tag{14}$$

Let the univariate ARMA/GARCH parameters in D_t and $\underline{u}_t$ be denoted by θ and the multivariate GARCH parameters in R_t by ϕ. The log-likelihood can be written as the sum of a volatility part and a correlation part:

$$L(\theta,\phi) = L_V(\theta) + L_C(\theta,\phi) \tag{15}$$

The volatility term is:

$$L_V(\theta) = -\frac{1}{2}\sum_{1}^{T}(n\log(2\pi) + 2\log|D_t| + \underline{\varepsilon}_t' D_t^{-1} D_t^{-1}\underline{\varepsilon}_t) \tag{16}$$

and the correlation component is

$$L_C(\theta,\phi) = -\frac{1}{2}\sum_{1}^{T}(-\underline{u}_t'\underline{u}_t + \log|R_t| + \underline{u}_t' R_t^{-1}\underline{u}_t) \tag{17}$$

The volatility part of the likelihood, therefore, is the sum of individual univariate GARCH likelihoods:

$$L_V(\theta) = -\frac{1}{2}\sum_t \sum_{i=1}^{n} (\log(2\pi) + \log(h_{i,t}) + \frac{\varepsilon_{i,t}^2}{h_{i,t}}) \tag{18}$$

The two-step approach now involves maximizing the likelihood for the volatility part first to find

$$\hat{\theta} = \arg\max\{L_V(\theta)\} \tag{19}$$

Once the univariate volatility models are estimated, the standardized residuals are:

$$\underline{u}_t = D_t^{-1}\underline{\varepsilon}_t \tag{20}$$

The standardized residuals are used to maximize the correlation component of the log likelihood to find the estimate for ϕ

$$\hat{\phi} = \arg\max\{L_C(\hat{\theta}, \phi)\} \tag{21}$$

The resulting maximum likelihood estimators $\hat{\theta}$ and $\hat{\phi}$ are consistent. In the implementation, we use standard GARCH techniques for the optimization in the first step. For the second step we use standard numerical optimization techniques as well as an analytic method suggested in Lucchetti (2002) and Hafner and Herwartz (2003). All computations were carried out using GPE2/GAUSS 6.0 with GARCH program modules developed by Lin (see Lin (2001)).

3 Empirical Results

Data and Summary Statistics

The dataset we use runs from January, 1993, through December, 2003, and includes end-of-day index values for the four main Chinese markets (Shanghai-A, Shanghai-B, Shenzhen-A and Shenzhen-B), the five main Asian markets, the U.S. market (S&P500), and the three main European markets.[7] In addition, we use daily exchange rate data for the countries included in our sample. Our data providers are the *Analyst Software Company* in China and *DataStream*.

We start our analysis with the calculation of summary statistics for index returns. First, we plot the raw series in Figure 1 after standardizing on January 1, 1993. We then calculate weekly returns through log differencing Wednesday closing prices.[8] We convert these returns to U.S. dollar returns.

In Tables 2 and 3 we present unconditional summary statistics. In Table 2 we present the mean, standard deviation, skewness, and kurtosis for all returns for the entire sample period. The Chinese markets stand out as they are more volatile and have fatter tails than other markets. Table 3 presents cross-correlations for all these returns. We find highest correlation for Shanghai-A and Shenzhen-A, 0.85, and for Shanghai-B and Shenzhen-B, 0.69. Both are statistically significant at conventional significance levels. This result illustrates that diversification opportunities across the Shanghai and Shenzhen markets are small for both domestic and international investors. Correlations between A- and B-share markets are also significant, but smaller—between 0.38 and 0.42. These results are consistent with Gordon's growth model, as, across the A- and B-share market only the dividend growth term contributes to return correlations, whereas across the Shanghai and the Shenzhen market, also the equity premium term contributes (see equation (2)). The correlations of the B-share markets with world equity markets are not all significant and range from 0.02 to 0.22, with an average of 0.10 for Shanghai-B and 0.09 for Shenzhen-B. These correlations are low for markets that are all accessible for the international investor and, therefore, should all respond to changes in "his" equity risk premium. The A-share markets do not correlate with world equity markets, as correlations are insignificant. This suggests that the common

[7] We select the following indices:All Ordinaries index for Australia; Hong Kong Hangseng index for Hong Kong; Taiwan weighted index for Taiwan; Nikkei 225 index for Japan; Straits time index for Singapore; S&P500 index for U.S.A.; CAC 40 index for France; DAX index for Germany; FTSE 100 index for the U.K.

[8] This is similar to Cappiello, Engle, and Sheppard (2003). The only difference is that we take Wednesday prices instead of Friday prices, as for some markets Friday trading is contaminated by option expiration trading potentially leading to distorted prices.

dividend growth factor related to the state of the world economy appears to be non-existent. These are all unconditional values and the interesting question is whether they have been stable over the life of the Chinese equity markets or whether they have trended upwards, consistent with China's growing importance for the world economy.

DCC Model Estimates 1: ARMA/GARCH

In the first step of the DCC model estimation, we identify and estimate the appropriate univariate ARMA(p,q)/GARCH(1,1) model on a market by market basis (see equation (8)). We note that the selected model specification for each market has passed the diagnostic checking with Breush-Pagan test for heteroscedasticity and Box-Pierce test for higher-order of autocorrelation. Table 4 presents the results for all of our markets. As the focus of this paper is on the volatility, the ARMA estimates of the conditional means for all markets are not reported here. These estimates are available from the authors upon request.

For the non-Chinese markets, we find, consistent with the literature, strong evidence of highly persistent and asymmetric volatility. Strong volatility persistence is reflected through relatively high estimates of the GARCH parameter λ—0.82 on average. We find asymmetric volatility for 6 out of 9 markets, as the asymmetry parameter γ is significant and for these markets we select the asymmetric GJR-GARCH model rather than the (symmetric) GARCH model. These include the two largest markets in the world: the U.S. and Japan. All γ estimates are positive, which means that large negative returns lead to stronger increases in volatility than large positive returns. Two explanations have been offered for this effect: (i) leverage and (ii) volatility feedback. The "leverage" effect says that the overall asset volatility change after a large shock is amplified for firms after a negative shock. The reason is that a negative stock return leads to a higher debt-to-equity ratio and as debt volatility is assumed constant, the overall asset volatility change will have to be reflected by a disproportional change in equity volatility. Similar reasoning reveals that a positive return will have a dampening effect on equity volatility. Christie (1982) documents a positive correlation between leverage ratios and volatility and is one of the first to find empirical support for the leverage effect. The "volatility feedback" explanation is developed in Campbell and Hentschell (1992) and is, essentially, a time-varying risk premium argument that says that after a large negative shock and a volatility increase, investors might be less willing to take on risk and demand higher returns. This then amplifies negative shocks.[9]

For the Chinese markets relative to world markets, we find less evidence of volatility persistence and no evidence of asymmetric volatility. Interestingly, for A-share market volatility we find levels of persistence that are comparable to world market estimates: λ is 0.80 for Shanghai and 0.93 for Shenzhen. For B-share market volatility, on the other hand, we find considerably less persistence: λ is 0.55 for Shanghai and 0.56 for Shenzhen. B-share volatility appears to be much more driven by the most recent return, as evidenced through relatively large estimates of k: 0.29 for Shanghai and 0.34 for Shenzhen. This is somewhat surprising as the B-share markets are in the realm of international investors, whereas for the A-share markets we could expect anything as they are truly segmented from international markets. For none of the markets do we find significant γ estimates and we, therefore, do not find evidence of asymmetric volatility. Large negative returns in Chinese markets, apparently, do not lead to disproportional volatility increases vis-à-vis large positive returns. A possible explanation for the B-share markets is that a "volatility feedback" effect is less likely as any volatility increases are relatively short-lived as persistence is considerably lower in these markets.

We illustrate our univariate GARCH estimates for all markets by plotting the volatility for the entire sample period. Figure 2 plots the volatility of the four Chinese indices and the graphs illustrate the strong volatility persistence for A-share markets and the more erratic, short-term bursts of high volatility in the B-share markets. Additionally, we find that A-share market volatility declined steadily over the entire sample period. This is evidence that the A-share market has "matured," as 2003 levels of volatility are comparable to volatility estimates for the main world markets, which are illustrated in figure 3. The world market graphs further illustrate that the volatility patterns for the B-share markets are the excep-

[9]Bekaert and Wu (2000) unify both explanations in an empirical model and show that the leverage effect cannot be the sole explanation for asymmetric volatility.

tion rather than the rule. Incidentally, we see the effect of the Asian crisis in 1997 through increased volatility levels in Hong Kong, Singapore, Taiwan, and Japan. For China, it is much more difficult to trace down an Asian flu effect in the volatility graphs.

DCC Model Estimates 2: Dynamic Correlations

We use the univariate GARCH estimates of volatility to standardize residuals and complete the estimation of the diagonal asymmetric DCC model (see equations (10), (11), and (12)). This second step, essentially, nails down the process for the dynamic correlations. Table 5 contains the parameter estimates of the covariance equation (10). High t-values indicate that correlations among markets are indeed dynamic.

For the non-Chinese markets, we find highly persistent correlations and strong evidence of asymmetric effects. The strong persistence is evident from the high values of b—the coefficient of the lag term Q_{t-1}—which range from 0.82 to 0.99 with an average value of 0.95. The most recent return co-movement, captured by the term $\underline{u}_{t-1}\underline{u}'_{t-1}$, carries relatively low weight as the a coefficient estimates range from 0.01 to 0.06 with an average of 0.02. We find strong evidence for asymmetric effects captured by the term $\underline{n}_{t-1}\underline{n}'_{t-1}$ as the c coefficient estimates are high relative to the a coefficient estimates and range from 0.05 to 0.28 with an average of 0.15. We, therefore, find stronger co-movement across markets after negative returns. This finding is consistent with previous studies that document that correlation among equity returns increases in bear markets and decreases in bull markets (see, e.g., Erb, Harvey, and Viskanta (1994), Santis and Gerard (1997), Longin and Solnik (2001), Ang and Bekaert (2002), and Das and Uppal (2004)).

For the Chinese markets, as compared to world markets, we find similar levels of correlation persistence and stronger asymmetric effects. The b coefficients for the Chinese A-share markets—0.99 for Shanghai and 0.98 for Shenzhen—are not much different than those for the B-share markets—0.97 for Shanghai and 0.95 for Shenzhen. All these estimates are somewhat higher than world market levels—0.95 on average. More interesting is that Chinese correlations are to a much larger extent driven by the most recent return co-movement as the estimates of the a coefficients are significantly higher. They range from 0.12 to 0.24 for the Chinese markets, whereas the highest value for non-Chinese markets is 0.06. Apparently, Chinese markets correlations are to a larger extent driven by recent history. In other words, a relatively high idiosyncratic shock in these markets depresses correlation with other markets for the oncoming weeks. By considering multi-market interaction, the estimated asymmetric effects for the A-share markets are somewhat weaker than for world equity markets, as the c coefficients are estimated at 0.12 for Shanghai and 0.10 for Shenzhen against an average 0.15 for non-Chinese markets. For the B-share market, on the other hand, we find stronger asymmetric effects with c estimates of 0.19 for Shanghai and 0.27 for Shenzhen. Apparently, Chinese B-share correlations are particularly sensitive to negative returns. This could be interpreted as an additional explanation for the B-share discount, as (low) correlations seem to disappear when you need them most, i.e. in downturns. We turn to graphs of conditional correlations to gauge the economic significance of these effects.

In the remainder of this subsection, we use the model estimates to plot the conditional correlations for (i) the four Chinese markets, for (ii) the A-share markets and the world equity markets, and for (iii) the B-share markets and the world equity markets.

Figure 4 plots the conditional correlations for the four Chinese markets and reveals that correlations have trended upwards. We find the highest correlations between Shanghai-A and Shenzhen-A and between Shanghai-B and Shenzhen-B. These correlations have increased throughout the decade and are, at the end of 2003, 0.89 for the A-share markets and 0.78 for the B-share markets. Hence, the diversification potential across markets is very small for both domestic and international investors. These levels of correlations are comparable to correlations among European markets after the introduction of the euro (see Cappiello, Engle, and Sheppard (2003)). The correlations among the A-share and B-share market are smaller and have also trended upwards. All four of them are approximately 0.50 at the end of 2003. This implies that, for all investors, there are considerable diversification benefits associated with lifting the dual-share structure. The Chinese government took a first step by allowing domestic investors to trade B-shares at the end of March 2001.

The graphs of the conditional correlations for the A-share markets and the main non-Chinese markets show that correlations hover around zero for the entire decade. Figure 5 plots these for Shanghai-A and the world markets. The graphs for Shenzhen-A are similar, but available on request in order to conserve space. The graphs show that price changes in the Shanghai-A market are independent of those in both the Asian and the Western markets. More importantly, this has been the case throughout the history of Shanghai-A share market. This is surprising as the Chinese economy has become increasingly export-oriented and company dividends should therefore reflect the state of the regional economies and the world economy.

The conditional correlations for the B-share markets and the main non-Chinese markets are moderate for Asian markets and close to zero for Western markets. Figure 6 plots these correlations for Shanghai-B. Again, Shenzhen-B graphs are similar and available on request. Clearly, correlations with Shanghai-B is highest for the Hong Kong and Singapore market (20%), lower for the Australian and Taiwanese market (10-15%), and lowest for the Japanese market and Western markets (0-5%). Again, we do not find evidence of an upward trend, which is contrary to the increasing correlation among world markets (see Cappiello, Engle, and Sheppard (2003)).

A Government Policy Driven Market?

Government policy is important for young and developing markets and, in particular, for China as a transition economy. It is, therefore, interesting to review the major events in the history of Chinese markets and relate them to our estimates of volatility and correlation. We include a necessarily subjective list of events as appendix to the current manuscript and review our results guided by this list.

Overall, we find strong evidence for an important role of government policy for volatility and correlation in the Chinese equity markets. We find, for example, that the largest peaks in volatility for the A- and B-share market—illustrated in figure 2—coincide with major events. First, the A-share market jump in volatility in the second half of 1994 appears to be triggered by the introduction of three policies to "save" the stock market on July 29, 1994. The second largest jump in A-share market volatility happens in the first months of 1997 and is, undoubtedly, related to the fact that on February 19, 1997, former president Deng Xiaoping passed away. This volatility jump is also visible in the B-share market. An example of an event that appears to trigger a change in correlations is July 1, 1999, the day that Hong Kong was returned to the Mainland. Figure 6 shows that for the consecutive year, correlation of Chinese B-shares with the Hong Kong market rise from 20% to 35%. These are examples to illustrate that changes in government policy appear to be an important source of changes in volatility and correlations.

4 Conclusion

For a sample period that covers the history of the Chinese markets through December, 2003, we study how variance, covariance, and correlation have developed for the four main Chinese indices—Shanghai-A, Shenzhen-A, Shanghai-B, and Shenzhen-B—and the main world equity markets. To capture the dynamic market correlations, we choose to estimate the diagonal asymmetric DCC model of Engle (2002). We allow for asymmetric effects, as changes might depend on whether the most recent return was positive or negative.

In the first step of the estimation, we identify and estimate appropriate univariate ARMA/GARCH models for weekly returns in each of the markets. Relative to world equity markets, A-share volatility is equally persistent and B-share market volatility is more erratic and short-lived. Neither of these markets exhibit asymmetric volatility, which is typical for international equity markets. Generally, large negative returns lead to higher volatility jumps than large positive returns. Over time, A-share volatility has steadily decreased to levels comparable to other world markets, which we interpret as a sign that the market matures. B-share volatility, on the other hand, does not show any trend.

In the second step of the estimation, we standardize returns based on the volatility estimates and use these to estimate the dynamic process for the correlation matrix. Relative to world markets, Chinese correlations are equally persistent, but more erratic as they appear to be more dependent on the most recent observations. We find that correlations across the two Chinese markets, Shanghai and Shenzhen, have increased to 80-90%. Comparing the A- and B-share market within both exchanges, we find the same upward trend with correlations around 50% at the end of 2003. These results are consistent with Gordon's growth model, as, across the A- and B-share market only the dividend growth term contributes to return correlations, whereas across the Shanghai and the Shenzhen market, also the equity premium term contributes. The correlations of the B-share markets with world equity markets do not appear to exhibit any trend and are, generally, in the 0-20% range. We find this surprising for markets that are all accessible for the international investor and, therefore, should all respond to changes in "his" equity risk premium. The A-share markets do not show an upward trend either, as correlations with other markets are close to zero and insignificant. This runs counter to the intuition that China's growing status as the world's factory should make Chinese dividends more sensitive to the state of the world economy. Finally, we find strong evidence that government policy is important for changes in volatility and correlations.

References

Ang, A., and G. Bekaert. 2002. "International Asset Allocation with Regime Shifts." *Review of Financial Studies* 15(4):1137–1187.

Bailey, W., P. Chung, and J.K. Kang. 1999. "Foreign Ownership Restrictions and Equity Price Premiums: What Drives the Demand for Cross-Border Investments?" *Journal of Financial and Quantitative Analysis* 34(4):489–511.

Bekaert, G., and G. Wu. 2000. "Asymmetric Volatility and Risk in Equity Markets." *Review of Financial Studies* 13(1):1–42.

Bollerslev, T. 1990. "Modeling the Coherence in Short Run Nominal Exchange Rates: A Multivariate Generalized ARCH Model." *Review of Economics and Statistics* 72(32):498–505.

Campbell, J.Y., and L. Hentschell. 1992. "No News is Good News." *Journal of Financial Economics* 31:281–318.

Cappiello, L., R.F. Engle, and K. Sheppard. 2003. "Asymmetric Dynamics in the Correlations of Global Equity and Bond Returns." Technical Report 204, European Central Bank.

Chakravarty, S., A. Sarkar, and L. Wu. 1998. "Information Asymmetry, Market Segmentation and the Pricing of Cross-Listed Shares: Theory and Evidence from Chinese A- and B-shares." *Journal of International Financial Markets, Institutions, and Money*, no. 8:325–355.

Chan, K.C., A.J. Menkveld, and Z. Yang. 2003a. "Are Domestic Investors more Informed than Foreign Investors? Evidence from the Perfectly Segmented Market in China." Technical Report, EFA 2003 Annual Conference Paper, `www.ssrn.com/abstract=424933`.

———. 2003b. "Evidence on the Foreign Share Discount Puzzle in China: Liquidity or Information Asymmetry?" Technical Report, WFA 2003 Annual Conference Paper, `www.ssrn.com/abstract=424460`.

Chen, C.H., and H.T. Shih. 2002. *The Evolution of the Stock Market in China's Transitional Economy.* Northampton, MA, USA: Edward Elgar.

Christie, A. 1982. "The Stochastic Behavior of Common Stock Variances." *Journal of Financial Economics* 10:407–432.

Das, S., and R. Uppal. 2004. "Systemic Risk and International Portfolio Choice." *Journal of Finance (Forthcoming, 2004 December).*

Engle, R. 2002. "A Dynamic Conditional Correlation: A Simple Class of Multivariate Generalized Autoregressive Conditional Heteroskedasticity Models." *Journal of Business & Economic Statistics* 20(3):339–350.

Erb, C., C.R. Harvey, and T. Viskanta. 1994. "National Risk and Global Fixed Income Allocation." *Journal of Fixed Income*, pp. 17–26.

Fernald, J., and J.H. Rogers. 2002. "Puzzles in the Chinese Stock Market." *The Review of Economics and Statistics* 84(3):416–432.

Glosten, L., R. Jagannathan, and D. Runkle. 1993. "Relationship between the Expected Value and the Volatility of the Nominal Excess Return on Stocks." *Journal of Finance* 48:1179–1801.

Gordon, M. 1962. *The Investment, Financing, and Valuation of the Corporation.* Homewood, IL: Irwin.

Hafner, C.M., and H. Herwartz. 2003. "Analytical Quasi Maximum Likelihood Inference in Multivariate Volatility Models." Technical Report 2003-21, Econometric Institute Report, Erasmus University Rotterdam, Netherlands.

Karolyi, G.A., and L. Li. 2003. "A Resolution of the Chinese Discount Puzzle." Technical Report 2003-34, Dice Center Working Paper, `www.ssrn.com/abstract=482487`.

Lin, K.-P. 2001. *Computational Econometrics: GAUSS Programming for Econometricians and Financial Analysts.* Los Angeles: ETEXT Publishing, `www.etext.net`.

Longin, F., and B. Solnik. 2001. "Extreme correlation of international equity markets." *Journal of Finance* 56(2):649–676.

Lucchetti, R. 2002. "Analytic Score for Multivariate GARCH Models." *Computational Economics* 19:133–143.

Mei, J., J.A. Scheinkman, and W. Xiong. 2003. "Speculative Trading and Stock Prices: An Analysis of Chinese A-B Share Premia." Technical Report, AFA 2005 Annual Conference Paper `www.ssrn.com/abstract=410021`.

Neoh, A. 2002. Technical Report, Presentation of Anthony Neoh, chief advisor of the China Security and Regulatory Commission (SCRC), at the Kennedy School of Government, Harvard University (see `www.harvardchina.org`).

Santis, G. De, and B. Gerard. 1997. "International Asset Pricing and Portfolio Diversification with Time-Varying Risk." *Journal of Finance* 52(5):1881–1912.

Sun, Q., and W.H.S. Tong. 2003. "China Share Issue Privatization: the Extent of its Success." *Journal of Financial Economics* 70:183–222.

Appendix: Main Events in First Decade Chinese Equity Markets

Date	Main Events
5/21/92	Shanghai introduces price limits. The Shanghai composite index rises from 617 points to 1266 points within the day.
11/25/92	CSRC (China Securities Regulatory Commission) is established.
5/15/93	PBOC (People's Bank of China) raises interest rates to restrain inflation.
7/11/93	PBOC raises interest rates again to restrain inflation. The market declines significantly.
7/29/94	The introduction of three policies to save the stock market ((i) security companies are allowed financing, (ii) a temporary ban on IPOs, (iii) joint venture funding is permitted). During the first three days of August, both SHSE and SZEX experience a rally—not a single stock decreases in value.
8/18/95	CSRC bans trading in government bond futures, which ends the 17-month Chinese government bond futures market. The stock index increases in the consecutive days.
2/20/96	The 2010 Chinese stock market development plan is announced. This is the first time that the most important policy document, the national 5-year plan, contains a security market development aim. After failed experiments with limited-responsibility contracts, profit retention, SOE (state-owned enterprise) restructuring, the government throws up its arms and aims at "stockification."
12/14/96	SCRC introduces price limits system.
12/16/96	To curb excess speculative activity, People Daily, the CPC's newspaper, publishes the special commentary article "How to Understand Chinese Stock Markets?"
2/19/97	Xiaoping Deng passes away. Stock markets fluctuate dramatically the next day.
5/17/97	CRSC announces that the 1997 total stock issue amounts to RMB30 billion, three times higher than the year before. Stock indices decline.
7/1/97	Hong Kong returned to motherland.
3/25/98	PBOC reduces interest rates three times in a row (3/25/98, 7/1/98, and 12/7/98) .
8/29/98	Hong Kong government fights with international traders. The total amount reaches HK$ 79 billion.
5/11/99	President of CSRC expresses concern on excess volatility in the stock markets and aims stabilization.
6/10/99	PBOC reduces interest rates.
9/9/99	CSRC stipulates that three kinds of companies (state-owned enterprises, state controlled companies, and listed companies) are allowed to invest in secondary markets with a holding period for stocks of at least 6 months. SHSE composite index increases by more than 6%.
2/19/01	CSRC announces that domestic investors can open trading accounts for B-shares, previously reserved for foreign investors.
4/26/01	CSRC announces punishment of four investment consulting companies for manipulating the stock price of listed company Yian Keji.
10/13/01	The State Council suspends the program of reducing state share ownership.
6/24/02	The State Council abandons its plan to sell off massive State holdings in listed companies through the domestic stock markets. China's stocks shoot up over 9%.
5/27/03	UBS Warburg and Vomura Securities are the first foreign companies to be awarded qualified foreign institutional investor (QFII). It is a historic first step of opening up the A-share market to foreign firms.

Table 1: Development of Chinese Stock Markets

This table puts the development of Chinese stock markets into perspective. Panel A summarizes how the Chinese stock markets developed since their start-up in the early nineties. The values are taken from Neoh (2002) and converted to US$ using the official (fixed) exchange rate. Panel B summarizes how the Chinese markets compare to others stock markets world-wide based on market capitalization, concentration, and turnover velocity in 2003.

Panel A: Development through Time

(Billion US$)	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Capitalization	13	43	45	42	119	212	136	320	581	526	463	513
Market Float		10	12	11	35	63	69	99	194	175	151	159
Float/ Cap.		24%	26%	27%	29%	30%	29%	31%	33%	33%	33%	31%
#Companies	53	183	291	323	530	745	851	949	1088	1160	1224	1287
Money Raised												
Total	1.7	5.5	1.6	1.4	4.1	11.3	9.7	10.8	18.6	14.3	9.4	9.9
Domestic[a]	0.9	4.8	1.2	1.0	3.5	10.3	9.4	10.8	18.4	14.3	9.4	9.9
Foreign[a]	0.8	0.7	0.4	0.4	0.6	1.0	0.3	0.0	0.2	0.0	0.0	0.0

[a]: Domestic shares can only be traded by Chinese citizens, foreign shares only by foreigner investors.

Panel B: Compared to Others (end of 2003)

	Market Capital-ization (Billion US$)	Concen-tration[a] (%)	Turnover Velocity[b] (%)
1 NYSE	11,329	58.6	89.5
2 NASDAQ	2,844	69.1	280.7
3 Tokyo	2,953	58.2	82.6
4 London	2,460	82.5	106.6
5 Euronext	2,076	70.3	112.6
6 Frankfurt	1,079	72.0	148.1
7 Toronto	889	64.0	65.8
8 Hong Kong	714	80.4	51.7
9 Mainland China[c]	**512**	**39.5**	**120.3**
9a Shanghai	**360**	**45.6**	**118.0**
9b Shenzhen	**152**	**26.0**	**125.8**
10 Taiwan	379	59.8	190.7

Source: Neoh (2002), China Statistical Yearbooks, and the International Organization of Stock Exchanges.
[a]: Concentration is turnover of the top 5% companies (as measured by market capitalization) divided by total market turnover.
[b]: Turnover velocity is total turnover for the year divided by total market capitalization. Turnover velocity gradually decreased from a 1996 high of 913% in Shanghai and 1,350% in Shenzhen.
[c]: These include the Shanghai and Shenzhen exchange.

Table 2: Summary Statistics

This table contains summary statistics of the 4 Chinese equity index weekly returns and 9 foreign equity index weekly returns. These returns are defined as: r_t=100*ln($(e_{t-1} \cdot x_t)/(e_t \cdot x_{t-1})$), where x_t indicates the index value and e_t indicates the exchange rate at the end of the week t Wednesday. The sample period runs from January 1993 trough December 2003.

	Mean	Standard Dev.	Skewness	Kurtosis
Shanghai A share	0.06^a	5.62	0.36	13.87
Shenzhen A share	0.02^a	5.62	−0.51	16.63
Shanghai B share	0.09	5.48	0.37	5.81
Shenzhen B share	0.16	5.79	0.94	10.72
Hong Kong	0.14	3.70	−0.41	4.07
Singapore	0.02	3.56	−0.09	6.78
Taiwan	0.05	4.09	−0.03	4.13
Japan	−0.06	3.31	0.24	4.09
U.S.A.	0.16	2.28	−0.12	4.82
France	0.11	3.01	−0.22	5.52
Germany	0.15	3.19	−0.43	5.54
U.K.	0.11	2.33	0.00	5.13
Australia	0.15	2.32	−0.45	4.29
Average^b	0.09	3.09	−0.17	4.93

^{a}: At the start of 1994, the Chinese government changed exchange rate of Chinese Yuan to U.S. dollar from 5.81:1 to 8.72:1.
^{b}: Average for all markets, excluding the Chinese mainland markets.

Table 3: Sample Correlations of Index Returns

This table presents cross-correlations of weekly returns for the 4 Chinese equity indices and the main world equity markets. The sample period runs from January 1993 trough December 2003. The standard deviation for all correlations is 0.04.

	Shanghai A-share	Shenzhen A-share	Shanghai B-share	Shenzhen B-share
Shenzhen A share	0.85	1.00		
Shanghai B share	0.41	0.38	1.00	
Shenzhen B share	0.42	0.41	0.69	1.00
Hong Kong	0.02	0.04	0.22	0.18
Singapore	0.00	0.01	0.19	0.13
Taiwan	-0.03	-0.02	0.12	0.12
Japan	0.01	0.05	0.02	0.05
U.S.A.	-0.03	-0.02	0.03	0.05
France	-0.02	-0.01	0.04	0.04
Germany	0.01	0.00	0.08	0.07
U.K.	-0.02	-0.02	0.05	0.05
Australia	-0.01	-0.04	0.15	0.13
Average[a]	-0.01	0.00	0.10	0.09

[a]: Average for all markets, excluding the Chinese mainland markets.

Table 4: ARMA/GARCH Estimates

This table contains the estimates of the ARMA/GARCH models for the main Chinese indices and other world market indices. Only the estimates of conditional variances (GARCH portion) are reported. For each market, we choose the market with the best fit, either a GARCH(1,1) or a GJR-GARCH(1,1). The variance equations in these models are:

$$h_{i,t}^2 = \omega_i + k_i \varepsilon_{i,t-1}^2 + \lambda_i h_{i,t-1}^2 \qquad \text{GARCH(1,1)}$$
$$h_{i,t}^2 = \omega_i + k_i \varepsilon_{i,t-1}^2 + \gamma_i 1_{[\varepsilon_{i,t-1}<0]} \varepsilon_{i,t-1}^2 + \lambda_i h_{i,t-1}^2 \qquad \text{GJR-GARCH(1,1)}$$

h_t represents the conditional volatility and ε_t the the ARMA-filtered return for week t. We report the parameters of these models and their t-values.

	Model Selected	ω	t-stat	k	t-stat	γ	t-stat	λ	t-stat
Shanghai A share	ARMA(3,5)/GARCH(1,1)	0.74	0.90	0.19	1.67			0.80	6.50
Shenzhen A share	ARMA(1,1)/GARCH(1,1)	0.16	0.68	0.06	1.74			0.93	21.54
Shanghai B share	ARMA(2,0)/GARCH(1,1)	5.35	2.34	0.29	3.17			0.55	4.45
Shenzhen B share	ARMA(1,0)/GARCH(1,1)	4.84	1.43	0.34	2.49			0.56	3.98
Hong Kong	ARMA(0,0)/GARCH(1,1)	0.45	1.28	0.09	2.45			0.88	17.34
Singapore	ARMA(0,0)/GJR-GARCH(1,1)	0.19	1.14	0.01	0.31	0.09	2.49	0.93	15.50
Taiwan	ARMA(1,0)/GARCH(1,1)	1.33	2.79	0.14	4.74			0.78	13.14
Japan	ARMA(0,0)/GJR-GARCH(1,1)	0.30	1.00	0.02	1.07	0.13	2.31	0.90	17.45
U.S.A.	ARMA(1,0)/GJR-GARCH(1,1)	0.15	1.83	-0.01^b	-0.47	0.17	3.00	0.89	31.64
France	ARMA(1,0)/GJR-GARCH(1,1)	0.95	2.24	0.02	0.42	0.21	2.48	0.76	10.29
Germany	ARMA(1,0)/GARCH(1,1)	0.04	0.87	0.07	2.81			0.92	31.34
U.K.	ARMA(1,0)/GJR-GARCH(1,1)	0.81	2.12	0.02	0.49	0.26	2.48	0.69	6.26
Australia	ARMA(2,0)/GJR-GARCH(1,1)	1.46	5.14	-0.09^b	-6.26	0.27	3.67	0.67	11.95
Average[a]		0.63		0.03				0.82	

[a]: Average for all markets, excluding the Chinese mainland markets.

[b]: Negative values of k is possible as long as $k + \gamma > 0$.

Table 5: Diagonal Asymmetric DCC Model Estimates

This table contains the estimates of a diagonal asymmetric DCC model, defined as:

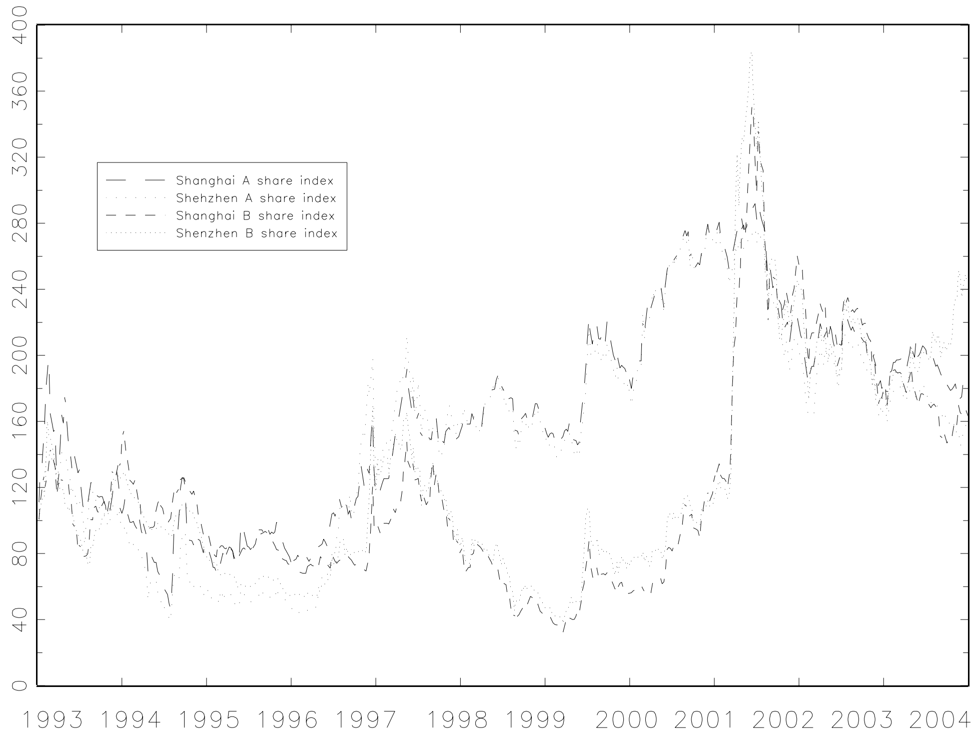
$$\begin{aligned} Q_t &= (\overline{\overline{Q}} - \mathrm{A}'\overline{\mathrm{Q}}\mathrm{A} - \mathrm{B}'\overline{\mathrm{Q}}\mathrm{B} - \mathrm{C}'\overline{\mathrm{N}}\mathrm{C}) + \\ &\quad \mathrm{A}'\underline{u}_{t-1}\underline{u}'_{t-1}\mathrm{A} + \mathrm{B}'Q_{t-1}\mathrm{B} + \mathrm{C}'\underline{n}_{t-1}\underline{n}'_{t-1}\mathrm{C} \\ \overline{\mathrm{Q}} &= \mathrm{T}^{-1}\sum_{t=1}^{\mathrm{T}} \underline{u}_t\underline{u}'_t \\ \overline{\mathrm{N}} &= \mathrm{T}^{-1}\sum_{t=1}^{\mathrm{T}} \underline{n}_t\underline{n}'_t, \quad \text{with} \quad n_{i,t} = 1_{[u_{i,t}<0]}u_{i,t} \end{aligned}$$

$$\mathrm{A} = \begin{bmatrix} a_1 & 0 & \dots & 0 \\ 0 & a_2 & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \dots & a_n \end{bmatrix} \mathrm{B} = \begin{bmatrix} b_1 & 0 & \dots & 0 \\ 0 & b_2 & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \dots & b_n \end{bmatrix} \mathrm{C} = \begin{bmatrix} c_1 & 0 & \dots & 0 \\ 0 & c_2 & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \dots & c_n \end{bmatrix}$$

Q_t is the conditional correlation matrix. $\overline{Q}$ is an estimate of the unconditional correlation matrix. $\underline{u}_t$ is a vector of standardized residuals of week t index returns; we use the GARCH volatility estimates for the standardization (see equation(9)). We would like to point out that the sign of all parameter estimates is not identified as the model definition in such that the likelihood depends on the cross products of the parameters. We report the parameters of these models and their t-values. Alternatively, coefficients of the covariance equation Q_t, in cross products (a_ia_j, b_ib_j, c_ic_j), may be calculated and reported.

	a	t-stat	b	t-stat	c	t-stat
Shanghai A share	0.12	37.38	0.99	804.90	0.12	18.84
Shenzhen A share	0.19	41.35	0.98	713.61	0.10	16.88
Shanghai B share	0.18	20.26	0.97	406.44	0.19	17.93
Shenzhen B share	0.24	20.52	0.95	294.42	0.27	18.83
Hong Kong	0.01	0.59	0.87	60.09	0.28	9.45
Singapore	0.02	2.42	0.97	139.28	0.09	7.04
Taiwan	-0.04	-3.28	0.98	130.75	0.11	6.17
Japan	-0.02	-0.57	0.82	21.78	0.34	5.85
U.S.A.	-0.06	-9.20	0.99	487.86	0.09	11.77
France	-0.04	-9.22	0.99	835.71	0.17	20.29
Germany	-0.03	-9.18	0.99	4391.30	0.08	17.83
U.K.	-0.06	-9.76	0.98	377.64	0.15	15.78
Australia	0.03	4.30	0.99	171.01	0.05	6.62
Average[a]	-0.02		0.95		0.15	

[a]: Average for all markets, excluding the Chinese mainland markets.



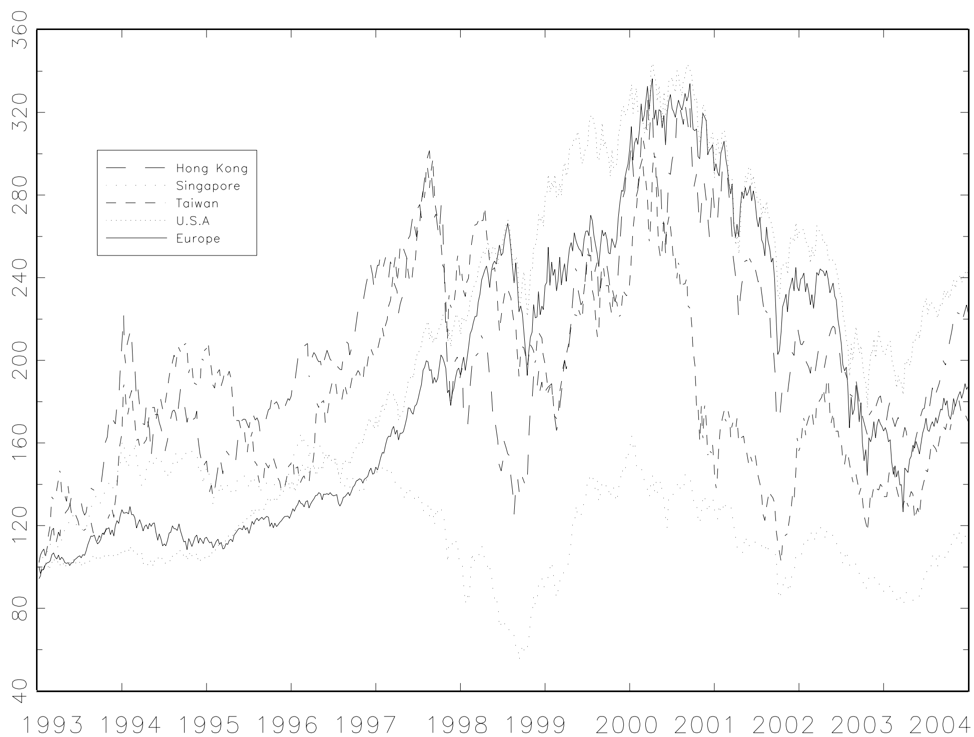


Figure 1: **Main Indices for the Sample Period.** In the top graph, we plot the four main Chinese indices for the entire sample period: the indices for the A-share (domestic) and B-share (foreign) index for the Shanghai as well as the Shenzhen market. In the bottom graph, we plot the main indices outside of China. All indices are standardized by setting their initial value to 100.

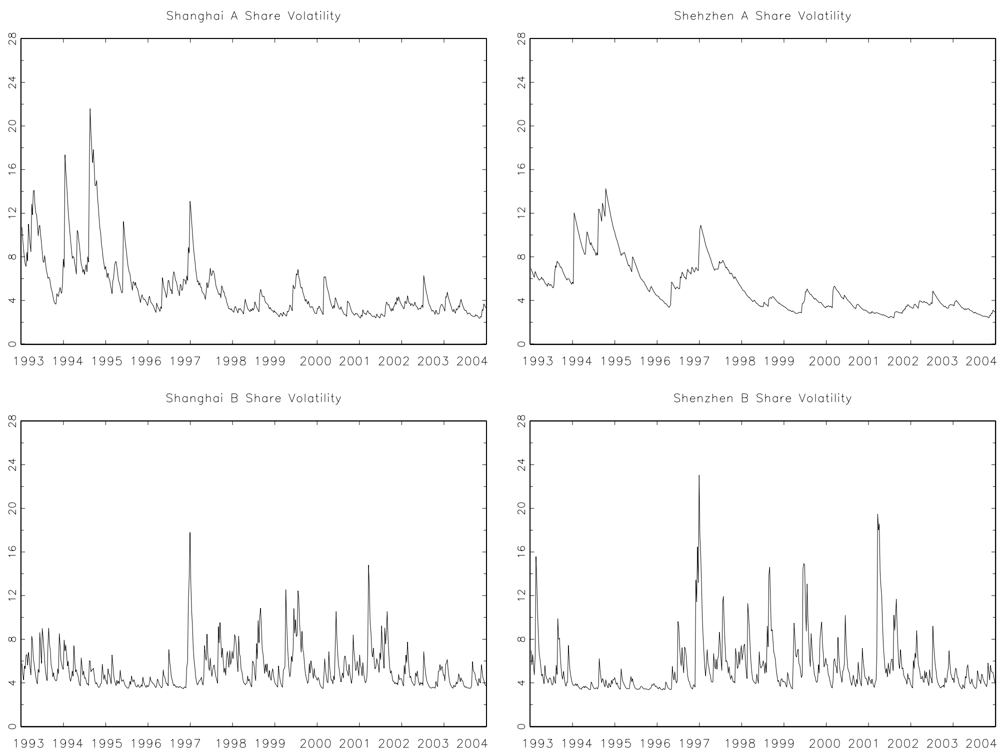


Figure 2: **Conditional Variance or Volatility: Main Chinese Indices.** These graphs present the conditional volatility of weekly index returns, based on univariate GARCH model estimates. We use the four main Chinese indices: the A-share (domestic) and B-share (foreign) index for the Shanghai and Shenzhen market. These results compare to similar graphs for world indices plotted in Figure 3.

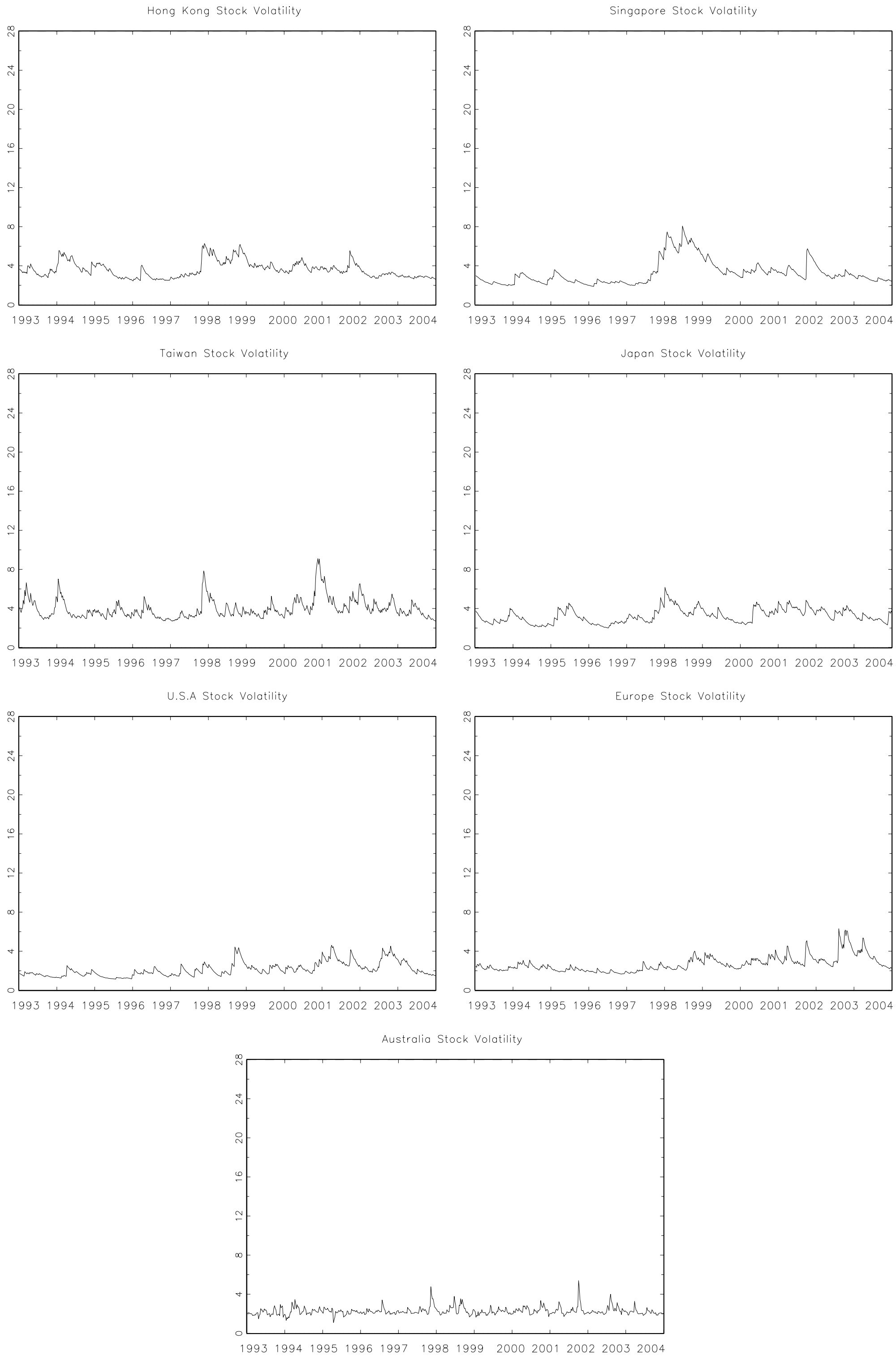


Figure 3: **Conditional Variance or Volatility: Main World Indices.** These graphs contain the conditional volatility of weekly index returns of the main world equity markets, based on univariate GARCH model estimates. We calculate European stock volatility as the average of French, German, and U.K. volatility. These results compare to similar graphs for world indices plotted in Figure 2.

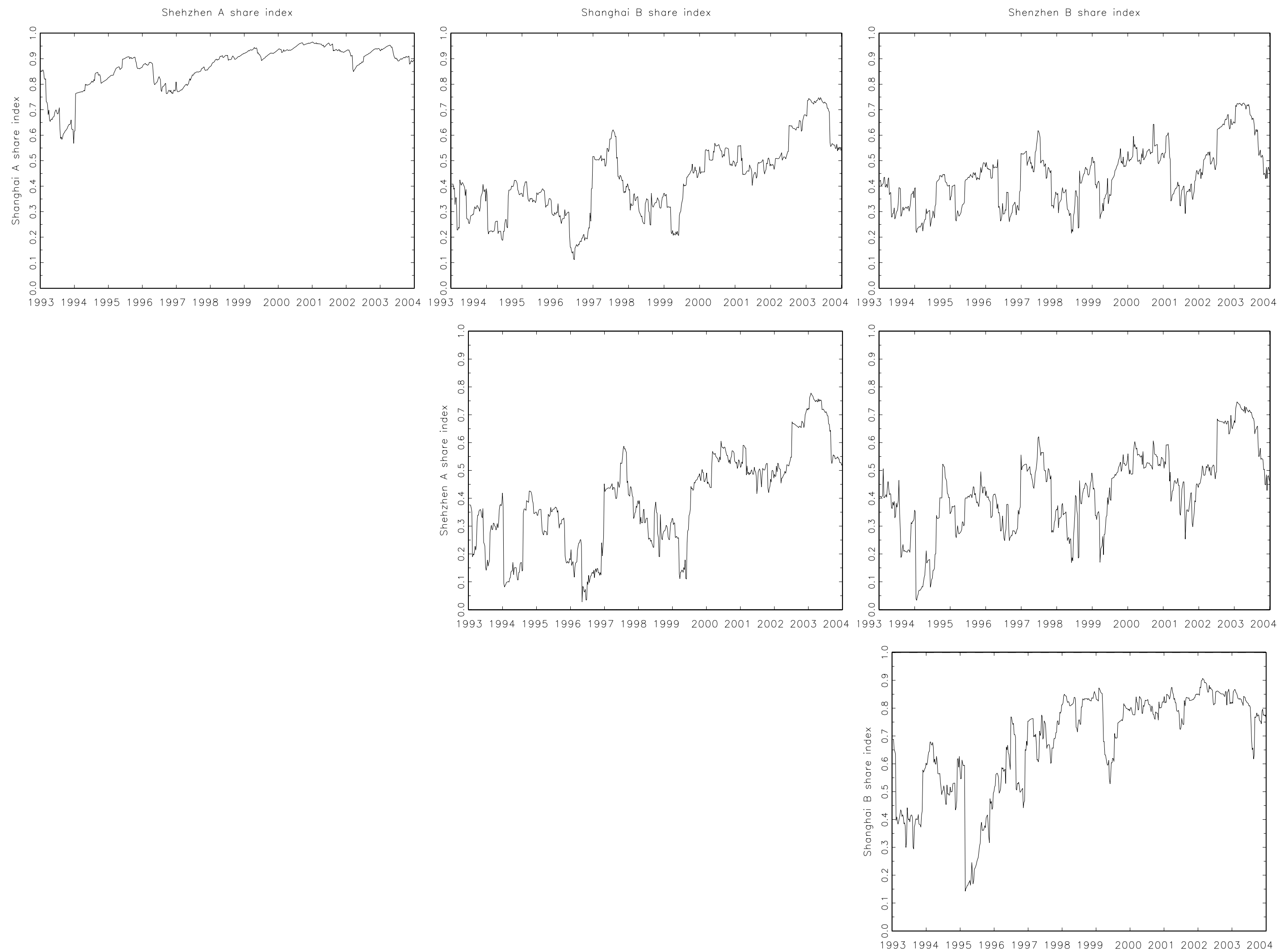


Figure 4: **Conditional Correlation: A-share (Domestic) and B-share (Foreign).** These graphs show the conditional correlation of the Shanghai A-share index, Shenzhen B-share index, Shanghai B-share index, and Shenzhen B-share index.

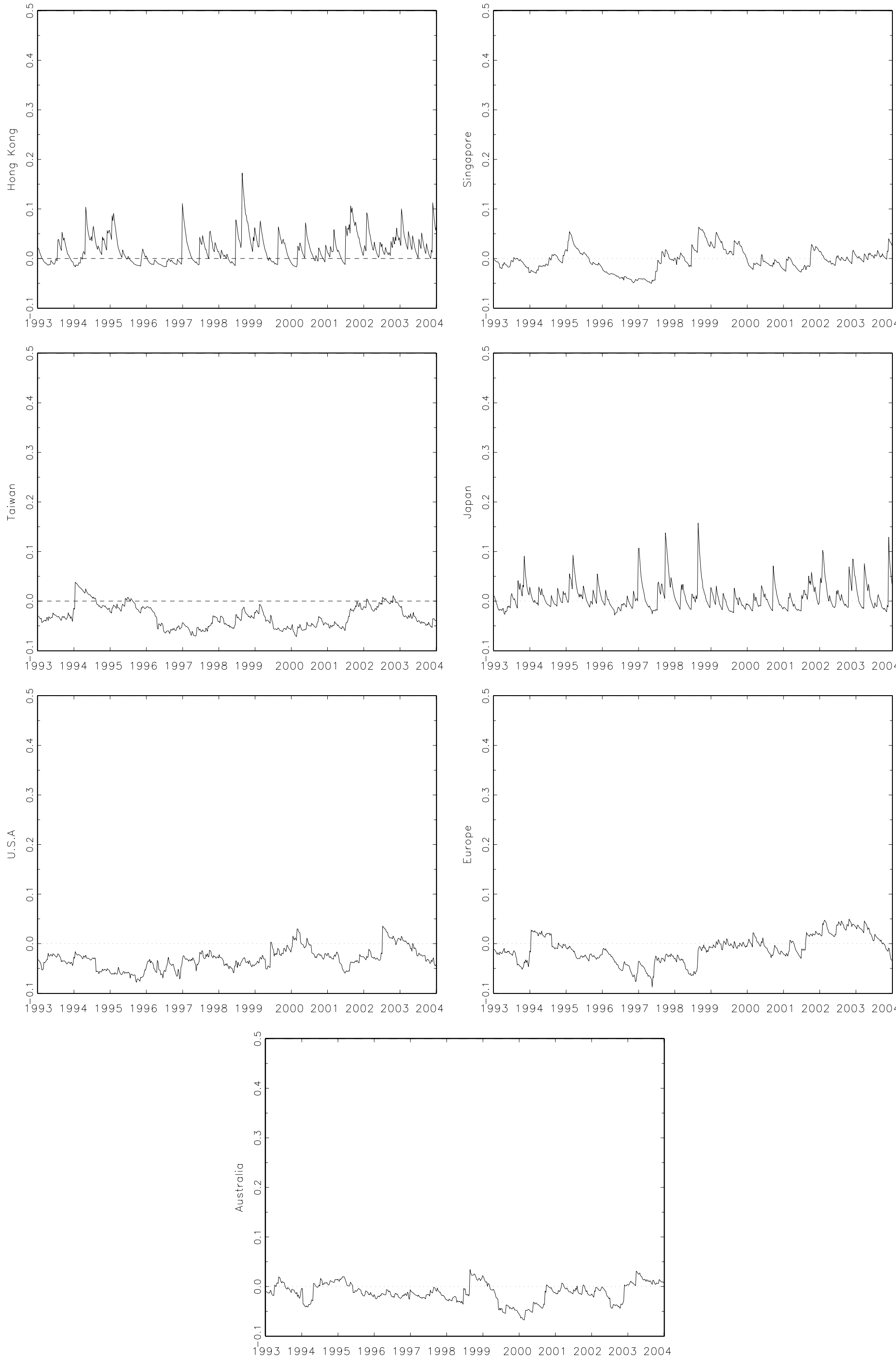


Figure 5: **Conditional Correlation: A-share (Domestic) and World Markets.** These graphs show the conditional correlation of the Shanghai A-share index with the main world indices. We do not report the results for the Shenzhen A-share index as they are very similar. These graphs, however, are available from the authors upon request. We calculate correlation with the European markets as the average of correlation with the French, German, and U.K. market. Results for the B-share indices are in Figure 6.

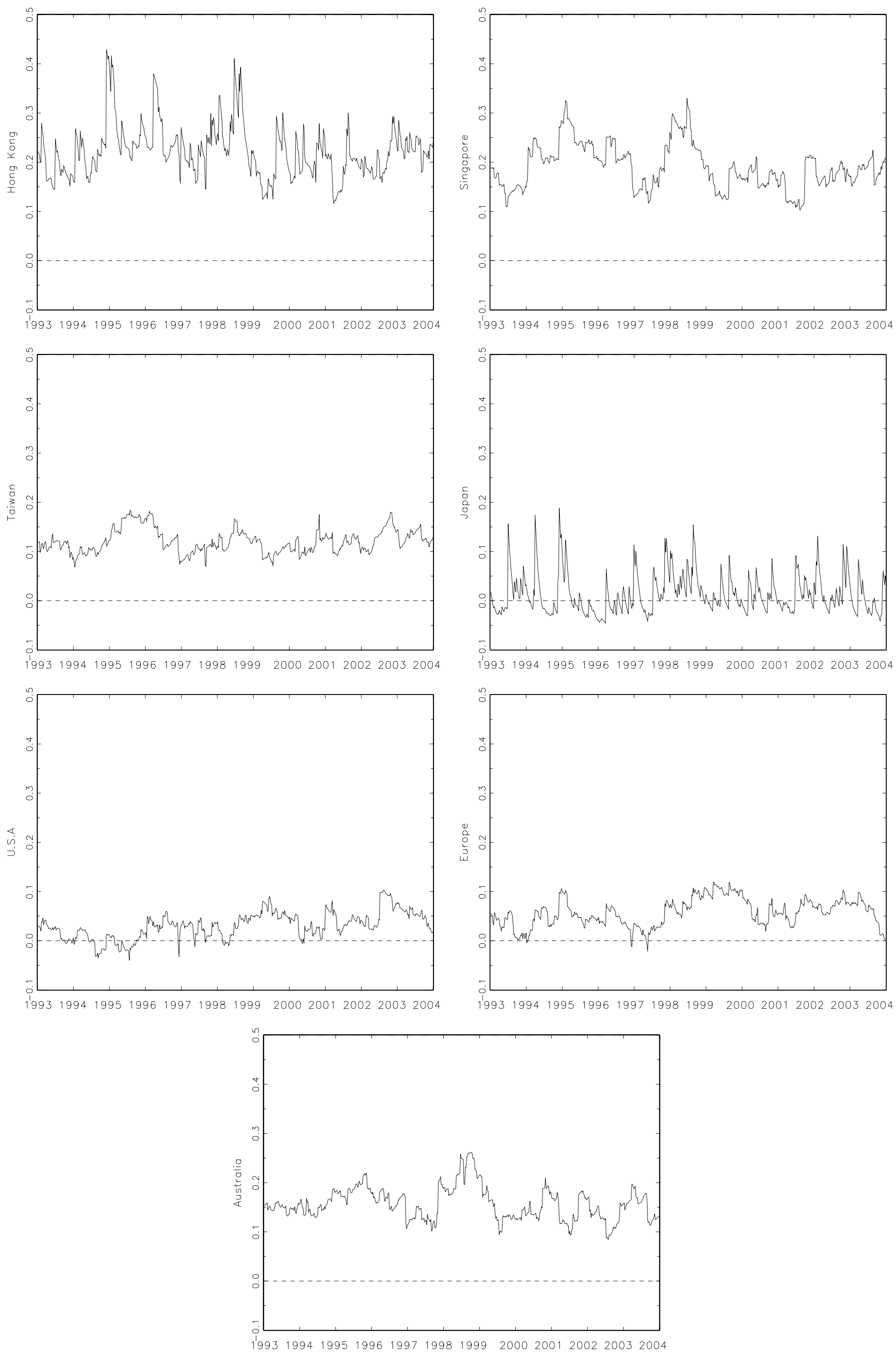


Figure 6: **Conditional Correlation: B-share (Foreign) and World Markets.** These graphs show the conditional correlation of the Shanghai B-share index with the main world indices. We do not report the results for the Shenzhen B-share index as they are very similar. These graphs, however, are available from the authors upon request. We calculate correlation with the European markets as the average of correlation with the French, German, and U.K. market. Results for the A-share indices are in Figure 5.