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Persistence Characteristics of the Chinese Stock Markets

Abstract

This paper identifies such fundamental characteristics as the lack of ergodicity, stationarity, and independence, and it identifies the degree of initial persistence of the Chinese stock markets when they were more regulated. The index series are from the Shanghai (SHI) stock market and Shenzhen A-shares (SZI) and B-shares (SZBI) stock markets, before and after the various deregulations and reregulations. Accurate and complete signal processing methods are applied to the complete series and to their sub-periods. The evidence of lack of stationarity and ergodicity can be ascribed to two causes: (1) the initial interventions in these stock markets by the Chinese government by imposing various daily price change limits, and (2) the changing trading styles in the course of the development of these emerging stock markets, after the Chinese government left these equity markets to develop by themselves. By computing the markets' monofractal Hurst exponents (and its accuracy range with a new statistic), using wavelet multiresolution analysis (MRA), we identify the markets' subsequent degrees of persistence. The empirical evidence shows that SHI, SZI, and SZBI are moderately persistent with Hurst exponents slightly greater than the Fickian 0.5 of the Geometric Brownian Motion. It also shows that these stock markets were considerably more persistent before the deregulations, but that they now move much more like geometric Brownian motions, i.e., efficiently. Our results also show that the Chinese stock markets are gradually and properly integrating into one Chinese stock market. Our results are consistent with similar empirical findings from Latin American, European, and other Asian emerging financial markets.

JEL classification: C15; C33, C53, G13, G15, G18

Keywords: Long-term dependence, degrees of persistence, Hurst exponent, wavelet multiresolution analysis, Chinese equity markets

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1 Introduction

One of the most important structural changes in China is the recent development and growth of its equity markets. This stock market growth is crucial to the Chinese government's attempts to successfully privatize and restructure state owned enterprises (SOEs). Although its equity markets are small relative to the overall economy and many structural and institutional problems remain, it appears that the development of its equity markets is on an irreversible path, holding out promising long-term prospects. In the meantime, however, government involvement is disproportionately large in its equity markets. This should not really be a surprise in China's transitional economy, but it may cause problems for its integration into the world's capital markets, now that it has become a member of the World Trade Organization, the term structure of its interest rates has extended its maturities, and China's exchange rate is no longer fixed to the dollar, but is put on an adjusting pegged regime (in July 2005).

In terms of market activity, China's equity market is infamous for its high turnover rate. In 2003, out of 49 international stock exchanges, the Shenzhen Stock Exchange ranked 9th qua highest turnover rate of domestic shares, and in 2004 it ranked 10th, while the Shanghai stock exchange ranked in 2003 10th and in 2004 17th, respectively.[1] This is quite a significant turnover rate for a market that is only 15 years old.

Furthermore, individual investors comprise a large part of market participants, currently about 60 millions strong.[2] Due to these characteristics of market activity and investor structure, modern portfolio management theory is hardly practiced in China. Understanding stock-market behavior is very important, because in a market consisting of risk-averse investors, greater volatility (risk) would lead investors to demand a higher risk premium, creating a higher cost of capital, which impedes investment and slows economic development.

[1] Source: *China's Capital Markets Handbook*, The Hong Kong and Shanghai Banking Corporation Limited (HSBC), December 2004, Table 1.8, Turnover Velocity of Domestic Shares. These turnover velocity rates have been calculated with monthly moving averages.

[2] Source: *China's Capital Markets Handbook*, The Hong Kong and Shanghai Banking Corporation Limited (HSBC), December 2004, p. 9.

The purposes of this paper are: (1) to investigates the empirical characteristics of the financial time series of the Chinese stock market by measuring the degree of persistence of both the Shanghai stock index and the Shenzhen stock index (including both the Shenzhen comprehensive stock index and the Shenzhen B share index); (2) to characterize the risk and return behavior in Chinese stock markets; and (3) to identify the impact of government policy on market movements.

We use Manderlbrot's (1969, 1972) concept of the long-term persistence to study the Chinese stock market price diffusions. recent empirical financial market research has demonstrated that the monofractal Hurst exponent, a measure of such long-term persistence, tends to provide a good characterization of the distributional scaling characteristics of financial price diffusion processes well (Mills, 1999; Los, 2003, Kyaw et al., 2005). We try to find out if this holds also true for the Chinese stock markets.

The paper is organized as follows. Section (2) provides a brief literature review of Chinese stock market research and of the theory of long-term market memory. The data sets are described in section (3). In section (4), our research methodology is introduced. Section (5) provides the analysis of empirical results. Our conclusions are presented in section (6).

2 Literature review

The extraordinary expansion and rapid growth of the Chinese stock markets have already initiated a large amount of research of Chinese stock markets. Researchers attempt to explore the distributional characteristics of the stock-market return and risk processes, focusing on establishing empirical models that capture the deterministic components of the variation in the stock market returns. For example, Su and Fleisher (1998) analyze the dynamic behavior of Chinese stock markets by characterizing the time-series properties of stock-market return as well as volatility and by testing the market efficiency hypothesis. They estimate an empirical model that captures the effect of local and global information variables on the conditional mean of stock-market returns and characterize the second order conditional moments using three error generation processes.

They find that stock-market volatility is time-varying, mildly persistent, and is best described by fat-tailed stable distributions. They also find that government's market liberalization policies have contributed to high stock-market volatility in China.

Mookerjee and Yu (1999a) also test the efficiency of Chinese stock market. They conclude that there are significant inefficiencies present on both Shanghai and Shenzhen exchanges. These can be traced to the unique structural and institutional problems that plague both exchanges. Their study also tests for the presence of seasonal anomalies on both exchanges. The results show that there are significant negative weekend and positive holiday effects, but there is no evidence of a January effect or early January effect.

Mookerjee and Yu (1999b) investigate the seasonal patterns in stock returns on the Shanghai and Shenzhen stock markets. The paper documents several interesting findings. First, the highest daily returns on both exchanges occur on Thursday rather than Friday. Second, price change limits exert an effect on the observed daily pattern of returns. Third, daily stock returns appear to be positively correlated with risk. These results are sharply at odds with the majority of comparable findings for other stock exchanges around the world.

Another line of research focuses on revealing the price differences between different classes of stocks, based on the special shareowner structure in Chinese state-owned firms. Chen and Xiong (2001) focus on the price differences between restricted institutional shares (RIS) and common shares of the same company, using both auction and private-transfer transactions for RIS shares. Among their findings, the average discount for RIS shares relative to their floating counterpart is 77.93% and 85.59%, respectively based on auction and private transfers. Thus price for illiquidity is very high, significantly raising the cost of equity capital. This illiquidity discount increases with both the floating shares' volatility and the firm's debt/equity ratio, but decreases with firm size, return on equity, and book/price and earnings/price ratios (based on the floating share price). However, RIS share price can either increase or decrease with the quantity being transacted, depending on whether it is through a private placement or an auction.

The particular line of research relevant for this paper is the exploration of the different price movements of A shares and B shares. Wang, Liu, and Wang (2004) investigate interactions between Chinese A shares and B shares traded on the Shanghai stock exchange (SHSE) and the Shenzhen stock exchange (SZSE), using an asymmetric multivariate time-varying volatility model. They find that there is a causal relation from B share markets to A share markets in the second moment, but no such relation is present in the first moment, suggesting B shares contain more prior information than A shares about risk, but not about return. This is probably due to differences in investment objectives and investment scopes between the two groups of investors and the existing barriers between the two markets. Moreover, there exist stronger links between shares of the same type, *i.e.*, between the two A (B) share markets, than those between shares of different types.

So far, most of research pays attention to using traditional time-series models such as GARCH or IGARCH models (Su and Fleisher, 1997) to estimate the return and risk behavior of the Chinese stock markets. Some research attempts to shed light on causal relationship between firm characteristics and stock prices (Chen and Xiong, 2001; Wang, Liu, and Wang, 2004). However, those traditional time-series models are criticized for not being able to model long-term dependence too well and for requiring (and often presuming) Gaussian distribution characteristics for the residuals (Kyaw et al. 2005).

Since Mandelbrot (1969, 1972) discussed the non-Gaussian distributions of financial prices and introduced the concept of the long-term persistence in economic series, financial researchers have been searching for models that can identify such typical behavior of financial time. Long-term dependence and persistence characterize well the scaling behavior of the non-stationary second moments of log-normal pricing processes. The Range-Scale (R/S) statistic-based Hurst exponent is currently the most widely used statistic to measure global long memory in time series (Hurst, 1951). The Hurst exponent is rather robust and makes no extraneous.

This long memory measure and LM price diffusion models are now extensively applied in estimating persistence characteristics of various financial time series and financial markets. Applying the very accurate wavelet MRA to high-frequency data for 1997, Karuppiah and Los (2000) find long-term dependencies in seven Asian currency markets (Japan, Hong Kong, Indonesia, Malaysia, Philippines, Singapore, Taiwan, Thailand) and in the German Mark (no longer existent). In particular, they were the first to find that the anchor currencies - the German Mark/Dollar and the Japanese Yen/Dollar rates are actually anti-persistent.

Lipka and Los (2002) measure the degrees of persistence of the daily returns of eight European stock market indices. They find that the global Hurst exponents, computed from wavelet multi-resolution analysis, measure the long-term dependence of the data series well. They find that the FTSE turns out to be an ultra-efficient market with abnormally fast mean-reversion, faster than theoretically postulated by a Geometric Brownian Motion (GBM). In addition, they demonstrate that the visualization of the wavelet resonance coefficients and their power spectra, in the form of localized scalograms and averaged scalegrams, forcefully assists with the detection and measurement of several nonlinear types of market price diffusion.

Kyaw et al. (2005) improve this methodology by analyzing the degree of long-term dependence of Latin American financial markets, measuring monofractal Hurst exponents from wavelet multiresolution analysis (MRA) of Latin American stock and currency markets. They find that the financial rates of return from are non-normal, non-stationary, non-ergodic and also long-term dependent.

Researchers also apply MRA on individual stocks. Mulligan (2004) examines technology equity prices series using five self-affine fractal analysis techniques for estimating the Hurst exponent, the Mandelbrot-Lévy characteristic exponent, and fractal dimension. He finds many technology equities to be anti-persistent, suggesting these markets do price the technology securities ultra-efficiently, but not equally efficiently.

However, thus far, the long memory and persistence characteristics of Chinese stock have not yet been identified. This paper attempts to fill this gap by estimating monofractal Hurst exponents of Chinese stock indices using also wavelet MRA. It provides scalograms and scalegrams to visualize the wavelet coefficients and the power spectrum of the rates of return. This research is important because it (1) establishes benchmark LM models for Chinese asset and option pricing, (2) provides measurements for investment selection and risk management, and (3) distinguishes the Chinese stock markets from the world financial markets.

3 Data

The data we use for this study are the daily closing price stock indices released by both the Shanghai and Shenzhen Securities Exchanges for shares traded on those exchanges. These stock index data are obtained from the China Center for Economics Research (CCER), at Beijing University in Beijing, China. The two classes of shares that trade on the Shanghai and Shenzhen exchanges are the A and B shares. A shares are for domestic individual investors, and B shares are for foreign investors.[3] Of these two types of shares listed on the domestic exchanges, A share trades dominate, both in terms of size and level of activity.

Table 1 gives a description of our data set. The Shanghai stock price index (SHI) has a starting date of December 19, 1990. The Shenzhen stock price index (SZI) commenced trading on December 23, 1991. The sample period for both the Shanghai and Shenzhen exchanges are from their respective initial trading days up to January 6, 2005. The development of the Chinese stock markets is characterized by a hesitating stop-go sequence of regulation–deregulation–and reregulation. This is illustrated by the price change limit regulation.

Since the stock markets were instituted by the Communist government, there had been daily price change limits in both the Shanghai and Shenzhen stock markets. In the Shenzhen stock market, the limit was 0.5%, but in the Shanghai Stock market, the limit was 1%. This price

[3] According to China Securities Regulatory Commission: "B Shares are foreign-invested shares issued domestically by Peoples Republic of China's (PRC) companies. B Shares are also known as Renminbi Special Shares. B Shares are issued in the form of registered shares and carry a face value denominated in Renminbi. B Shares are subscribed and traded in foreign currencies and are listed and traded in securities exchanges inside China. The B Share Market came into existence in 1991." And "The B Share Market is designed to attract foreign investors. The Market provides an additional channel for foreign capital thereby enhancing the progress of the evolvement of PRC's securities market." (China Securities Regulatory Commission's public statement-Notes on B share market, August 27, 2002, www.csrc.gov.cn/jsp/). A shares are denominated in yuan and can be traded only by domestic investors.

change regulation began in December 1990, to eliminate speculation. This heavy-handed price regulation heavily hurt both markets. After these price change limits were applied, the stock prices kept declining for six month. (We have no data available for this period). But then the Shenzhen stock exchange completely deregulated from in May 1991, whereas the Shanghai stock exchange relaxed its price change from 1% to 5% on February 18, and then completely removed its daily price change limit on May 21, 1992. On May 20, 1992 the Shanghai stock exchange announced that its price change limit would be completely removed on the next day.[4] From the beginning of December 13, 1996, new daily price change limits of 10% were imposed on daily aggregate price fluctuations on both the Shanghai and Shenzhen exchanges, presumably to reduce inter-day volatility.

To analyze how these changes of trading regulations influence the stock markets and to reveal the changes in trading persistence of stock indices due to the consequent changes in transaction style, we divide the stock indices into two groups. Group one covers the period from December 19, 1990 to December 12, 1996 (SHI), and from December 23, 1991 to December 12, 1996, (SZI), respectively; and group two include the data from December 13, 1996 to January 6, 2005, for both SHI and SZI.

Other stock market interventions had major market pricing consequences. For example, on July 31, 1994, the China Securities Regulatory Commission announced that there would no A-share IPOs within next half year in both the Shanghai and Shenzhen stock exchanges.[5] The background for this announcement is that both Shanghai and Shenzhen stock indices had declined more than 50% from the beginning of 1994 to then, presumably from a glut in the supply of new shares. Thus the Chinese government intervened in the markets by reducing the supply of new shares.

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[4] Source: *China Security Journal*, May 21, 1992, p. 1. (*CSJ* is is the No.1 security newspaper in China, as is *The Wall Street Journal* in the US). See in Fig. 2, the severe disruption of the distributional moments of the Shanghai market returns at observation no. 360 in our available data set.

[5] Source: *China Security Journal*, July, 31, 1994, p. 1. This had the greatest impact on the Shenzhen stock market, as is again visible in Fig. 2, at no. 648 of our available observations) where there is major disruption in the skewness and kurtosis of the Shenzhen market return distributions.

We also analyze the Shenzhen B shares index, ranging from October 7, 1992 to March 31, 2005. While B shares are for foreign investors, in March 2001, officials declared that the B shares market would be opened to domestic individual investors, i.e., citizens of the People's Republic of China. As a result, the B share prices spiked, rising 240% in Shenzhen. To investigate further the impact of government policy on stock market, we divided the Shenzhen B share index into two periods, from October 7, 1992 to February 28, 2001, and from March 1, 2001 to March 31, 2005, respectively.

4 Methodology

The first four moments are used to summarize the frequency distributions of the daily stock market returns: the mean, the standard deviation (or its variance), the skewness, and kurtosis of the daily rate of return. The skewness describes the degree of asymmetry of the return distribution and provides the degree of financial pressure. The kurtosis describes the degree of concentration of the return distribution and helps to characterize the style of trading. For example, a high degree of kurtosis or leptokurtosis indicates that there are many hedging noise traders in addition to few speculative position traders, but few intermediary range traders. While in the opposite case of low kurtosis, or platy-kurtosis, there is a more even distribution of all types of traders.

To test the stationarity and ergodicity of the stock market distributions, and thus the invariant character of the stock market trading, we compute the first four moments with increasing window sizes and, secondly with moving average window size (of 60 days) for each series. The ergodicity is mostly checked by increasing window size moments, the while stationarity is mostly checked by moving average window size.

Ergodicity is defined by Terence C. Mills (1999, p. 9) as follows: "... the process is ergodic, which roughly means that the sample moments for finite stretches of the realization approach their population counterparts as the length of the realization becomes infinite." A time series is said to be strictly stationary if the joint distribution of any set of n observations $X_{t_1}, X_{t_2}, \ldots, X_{t_n}$ is the same as the joint distribution of $X_{t_{1+k}}, X_{t_{2+k}}, \ldots, X_{t_{n+k}}$ for all n and all lags k.

The estimation of the degree of long-term dependence in this paper follows the methodology discussed in Kyaw, Los, and Zong (2005). They present a strong argument for the robustness of measuring long-term dependence, i.e., the degree of market persistence, by identifying the mono-fractal (or global) Hurst exponent of the price series: The measurement model is the encompassing Fractal Brownian Motion, in which the rate of return is an affine process with fractionally differenced white noise innovations (Elliott and Van der Hoek, 2003; Los, 2003):

There are three distinct classifications of market price diffusions measured by the identified Hurst exponents (H):

(1) Fickian, when $H = 0.5$, which describes the Geometric Brownian Motion; (2),

(2) Anti-persistent, when $0 < H < 0.5$, and

(3) Persistent, when $0.5 < H < 1$.

According to the theory of Fractional Brownian, $H = 0.5$ implies an independent innovation process. The news events are mutually independent throughout time. The present does not influence the future (and vice versa).

A persistent or anti-persistent market return series is characterized by a long memory effect. Theoretically, what happens today will impact the future forever in a nonlinear fashion. If a persistent market price change has been up (down) in the last period, then the chance are that it will continue to be positive (negative) in the next period. Trends are apparent, but these apparent trends will be unpredictably interrupted by sharp discontinuities, or in stock market terms, by severe drawdowns, or sharp upshifts. The strength of the trend-reinforcing behavior, or persistence, increases as the value of the Hurst exponent H approaches unity. The closer the Hurst exponent H is to 0.5, the choppier the pricing process and the less smooth the apparent trends will be.

Anti-persistent markets are "mean-reverting". If the market has been up in the previous period, it is more likely to be down in the next period. The strength of the anti-persistent behavior depends on how close the Hurst exponent H is to zero. The closer it is to zero, the more negative short-term dependencies are present. An anti-persistent market tends to covers less price distance than an independent geometric Brownian motion in the same amount of time. For the market price to cover less price distance, it must reverse itself more frequently than a market process with mutually independent news events.

5 Empirical results

Fig. 2 presents the first four moments for both the Shanghai and Shenzhen stock markets by computing these moments using incremental window sizes. These computed moments are plotted against their window length. These plots inspect visually the ergodicity of data sets, for both index level and return series. If the series are ergodic, the plots should converge gradually to a flat line and then stay constant at a certain value. However, neither data series show such gradual convergence to a flat time line, which strongly suggest that neither SHI nor SZI, including SZBI are ergodic.

Especially, the plots of skewness and kurtosis present sharp jumps and discontinuities, reflecting the high volatility of Chinese stock market. Interestingly, those jumps and discontinuities show up mostly in the first few years in our data set (from 1990 to 1992) when the Chinese stock markets were established, reflecting the fact that government interventions and policy changes are major volatile sources of Chinese stock market, as we discussed in Section 3. Such government interventions and policy changes include changes of interest rate, control of the growing supply of new shares traded in the exchanges, and changes of stock transaction regulations, such as the impositions and removals of daily price change limits, but other political events did also roil the Chinese stock markets. Official examples of such maVket turmoil in all three Chinese markets are given in Table 4.

However, from the plots, we can also see the continuous volatility decrease in last five years, as measured by the second moment of the standard deviation of the returns. These moment plots visually show that the Chinese government improved its capital markets management skills by applying more market-oriented methods and became less directly involved in the equity markets, leaving them to their own devices.

However, it also results from changes in the structure of the market participation. After the initial interruptions, the skewness appears to stabilize, indicating that there is not much market pressure upwards or downwards, but that the markets are mostly trading "sideways" in an even-handed fashion. The supply of new shares meets the new demand quite well. After the initial government-induced turmoil, we find a gradual upward trend in the level of kurtosis, This means that the Chinese stock market return distributions are becoming more leptokurtic, implying that the Chinese stock markets are sorting themselves out into a group of hedging noise traders, who provide liquidity to the markets, and a group of large speculative position takers, consisting of institutional investors and wealthy individuals.

Because of lack of space we don't show the figures of the moments computed with a moving window of fixed size (60 days = 2 - 3 month). In neither case constant moments and convergence are observed, since the Chinese markets are clearly emerging, developing markets in transition. Sharp shift occur in the moving average moments, indicating fractality of the data series and non-stationary of time series in either strict or wide sense.

To test the persistence characteristics of data series, we estimate their monofractal (global) Hurst exponents from the scalegrams (= wavelet scale spectra) produced by wavelet multiresolution analysis (MRA) (Los, 2003). To check the impact of government interventions on the Chinese stock markets, we subgroup our sample into two groups for each series, based on the date when Chinese government changed stock transaction regulation in two exchanges, as discussed in Section 3.

Table 2 reports the Hurst exponents for the three complete stock index series, while Table 3 breaks them down according to the market regime changes.

Figures 4, 5 and 6 the scalograms and scalegrams from the wavelet MRA. A scalogram measures all power spectra localized in time and frequency (=1/scale) domains at various scales and at various times. The wavelet resonance coefficients are computed by Mallat's (1989) cascading wavelet MRA with the use of the (very general) Morlet-6 wavelet. A scalogram, which is a visualization of the colorized wavelet resonance coefficients, allows one to identify the precise timing and power of the innovations or shocks occurring in the financial markets. A scalegram is a time-averaged scalogram, based on wavelet bases, and comparable to a Fourier spectrum based on trigonometric bases. Scalograms are plots of colorized squared resonance (correlation) coefficients of the proper time-frequency correlation of the time series with the properly time-frequency scaled (Morlet-6) wavelets. They show how well the time series "resonates" with the analytic time-frequency grid of properly scaled wavelets. Scalograms help to detect the periodicities, such as strict seasonality, and the (mostly institutional) aperiodic cyclicities (= uncertain "periodicities"), such as trading holidays of the financial markets, which cannot be easily identified by the usual stationarity and ergodicity-based statistical methodologies. All scalograms and scalegrams in this paper are computed with the help of software available on Kodak's ION website: http://ion.researchsystems.com/IONScript/wavelet.

There are three parts in each plot in Figures 4, 5 and 6. There are three parts in each plot. Part a is the plot of original time series together with the type of wavelet used to analyze the time series (*i.e.*, the Morlet$-$6.0 wavelet). Part b is the scalogram (= localized wavelet power spectrum), which is a colorized plot of the squared value of the wavelet resonance coefficients, *i.e.*, the time-frequency-localized "coefficients of determination.". Part c is the (global wavelet) scalegram, which plots the (horizontal) variances of the zero-mean wavelets against the (vertical) scales and forms the statistical time average of the scalogram. It demonstrates the monofractal scaling of the time series. The slope of the scalegram of the price levels equals $c = 2H + 1$, so that the Hurst exponent $H = (c - 1)/2$; the slope of the scalegram of the rates of return equals $d = 2H - 1$, so that $H = (d - 1)/2$. Both scalegrams give the identical value for H (*Cf.* Los, 2003, Chapter 8). The reported minimal accuracy ranges of $H + / - 0.01$ are based on the number of observations T daily observations reported in Table 1 for each series and the scale $a = 22$ days ($\approx$ one month of trading days), using the Chi-squared statistic introduced in Kyaw, Los and Zong (2005), as shown in the Appendix.

Table 2 provides the Hurst exponents of all three available historical price index series. From Table 2 we can see that (1) all three indices are persistent, but that (2) both the Shanghai Stock Index and the Shenzen (A Share) Stock Index are about equally less persistent than the Shenzen B Share Index, which is appears to be most persistent and therefore has the most unpredictable market risk. However, this global analysis is not very informative, since we know that Hurst exponents have different values according to the developmental stage or trading regime of financial markets (Di Matteo et al., 2005).

Therefore, in Table 3 we have collected the Hurst exponents from the regulated and deregulated trading regimes. A much clearer picture now emerges. As we discussed earlier, before December 12, 1996 there were no price change limits in the Shanghai and Shenzhen stock markets, but the access to the Shanghai and Shenzhen A-share stock market was restricted and there was limited market participation and trading. From the beginning of December 13, 1996, both the Shanghai and Shenzhen (A-share) stock markets were deregulated or liberalized, although some wide, hardly binding, daily price change limits of 10% either way were imposed. The market deregulation reduced the persistence of the stock markets and thus reduced the unpredictable market risk attributable to government intervention. Furthermore, after the Shenzen B share market was opened up to citizens of the People's Republic of China (domestic individuals) on March 1, 2001, and also deregulated otherwise, its persistence level has also become about equal to that of both the Shanghai and Shenzhen (A share) markets. In fact all three stock markets are now only slightly more persistent than Geometric Brownian Motion and move much more synchronously. This demonstrates that the various market deregulations and liberalizations of the market access, has helped to (still imperfectly) integrate these three separate markets into one Chinese stock market.

6 Conclusion

In this paper, we identify such fundamental characteristics as the lack of stationarity, ergodicity, and of independence of price innovations, and identify the changing degrees of persistence of the Chinese stock markets, as a whole and by various developing trading regimes over time. This paper makes three contributions: (1) new and rather lengthy sets of daily price data of the three Chinese stock markets obtained from the China Center for Economics Research (CCER) at Beijing University in China., (2) the application of advanced signal processing methodology of wavelet multiresolution analysis (MRA) to identity the Hurst exponent, and (3) a new and logically correct statistic to compute the minimal accuracy range of the Hurst exponent.

The available data series are the Shanghai (SHI), Shenzhen A-shave (SZI), and Shenzhen B-share (SZBI) stock price indices. Traditional analysis methodologies in finance that based on the Geometric Brownian Motion assumptions are not able to reflect the persistence characteristics of financial time series, nor can they deal with the pervasive non-stationarity, non-ergodicity and nonlinear dependence (long memory)of the return innovations, which are all three so characteristic for dynamic emerging markets. By computing the monofractal (global) Hurst exponents from wavelet multiresolution analysis (MRA), we identify the degree of persistence of each complete data series. But more importantly, we also identify the different consecutive degrees of persistence corresponding with the various sub-periods of regulated, deregulated and partially regulated markets in China. The empirical evidence shows that both SHI, SZI, and SZBI are persistent with Hurst exponent greater than 0.5, indicating that Chinese stock market does not match the strict efficient market hypothesis of Fama (1970), But we also show that the Chinese stock markets have moved much closer to that theoretical ideal.

The increase in efficiency over time, indicated by the reduced values of the Hurst exponents of the more recent periods, can be explained by the sequential stages of deregulation and liberalization of the Chinese stock markets, which in the early 1990s were still heavily interrupted by unpredicatable market interventions by the government, making these markets persistent and not neutral. Such non-Fickian or non-neutral market persistence allows for profit-making arbitrage opportunities, making these markets unfair. But now that the Chinese markets have become more efficient and neutral in the last three years implies that these markets do no longer allow abnormal profits and that they are much fairer for all traders.

We also notices that after the initial government interventions and other major news events, visible as singularity "spikes" in the return series and as high powered vortices in the scalograms, the volatility levels in the Chinese stock markets have been gradually declining, while the skewness remains almost stationary, with a slight positive (upward) tilt. In addition, the kurtosis of the Chinese stock markets is increasing because of the increased participation of many hedging noise traders, who trade "around the market mean" and fewer powerful institutional and wealthy investors, which are used to take a few large speculative buy-and-hold positions "away from the market mean." This increase in the leptokurtosis is more pronounced in the more globalized Shenzhen than in the still very domestic Shanghai stock market, implying that the integration of these two regional Chinese stock markets is still not complete.

Further research on the continually domestically integrating Chinese stock markets should continue to test the degrees of persistence and integration among the national Chinese stock market and the regional and continental stock markets in Asia, Europe and the United States.

7 Appendix: minimum accuracy range of the Hurst exponent

The reported minimum accuracy ranges are based on the number of observations T daily observations reported in Table 1 for each series and the scale $a = 22$ days ($\approx$ one month of trading days), using the Chi-squared statistic introduced in Kyaw, Los and Zong (2005). They show that the mean/dispersion ratio $\frac{\mu}{\sigma}$ of the Chi-squared distributed scalegram $P_w(a)$, with $\frac{T}{a}$ degrees of freedom, is (in the limit) equal to $\sqrt{\frac{T}{2a}}$, so that the noise/signal ratio of the scalegram $P_w(a)$ is

$\frac{\sigma}{\mu} = \sqrt{\frac{2a}{T}}$.The slope $c = (2H + 1)$ of the scalegram of price levels is, approximately

$$c \approx \frac{\log_2 P_w(a)}{\log_2 a} \tag{1}$$

so that the minimum uncertainty range of slope c is given by

$$\begin{aligned} \frac{\log_2[P_w(a) * (1 + \frac{+/-\sigma}{\mu})]}{\log_2 a} &= \frac{\log_2 P_w(a)}{\log_2 a} + \frac{\log_2(1 + \frac{+/-\sigma}{\mu})}{\log_2 a} \\ &= c + \frac{\log_2(1 + \frac{+/-\sigma}{\mu})}{\log_2 a} \\ &= c + / - \frac{\frac{\sigma}{\mu}}{\log_2 a} \end{aligned} \tag{2}$$

This implies that the uncertainty range of the Hurst exponent is given by

$$H + / - \frac{\frac{\sigma}{\mu}}{2 \log_2 a} = H + / - \frac{\sqrt{\frac{2a}{T}}}{2 \log_2 a} \tag{3}$$

which are the minimum Hurst exponent uncertainty ranges reported in Tables 2 and 3, using the number of observations T from Table 1 and the scale level $a = 22$ (trading days = one month of trading).

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9 Tables

Table 1: Indices of Shanghai and Shenzhen Stock Markets

Index Names, Covered Periods, and Numbers of Observations

Panel A provides the daily global stock indices for Shanghai and Shenzhen from the early 1990s until 2005, with both Shenzhen markets for the A and B shares. Panel B provides various sub-periods of these stock indices: the Shanghai and Shenzhen (A shares) stock indices before and after the deregulation and imposition of price-change limits on December 13, 1996, and the Shenzhen B share index, before and after it was opened up to citizens of the People's Republic of China (domestic individuals) on March 1, 2001.

Panel A

Index Name	Exchange	Period Covered	Number of Obs
Shanghai Stock Index	Shanghai Security Exchange	12/19/1990-01/06/2005	3460
Shenzhen Stock Index	Shenzhen Security Exchange	12/23/1991-01/06/2005	3179
Shenzhen B Share Index	Shenzhen Security Exchange	10/07/1992-03/31/2005	3025

Panel B

Index Name	Descriptions	Sub-Period	Number of Obs
Shanghai Stock Index	No price-change limit	12/19/1990-12/12/1996	1515
	Price-change limit	12/13/1996-01/06/2005	1945
Shenzhen Stock Index	No price-change limit	12/23/1991-12/12/1996	1234
	Price-change limit	12/13/1996-01/06/2005	1945
Shenzhen B Share Index	Not opened to domestic individuals	10/07/1992-02/28/2001	2043
	Opened to domestic individuals	03/01/2001-03/31/2005	982

Table 2: Identified Global Hurst Exponents of the Chinese Stock Indices

The Hurst exponent H is identified from plotting the logarithm of the scaled power $P_W(a)$ of the Fractional Brownian Motion (FBM) against the $\log_2(a)$, where a is the time scale. The slope coefficient of the resulting line is $c = (2H + 1)$, so that $H = (c - 1)/2$. A Hurst exponent of $H = 0.5$ indicates that the financial market follows a Geometric Brownian Motion (GBM), while a Hurst exponent $0.5 < H < 1.0$ means that the market is persistent (= trending with sharp, singular discontinuities), and a Hurst exponent $0 < H < 0.5$ means that the market is anti-persistent (= fast mean-reverting). The reported minimal accuracy ranges of $H +/- 0.01$ are based on the number of observations T daily observations reported in Table 1 for each series and the scale $a = 22$ days (≈ one month of trading days), using the Chi-squared statistic introduced in Kyaw, Los and Zong (2005), as shown in the Appendix. Notice that (a) all three indices are persistent, but that (b) both the Shanghai Stock Index and the Shenzen (A Share) Stock Index are about equally less persistent than the Shenzen B Share Index, which is most persistent and therefore has most unpredictable market risk.

Index Name	Exchange	Period Covered	Mean/dispersion of wavelet scalegram	Hurst exponents
Shanghai Stock Index	Shanghai Security Exchange	12/19/1990-01/06/2005	8.87	0.54+/-0.01
Shenzhen Stock Index	Shenzhen Security Exchange	12/23/1991-01/06/2005	8.50	0.55+/-0.01
Shenzhen B Share Index	Shenzhen Security Exchange	10/07/1992-03/31/2005	8.29	0.62+/-0.01

Table 3: Identified Hurst Exponents of the Chinese Stock Indices

For the unrestricted and restricted regimes

This table reports the identified mono-fractal Hurst exponents of the stock indices for the unrestricted and restricted trading regimes. These exponents are identified in the same fashion as in Table 1 and have similarly calculated minimum accuracy ranges (Cf. the Appendix). Before December 12, 1996 there were no price change limits in the Shanghai and Shenzhen stock markets, but the Shanghai stock market was heavily regulated. From the beginning of December 13, 1996, a 10% price change limit has been applied to both the Shanghai and Shenzhen (A-share) stock markets, which were otherwise deregulated. The total price change in one day can be only 20%, from -10% to +10% from the previous day's closing price. Notice that the market deregulation plus this rather lax price change limit reduced the persistence of the stock markets and thus reduced the unpredictable market risk. Furthermore, after the Shenzen B share market was opened up to citizens of the People's Republic of China (domestic individuals) on March 1, 2001, and also deregulated otherwise, its persistence level has become about equal to that of both the Shanghai and Shenzhen (A share) markets. All three stock markets are now only slightly more persistent than Geometric Brownian Motion.

Index Name	Descriptions	Sub-Period	Mean/dispersion of wavelet scalegram	Hurst exponents
Shanghai Stock Index	No price-change limit	12/19/1990-12/12/1996	5.87	0.63+/-0.02
	Price-change limit	12/13/1996-01/06/2005	6.65	0.54+/-0.02
Shenzhen Stock Index	No price-change limit	12/23/1991-12/12/1996	5.30	0.56+/-0.02
	Price-change limit	12/13/1996-01/06/2005	6.65	0.54+/-0.02
Shenzhen B Share Index	Not opened to domestic individuals	10/07/1992-02/28/2001	6.81	0.64+/-0.02
	Opened to domestic individuals	03/01/2001-03/31/2005	4.72	0.55+/-0.02

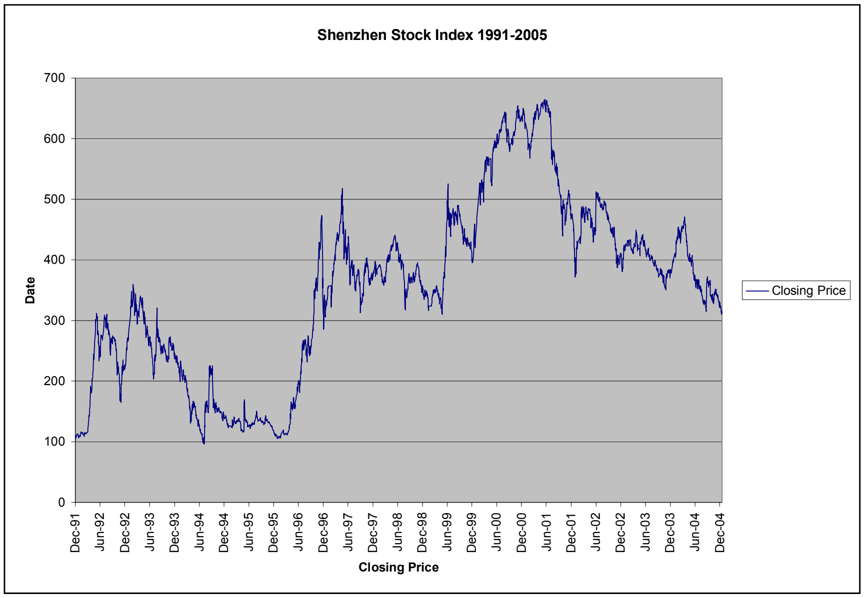
Table 4: Major News Events in the Chinese Stock Markets

Date	News events	Shanghai Index changes (%	Shenzhen A Index changes %	Shenzhen B Index change %	Citation
21-May-92	removal of price change limit in Shanghai stock exchange	105.269	1.07		*China Security Journal* May 21, 1992, Page 1
11-Aug-92	On Aug 10, Hong Kong citizens protested in the streets because they were not satisfied with the new IPO method	-10.44	-5.22		*China Security Journal* Aug 11, 1992, Page 1
1-Aug-94	Announcement that no IPO within next half year would be listed on the exchanges	33.45	31.27	0.4	*China Security Journal* July 31, Page 1
18-May-95	Stop Chinese treasure bond future transaction	30.98	28.3	1	*China Security Journal* May 18, 1995, Page 1
16-Dec-96	Apply 10% price change limit	-34 (in four days)	-24 (in four days)	-24 (in four days)	*China Security Journal* December 14, 1996, Page 1
8-May-97	Increase transaction tax	-7.27	-5.82	-3.35	*China Security Journal* May 8, 1997, Page 1
1-Jul-99	New China Security Law is effective	-7.61	-7.99	-5.7	*China Security Journal* July 1, 1999, Page 1
Sept 9,1999	Allowing state-owned companies to use their own funds to invest in A-share stock	6.5	6.03	6.96	*China Security Journal* Sept.9, 1999, Page 1
23-Oct-01	Temporarily quit transaction of state-owned shares	9.85	9.68	9.78	*China Security Journal* Oct 23, 2001, Page 1
24-Jun-02	Permanently cease transaction of state-owned shares	9.25	9.05	9.73	*China Security Journal* June 24, 2002, Page 1
Feb 28-Mar 4,2001	Open B shares to domestic investors			48.5 (in five days)	*China Security Journal* Feb 22,2001, Page 1

10 Figures

Fig. 1: Integration of the Shanghai and Shenzhen Stock Indices

Plotted are the daily closing prices of the Shanghai, Shenzhen (A Shares) and Shenzhen B Shares sock indices, between 1990 and 2005. The Shanghai and Shenzhen stock markets were deregulated and incued simultaneously an imposition of 10% daily price-change limits on December 13, 1996. This appears to have positively affected only the Shenzhen stock market in the half year leading up to this event. After this event the Shanghai and Shenzhen markets are now more in sync and move almost synchronously. The Shenzhen B share stock market was opened to citizens of the People's Republic of China (domestic individuals) on March 1, 2001, a rather cataclysmic, but positive event, clearly visible in its chart.


Shenzhen Stock Index 1991-2005
Date
Closing Price
Closing Price
0
100
200
300
400
500
600
700
Dec-91
Jun-92
Dec-92
Jun-93
Dec-93
Jun-94
Dec-94
Jun-95
Dec-95
Jun-96
Dec-96
Jun-97
Dec-97
Jun-98
Dec-98
Jun-99
Dec-99
Jun-00
Dec-00
Jun-01
Dec-01
Jun-02
Dec-02
Jun-03
Dec-03
Jun-04
Dec-04

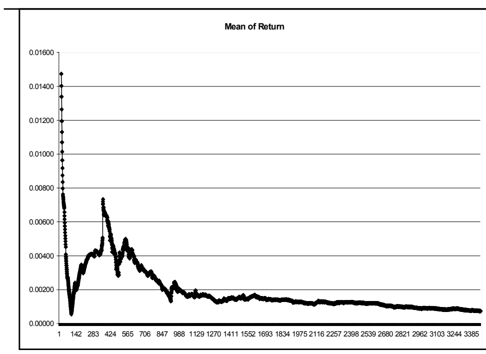
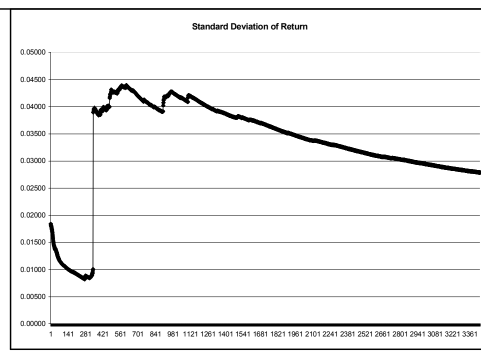

Shenzhen B-share Index 1992-2005
Closing Price
Date
Closing Price
0
50
100
150
200
250
300
350
400
450
500
Oct-92
Apr-93
Oct-93
Apr-94
Oct-94
Apr-95
Oct-95
Apr-96
Oct-96
Apr-97
Oct-97
Apr-98
Oct-98
Apr-99
Oct-99
Apr-00
Oct-00
Apr-01
Oct-01
Apr-02
Oct-02
Apr-03
Oct-03
Apr-04
Oct-04

Fig. 2: Four Moments of the Shanghai Stock Index Returns

with Increasing Window Sizes

This set of figures plots the first four moments of the Shanghai Stock Index return series (on the Y-axis) against the number of observations (on the X-axis). The magnitudes of the first four moments (mean, variance, skewness and kurtosis) are computed with increasing window sizes of the data sets, and the results are plotted against the window size. The non-converging plots with their sharp discontinuities (singularities) demonstrate that the data series are non-stationary and non-ergodic.

Shanghai Stock Index Return Moments

Mean	Standard Deviation
	

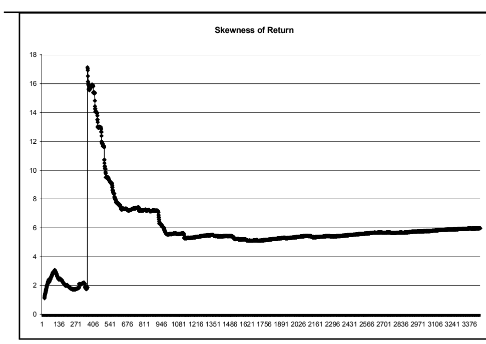
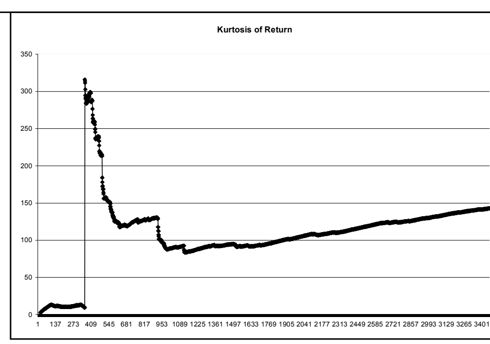
Skewness	Kurtosis
	

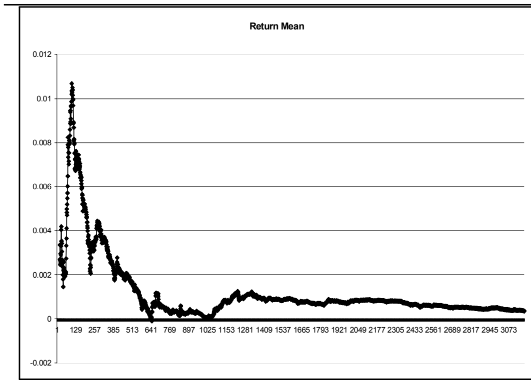
Fig. 3: Four Moments of the Shenzhen Stock Index Returns

with Increasing Window Sizes

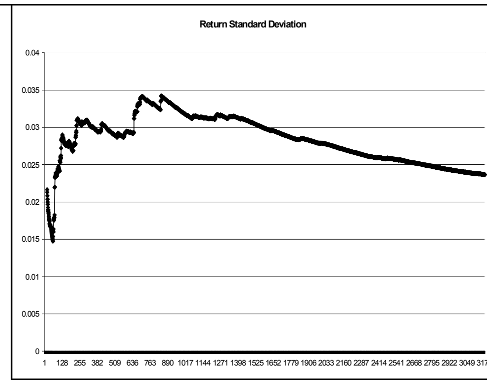
This set of figures plots the first four moments of the Shenzhen Stock Index return series (on the Y-axis) against the number of observations (on the X-axis). The magnitudes of the first four moments (mean, variance, skewness and kurtosis) are computed with increasing window sizes of the data sets, and the results are plotted against the window size. The non-converging plots with their sharp discontinuities (singularities) demonstrate that the data series are non-stationary and non-ergodic.

Shenzhen Stock Index Return Moments

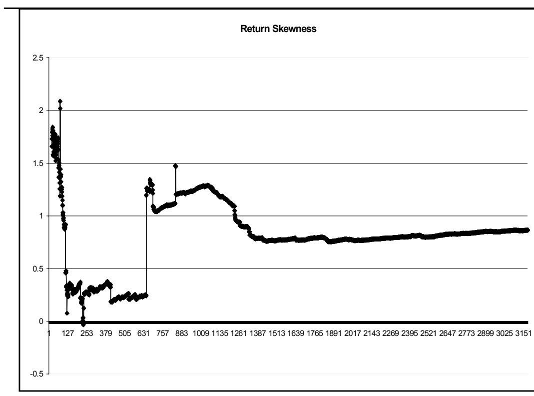
Mean



Standard Deviation



Skewness



Kurtosis

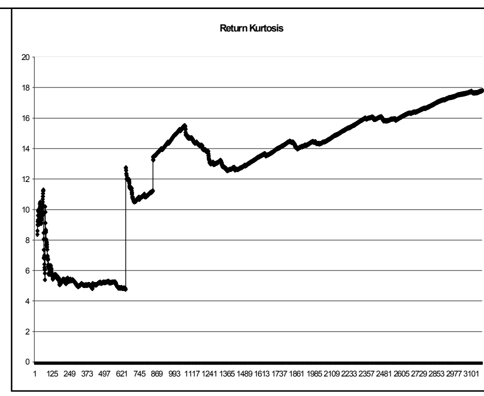
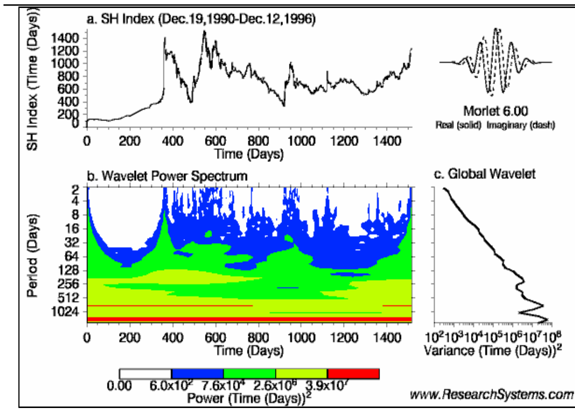


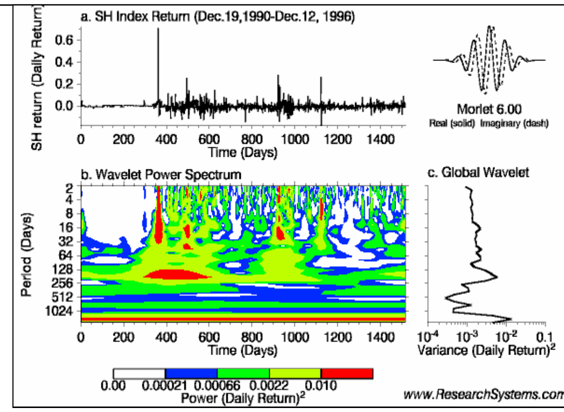
Fig. 4: Wavelet Scalograms and Scalegrams of the Shanghai Stock Index

This is a portfolio of figures containing each four panels consisting of time series, scalograms and scalegrams based on wavelet multiresolution analysis (MRA). Panel A analyzes the Shanghai price index levels in the period of December 19, 1990 - December 12, 1996, Panel B analyzes the corresponding rate of return series. Panel C analyzes the price levels, in the subsequent period of December 13, 1996 - January 6, 2005. Panel D analyzes the corresponding rate of return series. There are three parts in each plot. Part a is the plot of original time series together with the type of wavelet used to analyze the time series (*i.e.*, the Morlet−6.0 wavelet). Part b is the scalogram (= localized wavelet power spectrum), which is a colorized plot of the squared value of the wavelet resonance coefficients, *i.e.*, the time-fequency-localized "coefficients of determination.". Part c is the (global wavelet) scalegram, which plots the (horizontal) variances of the zero-mean wavelets against the (vertical) scales and forms the the statistical time average of the scalogram. It demonstrates the monofractal scaling of the time series. The slope of the scalegram for the price levels equals $2H + 1$, that of the scalegram, of the rates of return equals $2H - 1$ (*Cf.* Los, 2003, Chapter 8). When $H = 0.5$ we look at a Geometric Brownian Motion (GBM), when $0 < H < 0.5$, we look at an anti-persistent Fractional Brownian Motion (FBM) and when $0.5 < H < 1$, we look at a persistent FBM. Notice that The "bumps" in the scalegrams of the rates of return reveal some institutional aperiodic cyclicities. The sharp spikes in the daily rates of return with the corresponding (red) vortices in the Panel B scalogram indicate major singular news events in the stock market, mostly caused by early government interventions. Notice in Panel D that the rates of return remain within the 10% price change limits, although they show considerable volatility.

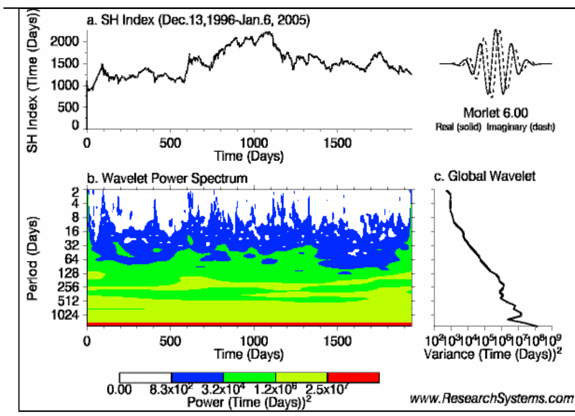
A: Price levels, Dec. 19, 1990 - Dec. 12, 1996



B: Rates of return, Dec. 19, 1990 - Dec. 12, 1996



C: Price levels, Dec. 13, 1996 - Jan. 6, 2005



D: Rates of return, Dec. 13, 1996 - Jan. 6, 2005

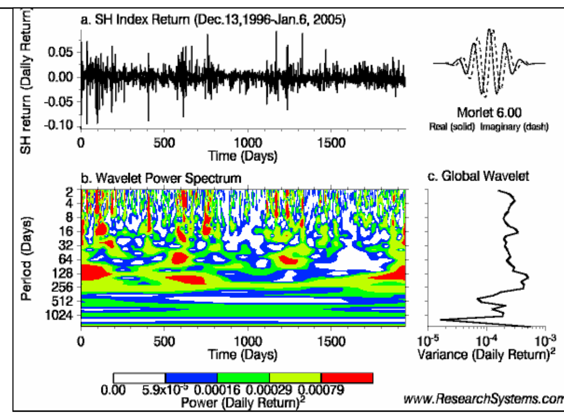
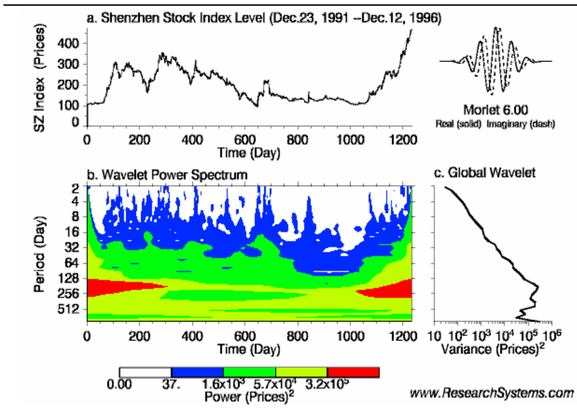


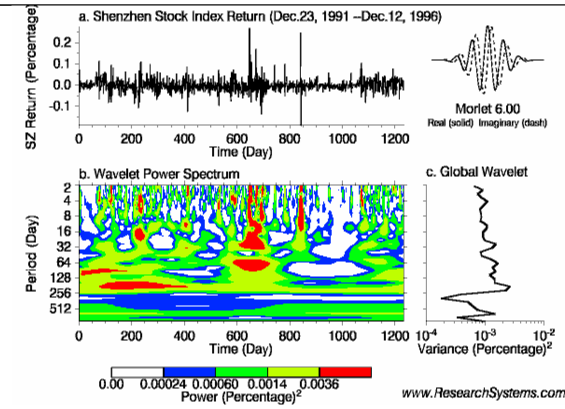
Fig. 5: Wavelet Scalograms and Scalegrams of the Shenzhen Stock Index

This is a portfolio of figures containing each four panels consisting of time series, scalograms and scalegrams based on wavelet multiresolution analysis (MRA). Panel A analyzes the Shenzhen price index levels in the period of December 23, 1991 - December 12, 1996, Panel B analyzes the corresponding rate of return series. Panel C analyzes the price levels, in the subsequent period of December 13, 1996 - January 6, 2005. Panel D analyzes the corresponding rate of return series. The wavelet analysis is similar to that in Fig. 4. Again, the sharp spikes in the daily rates of return with the corresponding (red) vortices in the Panel B scalogram indicate major singular news events in the stock market, mostly caused by early government interventions. Notice in Panel D that the rates of return remain within the 10% price change limits, although they show considerable volatility.

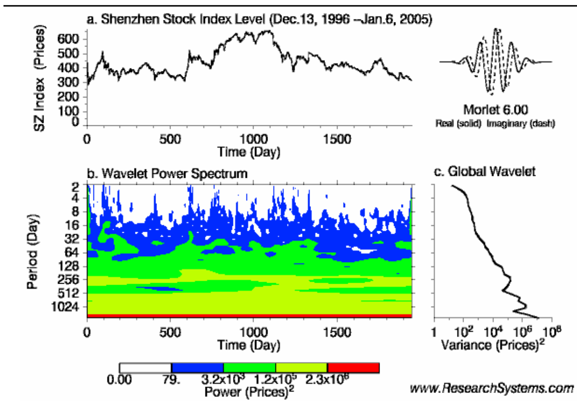
A: Price levels, Dec. 23, 1991 - Dec. 12, 1996



B: Rates of return, Dec. 23, 1991 - Dec. 12, 1996



C: Price levels, Dec. 13, 1996 - Jan. 6, 2005



D: Rates of return, Dec. 13, 1996 - Jan. 6, 2005

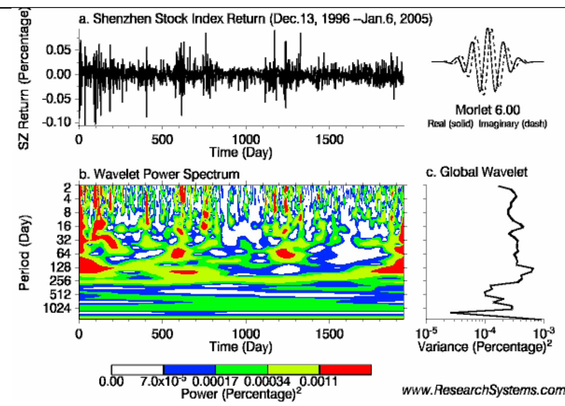
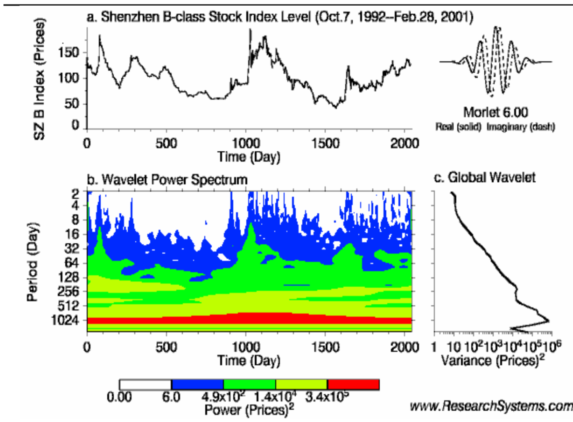


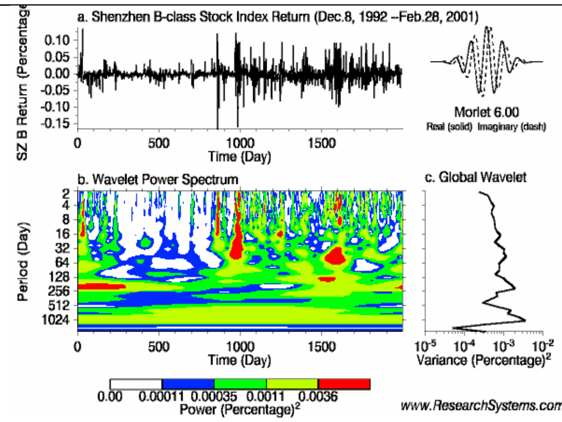
Fig. 6: Wavelet Scalograms and Scalegrams of the Shenzhen B Share Index

This is a portfolio of figures containing each four panels consisting of time series, scalograms and scalegrams based on wavelet multiresolution analysis (MRA). Panel A analyzes the Shenzhen B-share price index levels in the period of October 7, 1992 - February 28, 2001, Panel B analyzes the corresponding rate of return series. Panel C analyzes the price levels, in the subsequent period of March 1, 2001 - March 31, 2005. Panel D analyzes the corresponding rate of return series. The wavelet analysis is similar to that in Fig. 4. Again, the sharp spikes in the daily rates of return with the corresponding (red) vortices in the Panel B scalogram indicate major singular news events in the stock market, mostly caused by early government interventions. Notice in Panel D that, with the exception of one sharply negative event, the rates of return remain within the 10% price change limits, although they show considerable volatility in the early part. The volatility in the last three years has been very limited.

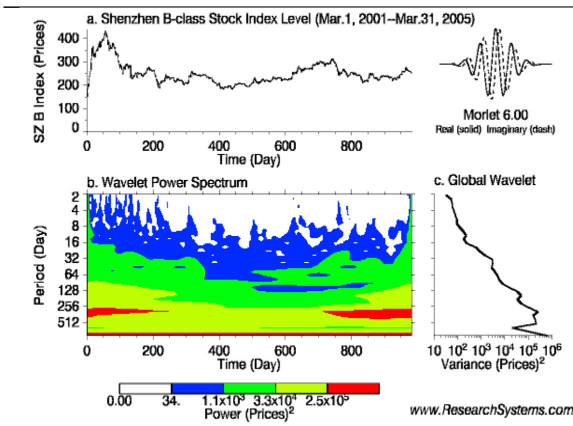
A: Price levels, Oct. 7, 1992 - Feb 28, 2001



B: Rates of return, Oct. 7, 1992 - Feb 28, 2001



C: Price levels, Mar. 1, 2001 - Mar. 31, 2005



D: Rates of return, Mar. 1, 2001 - Mar. 31, 2005