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Abstract

This paper uses linear and nonlinear Granger causality tests to study the lead-lag relations among China's segmented stock markets. In contrast to the weak lead-lag relation among A- and B-share markets disclosed by its linear counterpart, a nonlinear causality test provides evidence of strong bi-directional causal relations between two A-share markets as well as between two B-share markets. In addition, the evidence shows that since the implementation of a new policy allowing domestic citizens to invest in B-share markets, A-share markets tend to lead their B-share counterparts in the same stock exchange and B-share markets continue to lead the H-share market.

JEL Classification: F36; G15

Keywords: Stock market segmentation; Lead-lag relation; Granger causality; Nonlinearity

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1. Introduction

China's stock markets, initiated in the early 1990s, have been expanding tremendously in the past decade. Despite their short history and the coexistence of political and regulatory burdens, both the Shanghai and Shenzhen exchanges in China have been attracting a huge influx of domestic and foreign investments, amounting to 1378 listed companies and 72 million registered investors in 2005. As a mechanism for developing its stock markets, the Chinese government has adopted a market segmentation policy. First, each company's stock is restricted to only one of the official exchanges. Companies listed on the Shanghai Stock Exchange (SHSE) are likely to be big state-owned companies, many of which monopolize supplies to the domestic market. Those listed on the Shenzhen Stock Exchange (SZSE) tend to be smaller export-oriented companies, many of which are joint ventures (Kim and Shin, 2000). Although cross-listing is not permitted, these two exchanges are subject to the same macroeconomic and policy factors. Depending on the nature of the companies listed on each exchange, the sensitivity of stock price movements to the common market factors might be different between the two stock exchanges (Kim and Shin, 2000).

Second, to cater to the needs of different investors, Chinese companies can issue A shares to Chinese citizens living in mainland China and B shares and H shares to foreign investors and residents of Hong Kong, Macau, or Taiwan.[1] Although investors trading A shares outnumber those trading B shares, the former group is

[1]Some companies are allowed to issue N and S shares, which are traded on the New York Stock Exchange, and Singapore Stock Exchange, respectively.

composed mostly of individual investors without much experience or many resources to obtain and analyze new information, while the latter group is dominated by experienced foreign institutional investors (Tian and Wan, 2004). A and B shares are listed on the SHSE and the SZSE, namely, SHA, SHB, SZA, and SZB in mainland China. A shares are denominated in the local currency (the yuan, also called RMB), while B shares are denominated in U.S. dollars on the SHSE and Hong Kong dollars on the SZSE. H shares are listed on the Hong Kong Stock Exchange (HKSE) and are denominated in Hong Kong dollars.

In the finance literature, foreign investors are sometimes assumed to be less informed than domestic investors about the value of local assets (see, for example, Stulz and Wasserfallen, 1995; Brennan and Cao, 1997). These authors think that this could be due to various factors such as language barriers, different accounting standards in the receiving and investing economies, and a lack of reliable information about the local economy and firms. However, there is also evidence that foreign investors are better informed. For example, Froot et al. (2001) document that foreign investors' portfolio inflows have a noticeable ability to predict positive future returns in emerging markets but not in developed markets. Pan et al. (2001) also find that foreign investors are better informed than domestic investors in six East Asian emerging markets. Unfortunately, their analysis ignores the possible nonlinearity in the market variables. Thus, a detailed investigation of the nonlinear dependence between A and B shares could lead to a better understanding of the behaviors of domestic and foreign investors.

Furthermore, information transmission between the same types of shares on two exchanges also deserves analysis. Research in financial economics suggests that market-wide information may affect the prices of large-capitalization stocks more quickly than small-capitalization stocks; thus information is transmitted from the stocks of large firm to the stocks of small firms.[2] However, there is also evidence of bi-directional information transmission between large and small firms (Weigand, 1996). Studies of the lead-lag relations between the two A-share markets and between the two B-share markets within a nonlinear framework may provide more empirical results related to this issue.

Additionally, unlike A shares and B shares, which are traded on the same stock exchanges within mainland China, A shares and H shares are segmented in terms of stock ownership as well as the listing and trading locations (Li, et al., 2006). Since the RMB is not yet convertible to foreign currencies and the HKSE provides a more mature and established stock market, Kim and Shin (2000) claim that many overseas investors prefer trading H shares in Hong Kong rather than B shares in mainland Chinese markets. However, recently, investors have come to expect that the RMB will greatly appreciate in the long run. This appreciation, coupled with one of the strongest bull markets in China since 2005, will dramatically increase interest in purchasing A and B shares from both domestic and overseas investors, since investors will enjoy both stock appreciation and currency appreciation. Therefore, understanding the information transmission mechanism between the H-share market and the A- or B-

[2]See, for example, Lo and MacKinlay (1990), Mech (1993), and Chordia and Swaminathan (2000).

share market could provide useful information about relations across these differently segmented stock markets.

Given the unique feature of market segmentation in Chinese stock markets, the lead-lag relations among these segmented markets have been widely studied. Chakravarty et al. (1998) study the bivariate return correlations between the A- and B-share indices and find some evidence of two-way information flows between the A-share and B-share markets. Chui and Kwok (1998) examine the cross-autocorrelations between A and B shares to determine the information transmission mechanism between these two different types of shares. Recently, Yang (2003) finds that foreign investors in the Shanghai B-share market are better informed than Chinese domestic investors in two A-share markets and foreign investors in the Shenzhen market over time. Several studies have also applied Granger causality tests to determine the lead-lag relationships between the A-share and B-share markets, which, in turn, could also offer evidence on which investors are more efficient in obtaining and processing relevant information and trading on it. Laurence et al. (1997) observe a causal relationship from the SHB to all other Chinese markets and from the SHA and SZB to the SHB. Kim and Shin (2000) find that the A-share markets lead the B-share markets before 1996, but the relationship either disappears or reverses after 1996. In addition, they find that B-share markets tend to lead H-share market since 1996. Sjoo and Zhang (2000) find that information flows from foreign to domestic investors in the SHSE, but the direction is reversed in the smaller and less liquid SZSE. Tian and Wan (2004) find that the SHB and SZB exhibit causality relations with each other during the period 1993 to 1999. However, this relationship does not exist between the SHA and SZA. Their results also support the existence of a causal relationship from the H-share market to the two B-share markets and from the SHB to all other Chinese markets in the post-1996 period.

On February 19, 2001, the Chinese government adopted a new policy that removed the restriction on trading B shares by domestic citizens. Since that date, domestic investors have been allowed to exchange foreign currencies for the purpose of B-share investment, which has greatly stimulated the trading of B-shares and accelerated the market integration process of A-share markets with B-share markets and the international stock markets. Thus, it is of interest to explore the change in lead-lag relations among segmented stock markets caused by the policy change.

In this paper, we aim to explore the lead-lag relationships among Chinese segmented stock markets before and after the relaxation of government restrictions on the purchase of B shares by domestic investors. Our work extends the existing literature in the following two ways. First, in addition to a standard linear Granger causality test, which has been applied extensively in analyzing the linear lead-lag relations between stock markets, we apply a nonlinear Granger causality test developed by Hiemstra and Jones (1994) (hereafter referred as the HJ test) to investigate the existence of any nonlinear lead-lag relationship among Chinese segmented stock markets. Since many studies have reported that financial time series exhibit nonlinear dependence, a nonlinear Granger causality test is more suitable than a traditional linear Granger causality test, which generally has a low power against nonlinear relationships (Baek and Brock, 1992). Some research has used the HJ test to explore the nonlinear causal relation, for instance, between trading volume and stock/futures returns (Hiemstra and Jones, 1994; Ciner, 2002), between volume and volatility in the stock market (Brooks, 1998), between exchange rates (Ma and Kanas, 2000), among real estate prices and stock markets (Okunev et al., 2000), and so forth To our knowledge, no research has applied this test to explore the causal relation between stock markets. Thus, our work aims to fill a gap in this literature by applying this test to study the information transmission among China's segmented stock markets. More important, our approach of focusing on the nonlinear nature of segmented market variables could shed more light on understanding the information asymmetry between foreign investors and domestic investors as well as the information transmission of stocks of different sizes.

Second, to study the impact of government policy on stock markets, we use more recent data to comparatively analyze the Granger causality relations among China's segmented stock markets before and after the Chinese government relaxed the restriction on the purchase of B shares by domestic investors. The findings on this issue will also be useful for investors and government policy makers.

Our results reveal that the causality relation among China's stock indices is more complicated than what the linear causality test reveals. More specifically, our results show nonlinear dependence among the five stock markets. In sharp contrast to the linear causality test, which reveals the causal relation only between Shanghai A shares and Shenzhen A shares in the period before the change in the government policy, the nonlinear Granger causality test provides evidence of a bi-directional causal relationship between the two A-share markets as well as between the two B-share markets. This finding challenges the widespread assumption in the literature that information is transmitted from big stocks to small stocks but, rather, suggests a bi-directional information transmission. Furthermore, the evidence shows that since the implementation of the new policy allowing domestic citizens to invest in B-share markets, A-share markets tend to lead their B-share counterparts in the same stock exchange and B-share markets play a significant role in influencing the H-share market.

The remainder of this paper proceeds as follows. Section 2 discusses the data and methodology. Section 3 provides empirical results, and Section 4 summarizes our conclusions.

2. Data and methodology

2.1. Data

The data used in this study are daily price indices of Shanghai A shares (SHA), Shenzhen A shares (SZA), Shanghai B shares (SHB), Shenzhen B shares (SZB), and Hong Kong H shares (H).[3] All data are taken from *DataStream International.* Our sample covers January 1996 through December 2005. To study the possible change in the lead-lag relation among segmented stock markets due to policy change, the

[3]SHA (SHB), SZA (SZB) and H indices are constructed by the SHSE, SZSE, and Hang Seng Index Service Ltd., respectively. Their index samples include all corresponding A shares, B shares, and H shares listed on the SHSE, SZSE, and HKSE. The indices are market value-weighted indices. SHA starts from February 21, 1992. SHB starts from August 17, 1992. SZA starts from October 4, 1992, SZB starts from October 6, 1992. And H starts from August 8, 1994.

sample is divided into two sub-samples that have roughly the same number of observations. The first sub-sample covers the period January 1, 1996−February 16, 2001 and the second covers the period February 19, 2001−December 30, 2005. Here, we use a major policy change announced on February 19, 2001 as the cut-off point.[4] All of these indices are based on closing prices in U.S. dollars, and stock index returns are continuously compounded.

2.2. Methodology

This section presents the methodologies used to investigate the causal relations among segmented stock markets by first discussing the linear Granger causality test and thereafter the nonlinear Granger causality test in detail.

2.2.1. Cointegration and linear Granger causality

In order to test for linear causal linkages between segmented stock markets, we proceed in the following way. First, we apply the well-known Johansen procedure (Johansen and Juselius, 1990) to test for possible cointegration between any two series. Second, we test for Granger causality depending on whether a pair of series is cointegrated. If any pair of series is not cointegrated, we will adopt the following bivariate VAR model to test for Granger causality:

$$\Delta y_{1t} = c_1 + \sum_{i=1}^{m} \phi_{11}^{i} \Delta y_{1,\,t-i} + \sum_{i=1}^{m} \phi_{12}^{i} \Delta y_{2,\,t-i} + \varepsilon_{1t} \tag{1}$$

[4]Since February 17 and 18, 2001 were a weekend, the stock markets were closed. We choose February 19, 2001 as the cut-off point because as of that date, the Chinese government adopted a new policy that removed the restrictions on trading B shares by domestic citizens.

$$\Delta y_{2t} = c_2 + \sum_{i=1}^{m} \phi_{21}^{i} \Delta y_{1,\,t-i} + \sum_{i=1}^{m} \phi_{22}^{i} \Delta y_{2,\,t-i} + \varepsilon_{2t} \qquad (2)$$

where Δy_{1t} and Δy_{2t} denote the return series for any two stock markets being examined, $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t})'$ is the vector of the corresponding error terms, and m is the optimal lag length obtained by using AIC criterion.

If two series are cointegrated, we follow Engle and Granger (1987) to impose the error-correction mechanism (ECM) on the VAR to test for Granger causality between these variables. The ECM-VAR framework is as follows:

$$\Delta y_{1t} = c_1 + \alpha_1 ect_{t-1} + \sum_{i=1}^{m} \phi_{11}^{i} \Delta y_{1,\,t-i} + \sum_{i=1}^{m} \phi_{12}^{i} \Delta y_{2,\,t-i} + \varepsilon_{1t} \qquad (3)$$

$$\Delta y_{2t} = c_2 + \alpha_2 ect_{t-1} + \sum_{i=1}^{m} \phi_{21}^{i} \Delta y_{1t-i} + \sum_{i=1}^{m} \phi_{22}^{i} \Delta y_{2,\,t-i} + \varepsilon_{2t}\,. \qquad (4)$$

Here, the term ect_{t-1} is the error correction term. Thereafter, the Granger causality test examines the null hypothesis that $\phi_{12}^{i} = 0$ or $\phi_{21}^{i} = 0$, for all *i* (*i*=1,2, . . . , *m*), in the usual manner.

2.2.2. Nonlinear Granger causality

The linear Granger causality test is known to possess a low power in detecting nonlinear causal relationships. To circumvent this problem, we use a nonlinear Granger causality test on the residuals from the linear VAR (ECM-VAR) model as discussed above. This approach enables us to detect the existence of any strictly nonlinear causality relation among the variables being studied, since the VAR (ECM-VAR) has already purged the residuals of linear causality.

The nonlinear Granger causality test developed by Baek and Brock (1992) has been further modified by Hiemstra and Jones (HJ, 1994). This modified approach enables us to examine whether, by removing all of the linear model's predictive power, any remaining incremental predictive power of one residual series for another can be considered nonlinear predictive power.

Consider two strictly stationary and weakly dependent time series $\{X_t\}$ and $\{Y_t\}$, t=1,2,.... Let X_t^m be the m-length lead vector of X_t, and let $X_{t-L_X}^{Lx}$ and $Y_{t-L_y}^{L_y}$ be the L_x-length and L_y-length lag vectors of X_t and Y_t respectively. For given values of m, L_x, and L_y and for any e, $\{Y_t\}$ does not strictly Granger cause $\{X_t\}$ if

$$\begin{aligned} &\Pr\left(\left\|X_t^m - X_s^m\right\| < e \,\middle|\, \left\|X_{t-Lx}^{Lx} - X_{s-Lx}^{Lx}\right\| < e,\ \left\|Y_{t-Ly}^{Ly} - Y_{s-Ly}^{Ly}\right\| < e\right) \\ &= \Pr\left(\left\|X_t^m - X_s^m\right\| < e \,\middle|\, \left\|X_{t-Lx}^{Lx} - X_{s-Lx}^{Lx}\right\| < e\right) \end{aligned} \tag{5}$$

where $\Pr(\cdot|\cdot)$ denotes the conditional probability and $\|\cdot\|$ denotes the maximum norm. For given values of m, L_x and $L_y \geq 1$, and $e > 0$, under the assumption that $\{X_t\}$ and $\{Y_t\}$ are strictly stationary and weakly dependent, if $\{Y_t\}$ does not strictly Granger cause $\{X_t\}$, then

$$\sqrt{n}\left(\frac{C_1(m+L_x, L_y, e, n)}{C_2(L_x, L_y, e, n)} - \frac{C_3(m+L_x, e, n)}{C_4(L_x, e, n)}\right) \xrightarrow{a} N\left(0, \sigma^2(m, L_x, L_y, e)\right) \tag{6}$$

where C_1, C_2, C_3 and C_4 are the correlation-integral estimators of the joint probabilities, n=T+1-m-max(L_x , L_y) and $\sigma^2(m, L_x, L_y, e)$ can be estimated by following the approach described by Hiemstra and Jones (1994). A significant positive value of the test statistic implies that lagged values of $\{Y_t\}$ help to predict $\{X_t\}$, whereas a significant negative value suggests that lagged values of $\{Y_t\}$ confuse the prediction of $\{X_t\}$. This test has very good power properties against a variety of nonlinear Granger causal and noncausal relations, and its asymptotic distribution is the same if the test is applied to the estimated residuals from the VAR models. To implement the HJ test, we have to select values for the lead length, *m*, the lag lengths, L_x and L_y, and the scale parameter, *e*. Following Hiemstra and Jones (1994), we set lead length $m=1$ and $L_x = L_y$ for all cases. Also, common lag lengths of 1–10 lags and a common scale parameter of $e = 1.5\sigma$ are used, where $\sigma = 1$ denotes the standard deviation of standardized series.[5]

3. Empirical results

We summarize the basic statistics of daily returns of price indices for each sub-period in Table 1. Upon confirming that all indices possess unit roots of the same order, we apply the Johansen procedure to look for evidence of cointegration for pairs of indices. We first report our findings among A-share and B-share stock markets and thereafter discuss their relations with the H-share stock market.

3.1. Granger causality among A-share and B-share stock markets

We find evidence of one cointegration relation in SHB-SZB for the first sub-period and another cointegration relation in SHA-SHB for the second sub-period with *p*-values smaller than conventional levels.[6] Thus, for these two pairs, we further

[5]Diks and Panchenko (2006) report that the HJ test may have an over-rejection bias as sample size increases. Their simulation results show that, under certain assumptions, when sample size is very big (say, for example, 100,000), the rejection probability may tend to be one. We would like to show our appreciation to the referee for pointing out the limitation of the HJ methodology.

[6]The unit root test results and Johansen cointegration test results are not reported here but are available upon request.

use the linear Granger causality test to examine their relationships in the ECM-VAR framework as shown in Equations (3)-(4). For other pairs of markets, we adopt the usual VAR displayed in Equations (1)-(2) to test Granger causality.[7]

We conduct the conventional Granger causality test among A-share and B-share stock markets and report the results in Table 2. The results indicate that before the Chinese government relaxed the restrictions on the purchase of B shares by domestic investors, SHA and SZA exhibit strong causality relations with each other. For B-share stock markets, we find a strong causal relation from SZB to SHB, while the causal relation running from SHB to SZB is very weak (significant only at the 8% level). This result suggests that there is bi-directional information transmission between the big stocks and small stocks for A shares, which is consistent with the Weigand's (1996) finding. However, for B shares, we find that small stocks lead big stocks. For the interaction between A-share and B-share markets, we find evidence that SZB weakly leads SZA, implying that experienced foreign institutional investors may have some information advantage over individual domestic investors on the SZSE.

In contrast, for the sub-sample period 2, after the Chinese government adopted a more liberal policy allowing domestic investors to invest in B-share markets, a linear Granger causality test shows that a causality relation exists only from SZA to SZB and that there is no lead-lag relation between other pairs of markets. This suggests that after February 19, 2001, information transmission among these four markets

[7]The complete estimation results for the VAR and ECM-VAR are not reported here but are available upon request.

becomes much weaker.

Before testing for nonlinear Granger causality in the residuals from the linear VAR (ECM-VAR), we conduct two sets of diagnostic tests on the residuals from the VAR models. The Ljung–Box Q-test is used to determine whether any linear dependency remains in the residuals, and the Q^2-test is used to test for nonlinear dependency. The null hypothesis of the Q-test is no serial correlation in residuals and the null hypothesis of the Q^2-test is no serial correlation in squared residuals. The results of these diagnostic tests, as reported in Table 2, point out that the VAR (ECM-VAR) models successfully account for linear dependency, as indicated by the insignificant values of the Q-test. However, the persistence of nonlinear dependency remains in the residuals, as suggested by the Q^2-test.[8]

Considering the low power of conventional linear Granger causality against nonlinear relationships, we apply the HJ nonlinear Granger causality test to the residuals from the above linear VAR (ECM-VAR) model. The results are reported in Table 3. Different from its linear counterpart, for the first sub-sample, the nonlinear Granger causality test reported in the upper portion of Panel A of Table 3 indicates that there is a strong bi-directional information transmission not only between the two A-share markets (SHA and SZA) but also between the two B-share markets (SHB and SZB), since the test statistics are all significant at the 5% or 1% level for all lags. In

[8]McLeod and Li (1983) argue that the Q^2-test can be used to identify nonlinear dependency in time series. Gao and Wang (1999) report Monte Carlo evidence on the finite sample behavior of this test statistic, indicating that the Q^2-test is particularly useful for detecting dependency in the conditional variance. See Ciner (2002) for more information.

the second sub-sample, instead of there being no information transmission between the two A- (B-) share markets, as disclosed by the linear Granger causality test, the nonlinear causality test provides evidence of a strong bi-directional causal relation between the two A-share markets as well as between the two B-share markets. The upper portion of panel B shows that, for the relation from SHA to SZA, the test statistic is positive and significant at the 5% level when 8 or more lags are included. For the rest of the relations, the test statistic becomes significant with lower lags. Overall, our findings contradict the widely reported findings in the literature that information transmission is from big stocks to small stocks. We find bi-directional information transmission between large and small stocks.

Moreover, results of the nonlinear causality test in the lower portion of Panel B show that SHA leads SHB and SZA leads SZB when 8 or more lags are included, implying that since February 19, 2001, A-share markets tend to lead their B-share counterparts in the same stock exchange. A possible explanation for this phenomenon is that as the number of domestic investors participating in the trading of B-share stocks increases, previous possible factors that caused the B-share stock markets to lead the A-share stock markets, such as foreign investors in B-share markets having more advanced technology for processing and analyzing information than domestic investors, become comparatively less important than before. Since the A-share markets have much larger market capitalization and participation, faster growth rates, and higher liquidity, it is logical that they would attract more attention from investors, and thus, information is more likely to flow from A-share to B-share stock markets, resulting in A-share markets leading B-share markets. In Fig. 1, we summarize these results.

3.2. Granger causality between H-share and A- (B-) share stock markets

As mentioned in Section 1, because the H-share market has special features due to segmentation, it is also of interest to explore the lead-lag relation between the H-share market and the A-share or B-share markets. We present the linear causality test results in Table 4, which reveal only a very weak causal relation running from the H-share market to SHB in the first sub-sample period. In contrast, the nonlinear causality test results displayed in Table 5 disclose bi-directional causal relations do exist between the H-share and the two B-share markets in the first sub-sample period, suggesting an active information transmission among these markets. This is reasonable because H shares listed in Hong Kong and B shares listed in mainland China are both denominated in foreign currencies and traded by similar groups of investors, even though they are subject to different regulatory policies. Therefore, it is natural that we observe information exchange among these markets. We note the test statistics for the lead-lag relations between SHB and H are significant in either direction for all lags at the 1% level. But the relation from SZB to H is significant only at the 5% level with 9 lags, while the relation from H to SZB is significant up to 5 lags. This suggests that the relation between Shanghai B shares and Hong Kong H shares tends to be more pronounced and persistent than the relation between Shenzhen B shares and H shares.

Finally, for the second sub-sample period, while the linear test fails to detect any causal relations running from the two B-share markets to the H-share market, nonlinear tests reveal that the two B-share markets still play a significant role in influencing the H-share market.[9] For instance, the test statistics for the causal relations running from SHB to H and from SZB to H are significant at the 1% or 5% level when 7 or more lags are included in the tests. However, the causal relations running from the H-share market to either B-share market are not significant for any lag. Overall, our nonlinear test results suggest that after the policy change on the B shares, A-share markets tend to lead B-share markets, which, in turn, tend to lead the H-share market. Since mainland China's stock markets close one hour earlier than the stock market in Hong Kong, the persistence of the lead-lag relation from the mainland to Hong Kong even after the government policy change is consistent with the difference in the markets' trading hours.

4. Conclusions

The unique features of segmented Chinese stock markets have attracted a great deal of attention from researchers and led them to investigate the lead-lag relations among these markets. However, the methodology used by most researchers is based on traditional linear models such as linear Granger causality test, which, it is well known, possesses a low power in detecting nonlinear causal relationships. To circumvent this problem, this paper contributes to the literature by using a nonlinear

[9]Following Eun and Sabherwal (2003) and Kutan and Zhou (2006), we did a robust test by using indices constructed only with stocks that are cross-listed in different segments (i.e., A-share and B-share markets, and A-share and H-share markets). The results are qualitatively similar.

Granger causality test. Our empirical results show that the causality relation among China's stock markets is more complicated than what the linear causality test reveals. More specifically, we find strong nonlinear dependence among the five segmented markets in China. In sharp contrast sharply to the results of the linear Granger causality test, the nonlinear causality test provides evidence of strong bi-directional causal relations between the two A-share markets as well as between the two B-share markets before and after the Chinese government adopted a more liberal policy that allowed domestic investors to invest in B-share markets. In addition, the evidence shows that since the implementation of this new policy, A-share markets tend to lead their B-share counterparts in the same stock exchange and B-share markets still play a significant role in influencing the H-share market.

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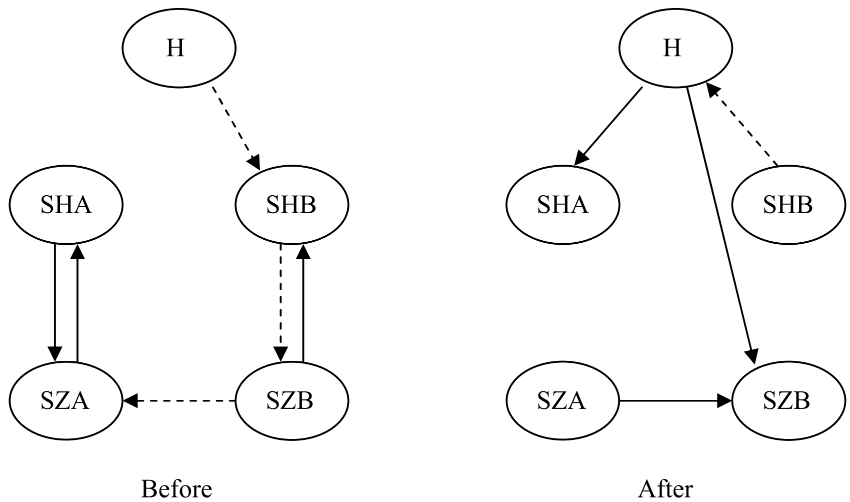
Panel A. Granger causal relations based on linear Granger causality test



Panel B. Granger causal relations based on nonlinear Granger causality test

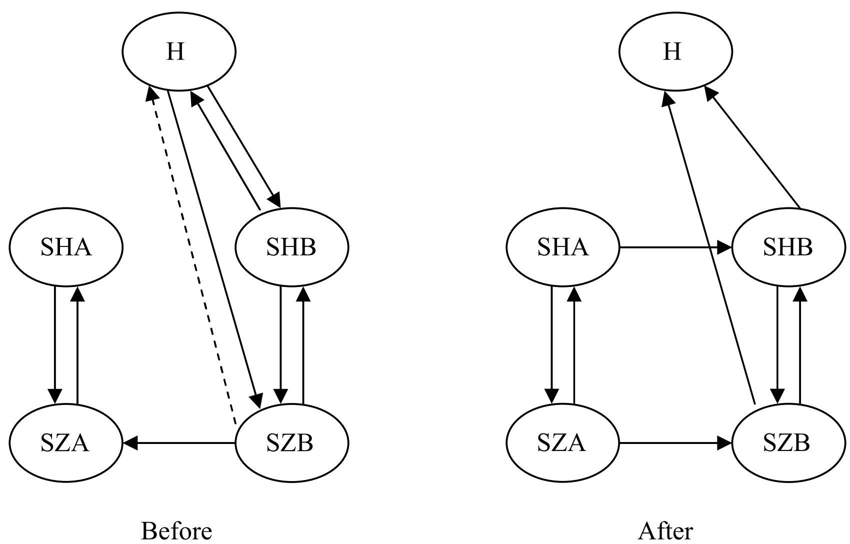


Fig. 1. Summary of Granger causalities among four Chinese stock indices. This figure demonstrates the Granger causal relations among our Chinese stock indices based on linear and nonlinear Granger causality tests before and after the Chinese government relaxed the restriction on the purchase of B shares by domestic investors. The solid line indicates that the Granger causal relation is significant at 5% or above, while the dashed line indicates that the Granger causal relation is significant at 10%. SHA is the Shanghai A-share index. SZA is the Shenzhen A-share index. SHB is the Shanghai B-share index. SZB is the Shenzhen B-share index. H is the Hong Kong H-share index.

Table 1

Descriptive statistics for daily returns of Chinese stock markets

Index	SHA	SHB	SZA	SZB	H
Panel A. 1 January 1996−16 February 2001					
Mean	0.102	0.040	0.135	0.060	-0.070
Median	0.106	-0.095	0.160	0.000	-0.077
Maximum	9.481	12.184	11.066	12.442	15.793
Minimum	-10.442	-13.085	-10.529	-16.700	-17.629
Std. Dev.	1.966	2.580	2.183	2.729	3.048
Skewness	-0.400	0.335	-0.532	0.124	0.207
Kurtosis	8.188	6.561	7.356	8.362	6.835
Panel B. 19 February 2001−30 December 2005					
Mean	-0.042	-0.022	-0.063	0.038	0.074
Median	-0.045	-0.097	-0.019	-0.010	0.040
Maximum	9.402	9.453	9.242	9.395	7.313
Minimum	-6.508	-10.292	-6.746	-9.585	-8.032
Std. Dev.	1.354	2.013	1.433	2.143	1.676
Skewness	0.865	0.395	0.593	0.366	-0.112
Kurtosis	9.024	8.617	7.865	7.489	5.807

The total number of observations is 2408. SHA is the Shanghai A-share index. SZA is the Shenzhen A-share index. SHB is the Shanghai B-share index. SZB is the Shenzhen B-share index. H is the Hong Kong H-share index.

Table 2

Testing for linear Granger causality among A-share and B-share markets

Markets	Wald statistics	LB(6)	LBS(6)
Panel A. 1 January 1996−16 February 2001			
SHA→SHB	1.081(0.356)	3.114(0.794)	250.08(0.000)***
SHB→SHA	0.654(0.562)	1.061(0.983)	388.38(0.000) ***
SZA→SZB	1.362(0.227)	0.536(0.997)	369.70(0.000) ***
SZB→SZA	2.040(0.058)*	0.111(1.000)	319.86(0.000) ***
SHA→SZA	2.961(0.000) ***	0.238(1.000)	138.76(0.000) ***
SZA→SHA	2.419(0.002) ***	0.101(1.000)	280.46(0.000) ***
SHB→SZB	9.801(0.081)*	0.072(1.000)	345.14(0.000) ***
SZB→SHB	14.560(0.012)**	0.422(0.999)	299.47(0.000) ***
Panel B. 19 February 2001−30 December 2005			
SHA→SHB	1.658(0.437)	2.801(0.833)	31.384(0.000) ***
SHB→SHA	3.122(0.210)	4.853(0.563)	155.39(0.000) ***
SZA→SZB	5.340(0.000) ***	0.679(0.995)	63.072(0.000) ***
SZB→SZA	0.569(0.685)	4.495(0.610)	183.19(0.000) ***
SHA→SZA	0.089(0.765)	3.962(0.682)	32.918(0.000) ***
SZA→SHA	0.412(0.521)	3.350(0.764)	66.984(0.000) ***
SHB→SZB	1.364(0.208)	1.716(0.944)	115.37(0.000) ***
SZB→SHB	1.615(0.116)	2.797(0.834)	167.59(0.000) ***

LB(6) is the Ljung-Box statistic based on the level of the residual series of dependent variables in the VAR (or ECM-VAR) model, up to the 6^{th} lag. LBS(6) is the statistic based on the squared residual. In parentheses are *p*-values. The results of the Ljung-Box, however, are robust to other lag-length specifications.

* Significant at the 10% level.

** Significant at the 5% level.

***Significant at the 1% level.

Table 3

Testing for nonlinear Granger causality among A-share and B-share markets

Panel A. 1 January 1996−16 February 2001				
Lags	SHA→SZA	SZA→SHA	SHB→SZB	SZB→SHB
1	3.606 (0.000) ***	4.037 (0.000) ***	3.320 (0.000) ***	3.397 (0.000) ***
3	4.402 (0.000) ***	4.661 (0.000) ***	4.879 (0.000) ***	3.568 (0.000) ***
5	3.811 (0.000) ***	4.956 (0.000) ***	4.412 (0.000) ***	3.304 (0.000) ***
7	4.020 (0.000) ***	4.328 (0.000) ***	3.230 (0.001) ***	2.778 (0.003) ***
8	3.756 (0.000) ***	4.091 (0.000) ***	3.308 (0.000) ***	2.201 (0.014) **
9	4.007 (0.000) ***	3.439 (0.000) ***	2.922 (0.002) ***	1.935 (0.027)**
10	4.241 (0.000) ***	3.230 (0.000) ***	2.799 (0.003) ***	2.144 (0.016)**
	SHA→SHB	SHB→SHA	SZA→SZB	SZB→SZA
1	0.447 (0.327)	0.631 (0.264)	1.372 (0.085)*	2.385 (0.009)***
3	-1.022 (0.153)	-0.626 (0.266)	-0.423 (0.336)	1.837 (0.033)**
5	-1.416 (0.078)	-2.158 (0.015)	-1.182 (0.119)	0.869 (0.192)
7	-1.804 (0.036)	-3.474 (0.000)	-0.664 (0.253)	0.553 (0.290)
8	-1.979 (0.024)	-3.237 (0.001)	-0.251 (0.401)	0.340 (0.367)
9	-2.033 (0.021)	-2.920 (0.002)	-0.068 (0.473)	-0.120 (0.452)
10	-1.880 (0.030)	-2.687 (0.004)	0.092 (0.463)	0.038 (0.485)
Panel B. 19 February 2001−30 December 2005				
Lags	SHA→SZA	SZA→SHA	SHB→SZB	SZB→SHB
1	0.395 (0.347)	0.842 (0.200)	2.946 (0.002) ***	0.881 (0.189)
3	1.100 (0.136)	4.071 (0.000) ***	2.660 (0.004) ***	2.575 (0.005) ***
5	1.428 (0.077)*	4.397 (0.000) ***	1.606 (0.054)*	1.676 (0.047)**
7	1.244 (0.107)	4.329 (0.000) ***	2.473 (0.007) ***	2.296 (0.011)**
8	1.837 (0.033)**	4.073 (0.000) ***	2.611 (0.005) ***	2.048 (0.020)**
9	2.166 (0.015)**	4.657 (0.000) ***	2.837 (0.002) ***	1.892 (0.029)**
10	1.658 (0.049)**	4.846 (0.000) ***	2.769 (0.003) ***	1.868 (0.031)**
	SHA→SHB	SHB→SHA	SZA→SZB	SZB→SZA
1	0.108 (0.457)	0.711 (0.239)	0.519 (0.302)	-0.900 (0.184)
3	0.915 (0.180)	-0.108 (0.457)	-0.257 (0.398)	-1.059 (0.145)
5	0.649 (0.258)	-0.302 (0.381)	-0.012 (0.495)	-1.385 (0.083)
7	1.299 (0.097)*	-0.391 (0.348)	1.156 (0.124)	-1.393 (0.082)
8	1.922 (0.027)**	-0.279 (0.390)	1.694 (0.045)**	-1.438 (0.075)
9	1.756 (0.040)**	-0.033 (0.487)	1.984 (0.024)**	-0.771 (0.220)
10	1.999 (0.023)**	0.519 (0.302)	2.024 (0.022)**	-0.485 (0.314)

The table reports the standardized test statistics of Hiemstra and Jones (1994) with *p*-values in parenthesis. Under the null hypothesis of nonlinear Granger noncausality, the test statistic is asymptotically distributed $N(0,1)$. A significant positive test statistic implies nonlinear Granger causality under a one-tail test.

* Significant at the 10% level.

** Significant at the 5% level.

***Significant at the 1% level.

Table 4

Testing for linear Granger causality between H-share and A- and B- share markets

Markets	Wald statistics	LB(6)	LBS(6)
Panel A. 1 January 1996−16 February 2001			
SHA→H	0.001(0.969)	11.593(0.072)*	376.77(0.000)***
H→SHA	0.295(0.587)	10.071(0.122)	276.36(0.000)***
SZA→H	0.820(0.555)	0.125(1.000)	365.53(0.000)***
H→SZA	1.068(0.380)	0.176(1.000)	381.87(0.000)***
SHB→H	1.078(0.357)	10.750(0.096)*	387.68(0.000)***
H→SHB	2.292(0.077)*	1.288(0.972)	399.33(0.000)***
SZB→H	0.581(0.446)	11.953(0.063)*	379.40(0.000)***
H→SZB	1.748(0.186)	7.920(0.244)	392.97(0.000)***
Panel B. 19 February 2001−30 December 2005			
SHA→H	0.062(0.804)	2.907(0.820)	155.11(0.000)***
H→SHA	4.561(0.033)**	4.576(0.599)	35.854(0.000)***
SZA→H	0.284(0.594)	2.936(0.817)	154.46(0.000)***
H→SZA	1.658(0.198)	3.512(0.742)	68.00(0.000)***
SHB→H	2.546(0.079)*	0.856(0.990)	155.52(0.000)***
H→SHB	0.005(0.995)	6.031(0.420)	221.43(0.000)***
SZB→H	0.970(0.452)	0.200(1.000)	164.57(0.000)***
H→SZB	2.462(0.017)**	4.248(0.643)	206.79(0.000)***

LB(6) is the Ljung-Box statistic based on the level of the residual series of dependent variables in the VAR (or ECM-VAR) model, up to the 6^{th} lag. LBS(6) is the statistic based on the squared residual. In parentheses are *p*-values. The results of the Ljung-Box, however, are robust to other lag-length specifications.

* Significant at the 10% level.

** Significant at the 5% level.

***Significant at the 1% level.

Table 5

Testing for nonlinear Granger causality between H-share and A- and B- share markets

Lags	SHA→H	H→SHA	SZA→H	H→SZA
Panel A. 1 January 1996−16 February 2001				
1	0.215 (0.415)	-0.630 (0.264)	-0.218 (0.414)	-1.452 (0.073)
3	-1.035 (0.150)	-1.701 (0.045)	-1.389 (0.082)	-1.498 (0.067)
5	-1.831 (0.034)	-2.072 (0.019)	-2.211 (0.014)	-0.931 (0.176)
7	-2.515 (0.006)	-2.553 (0.005)	-2.993 (0.001)	-1.365 (0.086)
8	-2.989 (0.001)	-2.561 (0.005)	-3.422 (0.000)	-1.228 (0.110)
9	-3.144 (0.001)	-2.091 (0.018)	-3.247 (0.001)	-1.129 (0.129)
10	-3.285 (0.001)	-2.389 (0.008)	-3.080 (0.001)	-1.368 (0.086)
	SHB→H	H→SHB	SZB→H	H→SZB
1	2.440 (0.007)***	2.715 (0.003) ***	0.918 (0.179)	2.219 (0.013)**
3	2.515 (0.006)***	3.808 (0.000) ***	0.859 (0.195)	2.902 (0.002)***
5	2.804 (0.003)***	3.513 (0.000) ***	1.124 (0.130)	2.462 (0.007)***
7	3.305 (0.000)***	2.639 (0.004) ***	1.178 (0.119)	1.275 (0.101)
8	3.570 (0.000)***	2.909 (0.002) ***	1.429 (0.077)*	0.931 (0.176)
9	3.838 (0.000)***	2.430 (0.008) ***	1.659 (0.049)**	0.736 (0.231)
10	3.851 (0.000)***	2.436 (0.007) ***	1.609 (0.054)*	0.203 (0.419)
Panel B. 19 February 2001−30 December 2005				
Lags	SHA→H	H→SHA	SZA→H	H→SZA
1	-1.001 (0.158)	-0.486 (0.314)	-2.742 (0.003)	-1.566 (0.059)
3	-1.430 (0.076)	-2.197 (0.014)	-2.239 (0.013)	-3.306 (0.000)
5	-1.177 (0.120)	-2.360 (0.009)	-2.015 (0.022	-3.269 (0.001)
7	-0.295 (0.384)	-2.493 (0.006)	-1.172 (0.121)	-3.353 (0.000)
8	-0.524 (0.300)	-1.827 (0.034)	-1.323 (0.093)	-2.799 (0.003)
9	-0.360 (0.359)	-1.574 (0.058)	-1.158 (0.123)	-1.566 (0.059)
10	0.331 (0.370)	-1.337 (0.091)	-0.745 (0.228)	-2.051 (0.020)
	SHB→H	H→SHB	SZB→H	H→SZB
1	0.213 (0.416)	0.017 (0.493)	0.833 (0.202)	0.570 (0.284)
3	1.613 (0.053)*	-0.460 (0.323)	1.357 (0.087)*	0.031 (0.488)
5	1.638 (0.051)*	0.247 (0.403)	1.069 (0.143)	0.360 (0.360)
7	2.004 (0.023)**	0.155 (0.438)	2.425 (0.008)***	0.015 (0.494)
8	2.107 (0.018)**	0.586 (0.279)	2.795 (0.003)***	0.080 (0.468)
9	1.941 (0.026)**	0.512 (0.304)	3.078 (0.001)***	0.008 (0.497)
10	1.422 (0.077)**	0.927 (0.177)	2.115 (0.017)**	0.499 (0.309)

The table reports the standardized test statistics of Hiemstra and Jones (1994) with *p*-values in parenthesis. Under the null hypothesis of nonlinear Granger noncausality, the test statistic is asymptotically distributed $N(0,1)$. A significant positive test statistic implies nonlinear Granger causality under a one-tail test.

* Significant at the 10% level.

** Significant at the 5% level.

***Significant at the 1% level.