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Adcock, C., Ye, C., Yin, S. et al. (1 more author) (2023) Are Chinese B-shares dead? An analysis of price limits on AB-shares on the Shanghai and Shenzhen Stock Exchanges. International Review of Economics & Finance, 85. pp. 306-315. ISSN 1059-0560

https://doi.org/10.1016/j.iref.2023.01.012

International Review of Economics and Finance 85 (2023) 306–315

Contents lists available at ScienceDirect

International Review of Economics and Finance

journal homepage: www.elsevier.com/locate/iref

Are Chinese B-shares dead? An analysis of price limits on AB-shares on the Shanghai and Shenzhen Stock Exchanges

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ARTICLE INFO

Keywords:
Truncated-GARCH
Chinese AB shares
B-Shares
Price limits
Price continuation
Volatilities

ABSTRACT

Firms listed on the Shanghai and Shenzhen Stock Exchanges can simultaneously issue two types of shares: A and B-shares, subject to the same price limits. After July 2003, both Chinese citizens and Qualified Foreign Institutional Investors (QFIIs) were able to trade both A and B-shares in China. Following this regulatory change, some media posts predict that B-share markets will cease to exist in the future. However, are B-shares really dead? Are there no differences at all between these two markets today? In this paper, we will try to answer this question by analysing these two markets with the perspective of price limit efficacy. The rationale behind price limits is to provide investors with a cooling-off period to counter noise trading and alleviate market panic. By applying a truncated-GARCH model that explicitly incorporates the truncation in the distribution of returns that is induced by price limits, we investigate whether price limits have the same effects on price behaviour and volatility on different types of share. In general, A and B-shares enjoy a quite similar pattern in regards to volatility spillover. However, B-shares tend to have more upper price reversal and lower price continuation. This suggests price limits work more efficiently in the B-share market.

1. Introduction

The Shanghai Stock Exchange (SSE) and Shenzhen Stock Exchange (SZSE) are the two main Chinese stock exchanges, established in 1990. Firms listed on these stock markets can issue both A and B-shares (collectively known as AB-shares). A-shares are denominated in Renminbi (RMB) and were initially traded only by domestic citizens, but Qualified Foreign Institutional Investors (QFIIs) were also allowed to trade after 2002. The first trading of A-shares by QFIIs was executed in July 2003. B-shares, on the other hand, are denominated in US Dollars (USD) on the SSE and Hong Kong Dollars (HKD) on the SZSE. They were initially traded only by foreign investors, but then also by local Chinese citizens after 2000. B-shares have been available to all local citizens since June 2001. Thus as of 2003, all investors are able to trade on both platforms. A series of regulatory changes aimed to reduce the segmentation between the two markets. Before these changes, B-shares tended to trade at a lower price than the corresponding A-shares. This has been referred as the B-share discounts in the literature (Chen et al., 2001; Sun & Tong, 2000). Nowadays it is reasonable to expect that the regulation changes would integrate the two exchanges and that the B-share discount would eventually be eliminated. Due to low liquidity and trading activities, however, the discounts persist. There have been hints from a policy paper mentioning that B-shares are en route to

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https://doi.org/10.1016/j.iref.2023.01.012
Received 21 March 2022; Received in revised form 2 November 2022; Accepted 18 January 2023
Available online 19 January 2023
1059-0560/

reform (The State council of the people's republic of China, 2014) and various elements of the financial media believe that the closure of the B-shares market would be the goal of such reforms. At present, however, there are several research questions of interest and relevance to market participants: Are B-shares dead? Are there no differences between to two markets? Are there benefits from investing in B-shares? The study of these questions is complicated by the fact that both exchanges operate a system of price limits.

Price limits, usually defined as a percentage of the closing price on the previous trading day, are implemented by market regulators to constrain security price movements. When the price reaches its upper or lower limit, any order with a price beyond the price limit will be rejected by the exchange. This allows investors adequate time to evaluate current market information, impede potential losses and relieve fear. In the presence of price limits, daily volatility is restricted. Price limits in the Chinese stock market can be traced back to 1990 when the SSE and SZSE were established. Throughout the 1990s, these two exchanges experienced distinct price limit rates ranging from 0.5% to 10%. The SZSE even enforced different price limits for upward and downward price movements. After 16th December. 1996, however, the SSE and SZSE consistently implemented a single level of price limits, which is 10%. They also introduced 5% price limits after 22nd April, 1998 when the rule of ST shares was promulgated. Overall, a stable 10% level price limit was set up from 16th December, 1996 on both A- and B-shares, while a 5% price limits was implemented against ST shares after 22nd April, 1998. Despite some well-documented differences in risk and return between A- and B-shares (Chan et al., 2008; Mei et al., 2009; Darrat et al., 2010; Li, 2013; Li, 2014; Lien & Chen, 2018; Lu et al., 2007), none of these studies investigate the effects of price limits on the returns and volatilities of these shares.

Theoretically, the debate about price limits is grounded in two hypotheses. The first is the delayed price discovery hypothesis, which states that prices will continue to move in the same direction in the subsequent period after a price limit hit. The second is the volatility spillover hypothesis, which holds that the stock will have a higher volatility after a price limit hit. There is a comprehensive review of the literature on price limits in Ye (2016) and a shorter summary in Adcock et al. (2019). Until recently, the standard methodology to study price limits was a GARCH model used in conjunction with dummy variables which described the existence of price limit hits in the mean equation. In their paper, Adcock et al. (2019) introduce a GARCH model that explicitly includes the truncation effects. This results in different values for the estimated model parameters and hence different insights into the effects of price limits. The truncated GARCH model also allows the computation of tail probabilities; that is, the estimated probability that the price would move beyond the limit after a price limit hit under the circumstance that the limit was not in place. Such information offers potentially useful input for stock trading rules.

In order to answer the research questions outlined in the previous paragraph, we investigate the A-and B-share markets from the perspective of price-limit efficiency using the truncated-GARCH model. The contribution of this paper is twofold. First, to the best of our knowledge, this is the first study to explore and compare the differences of price limits efficiency between A- and B-shares in the Chinese stock markets. This adds to the existing literature regarding the differences between A- and B-share markets. Secondly, the unique fair comparison of A -and B-shares shed light on what factors may improve the price limit efficiency. The results reported below show that A- and B-shares exhibit a similar pattern in terms of volatility spillover. However, in regard to price continuation, B-shares tend to have more upper price reversal but lower price continuation. This indicates price limits work relatively more efficiently in the B-shares market. Given that the B-shares markets are still dominated by institutional investors, we believe the information advantage and investment horizon of these investors play an important role in achieving market efficiency.

The remainder of the paper is as follows: Section 2 introduces the data and descriptive statistic; Section 3 describes the characteristic of the models; Section 4 presents the empirical results; Section 5 concludes.

2. Data and descriptive statistics

Daily time series data covering the period 31st December, 2003 to 17th May, 2018 is used. B-shares were made available to all local citizens in June 2001. A-shares became available to QFIIs in November 2002 and the first trading of A-shares by QFIIs was executed in July 2003. The study period starts after this transitional phase. During the study period, 41 companies issued AB-shares on the SSE and 38 companies issued AB-shares on the SZSE.[1]

Stock market data such as daily closing prices, market value, and negotiable market value were collected from the Chinese Stock Market & Accounting Research (CSMAR) database (GTA Education Tech Ltd. 2020).[2] Logarithmic returns were calculated in the usual way using the daily closing prices. Summary statistics for the data are reported in Table 1 for the SSE and SZSE, respectively. A-shares have a higher daily mean return of 0.0009% than the 0.0006% of B-shares during the entire sample period of 2004–2018 on the SSE. In unreported statistics of returns for individual shares,[3] the Jarque-Bera test shows that very few stocks exhibit normal return distributions. Although common in stock returns data, evidence of non-normality in this study is at least partly attributable to the truncation effect of the price limits. Fig. 1 shows density plots of the returns on AB-shares at both exchanges. As well as providing visual evidence of non-normality, the figure shows that there are humps in the histograms around the price limits. This feature motivates the use of the truncated normal distribution in the model, which is discussed in the next section.

Table 2 reports comparisons of the mean return, variance and negotiable market value of AB-shares on each exchange. As A- and B-shares are issued by the same firm, their returns are almost certain to be correlated. We, therefore, applied the paired sample *t*-test and

[1] The difference between 45 (45) and 41 (38) on the SSE (SZSE) is that some companies only issue B-shares.

[2] The data that support the findings will be available in CSMAR at us.gtadata.com following an embargo from the date of publication to allow for commercialization of research findings.

[3] Available on request from the corresponding author.

Table 1
Descriptive statistics.

	Mean	SD	Skewness	Kurtosis	JB[a]	JB-S[b]	JB-K[c]
SSE A							
Daily Return	0.0009	0.0338	2.24	84.85	0.001	0.161	0.001
Daily Market Value (Thousand RMB)	7049492	4662135	1.03	4.03	0.001	0.019	0.048
Daily Negotiable Market Value (Thousand RMB)	5146207	4274553	0.89	3.52	0.001	0.013	0.030
SZSE A	Mean	SD	Skewness	Kurtosis	JB	JB-S	JB-K
Daily Return	0.0009	0.0322	1.91	82.14	0.002	0.144	0.001
Daily Market Value (Thousand RMB)	10639327	7624199	1.02	3.89	0.011	0.000	0.050
Daily Negotiable Market Value (Thousand RMB)	8166826	6710109	0.85	3.34	0.011	0.005	0.020
SSE B	Mean	SD	Skewness	Kurtosis	JB	JB-S	JB-K
Daily Return	0.0006	0.0260	0.65	27.75	0.001	0.222	0.001
Daily Market Value (Thousand RMB)	185925	95353	0.62	3.14	0.001	0.009	0.024
Daily Negotiable Market Value (Thousand RMB)	185925	95353	0.62	3.14	0.001	0.009	0.024
SZSE B	Mean	SD	Skewness	Kurtosis	JB	JB-S	JB-K
Daily Return	0.0007	0.0255	0.03	6.13	0.003	0.162	0.001
Daily Market Value (Thousand RMB)	2016710	1100118	0.75	3.50	0.005	0.016	0.043
Daily Negotiable Market Value (Thousand RMB)	2016710	1100118	0.75	3.50	0.005	0.016	0.043

Note: All results are the average statistics across all AB-share stocks.

[a] Reporting the p-value of overall Jarque-Bera test. Matlab restricts the p-value within the range [0.001,0.50].

[b] Reporting the p-value of skewness part of the Jarque-Bera test.

[c] Reporting the p-value of kurtosis part of the Jarque-Bera test.

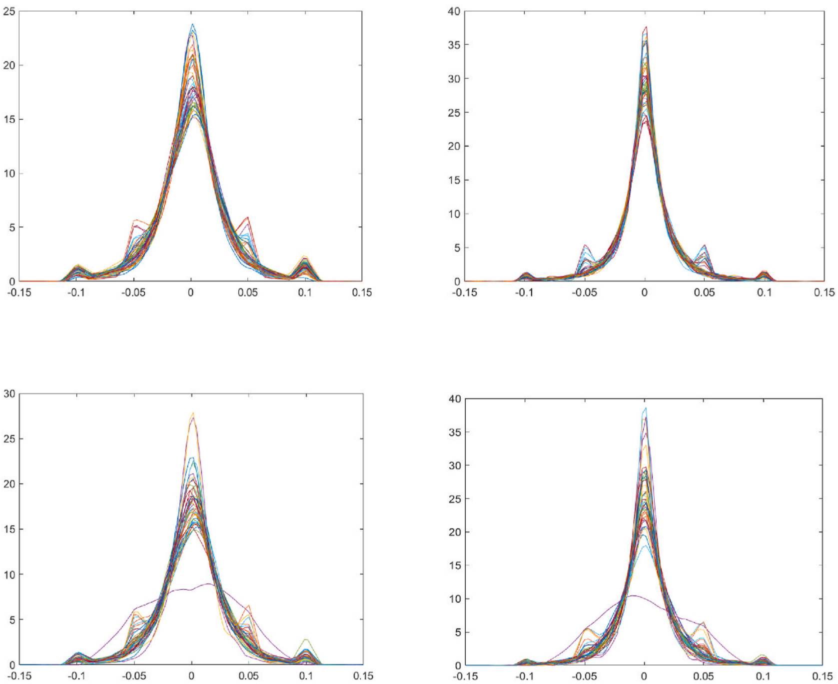

Fig. 1. Return distribution.
These figures display the return distribution of the AB-shares on the Shanghai Stock Exchange (SSE) and Shenzhen Stock Exchange (SZSE) over the period 01/2004–05/2018.

Table 2
Sample Comparisons between A- and B-shares on the SSE and SZSE This table reports sample return mean, return variance and market value comparisons between A- and B-shares. AB-share means an A-share has a corresponding B-share. As B-shares are denominated in USD (HKD) on the SSE (SZSE), the market values are converted into RMB in order to facilitate comparisons across markets. These three comparisons summarise the numbers of AB-shares that have significant different return mean, return variance and market value.

Significance Level	1%	5%	1%	5%	1%	5%
Panel A: SSE (N = 41)						
Return Mean	$\mu_A < \mu_B$		$\mu_A \neq \mu_B$		$\mu_A > \mu_B$	
	0	1	0	0	0	0
Return Variance[a]	$\sigma_A^2 < \sigma_B^2$		$\sigma_A^2 \neq \sigma_B^2$		$\sigma_A^2 > \sigma_B^2$	
	0	0	40	40	40	40
Negotiable Market Value[b]	$MV_A < MV_B$		$MV_A \neq MV_B$		$MV_A > MV_B$	
	1	1	41	41	40	40
Panel B: SZSE (N = 38)						
Return Mean	$\mu_A < \mu_B$		$\mu_A \neq \mu_B$		$\mu_A > \mu_B$	
	0	0	0	0	0	0
Return Variance[a]	$\sigma_A^2 < \sigma_B^2$		$\sigma_A^2 \neq \sigma_B^2$		$\sigma_A^2 > \sigma_B^2$	
	0	1	36	37	36	36
Negotiable Market Value[b]	$MV_A < MV_B$		$MV_A \neq MV_B$		$MV_A > MV_B$	
	0	0	38	38	38	38

[a] The test of return variance is based on the modified F-test (Pitman, 1939) which takes the correlated variables into account.
[b] Mean and negotiable market value are based on the paired sample *t*-test.

Pitman's modified F-test.[4] (Pitman ,1939). As B-shares are denominated in USD on the SSE and HKD on the SZSE, the negotiable market value is converted into RMB using the daily exchange rates obtained from CSMAR database. In Table 2, tests are reported at both the 5% and 1% level of significance. The results show that the mean returns for A-shares are not significantly different from those of B-shares on either exchange. A-shares, however, have a higher variance than B-shares. Panel A (B) of Table 2 shows that, at the 1% significance level, 40 out of 41 (36 out of 38) A-shares on the SSE (SZSE) have a higher variance than B-shares during the study period. A-shares generally have a higher negotiable market value than their corresponding B-shares on both stock exchanges.

This study uses daily closing prices rather than high and low prices to identify price-limit-hits. This is because, according to Fama (1989) and Kodres (1993), the theory states that the price is prevented from reaching its equilibrium value when the closing price stays at the limits, thus delaying price discovery. According to Panel B of Table 3, the number of upper-limits-hits is larger than that of the lower-limits-hits. In total there are 3878 and 2844 upper-limit-hits against 2706 and 2156 lower-limit-hits on the SSE and SZSE, respectively. Moreover, A-shares are more inclined to hit price limits than B-shares. A-shares on the SSE and SZSE have 4521 and 3690 price-limit-hits, whereas B-shares have 2063 and 1310 price-limit-hits. The chi-squared test in Panel C of Table 3 shows that the number of limit-hits in A-shares is significantly (p-value 0.27%) greater than that of B-shares. The test also shows that the number of limit-hits on the SSE is significantly (p-value 2.91%) larger than that on the SZSE.

Panel D of Table 3 summarises the number of price-limit-hits. First, the number of limit-hits varies greatly for different shares. For instance, the mean values of upper-limit-hits are 62, 26, 49 and 17 for A- and B-shares on the SSE and SZSE, respectively. The corresponding standard deviations, however, are 37, 16, 35 and 14. Similar results are found for lower-limit-hits. Panel D also reports that the mean (median) values of the number of days between consecutive limit-hits are 39, 75, 49, 124 (31, 68, 45, 109) for A- and B-shares on the SSE and SZSE, respectively. This suggests that more than one limit-hit in two months is likely to occur on average for A-shares. However, for B-shares, a price limit hit happens less often; there is roughly one hit every 4months in SSE B-shares and one in every half-year in SZSE B-shares.

3. Methodology

The price limits result in a set of time series data for which the observation at time *t* cannot deviate from its predecessor by more than ±10%. As shown in Fig. 1, returns do not follow normal distribution and are truncated at the limits. As stated in the introduction, we implement a GARCH model in which the effect of truncation is explicitly included in the likelihood function. The description of the method in this section of the paper is a summary of that in Ye (2016) or Adcock et al. (2019). In the usual notation, the mean equation for the truncated GARCH model is

$$R_t = \mu_t + \varepsilon_t; \quad \varepsilon_t \big| \ \Omega_t \ \sim \ N\left(0, \sigma_t^2\right), \tag{1}$$

with

$$\mu_t = \beta_1 + (\beta_2 + \beta_3 T_{t-1} + \beta_4 \sigma_{t-1} + \beta_5 U_{t-1} + \beta_6 L_{t-1} + \beta_7 U9_{t-1} + \beta_8 L9_{t-1}) R_{t-1}, \tag{2}$$

[4] Let $D = X_1 - X_2$, $S = X_1 + X_2$ where $X_{1,2}$ are two standardised samples each of size n. If $\text{correlation}(D, S)$ is significantly greater (less) than 0, *then* $\sigma_1^2 > (<) \sigma_2^2$. Degrees of freedom are n-2.

Table 3
Price hits analysis. The Panel A of this table shows the procedures to exactly identify price limits. $P_{c,t-1}$ is closing price on day *t-1*; $P_{\max}$ and $P_{\min}$ are permissible maximum and minimum prices rounded to two decimal places (three decimal places for B-shares on the SSE). The Panel B of this table reports the total numbers of upper and lower limits hits of AB-shares on both stock exchanges[a]. The Panel C shows the chi-squared tests in terms of the number of price-limit-hits between A- and B-shares, as well as between the SSE and SZSE. The Panel D summarises the number of price-limit-hits.

Panel A: Procedures to Identify Price Limits Hits

Price limits hits	Step 1	Step 2	Trading Status
Upper	$P_{c,t-1} \times 1.1 \approx P_{\max,t}$	$P_{\max,t} = P_{c,t}$	Normal
	$P_{c,t-1} \times 1.05 \approx P_{\max,t}$	$P_{\max,t} = P_{c,t}$	ST
Lower	$P_{c,t-1} \times 0.9 \approx P_{\min,t}$	$P_{\min,t} = P_{c,t}$	Normal
	$P_{c,t-1} \times 0.95 \approx P_{\min,t}$	$P_{\min,t} = P_{c,t}$	ST

Panel B: Numbers of Price Limits Hits

	SSE (N = 41)				SZSE (N = 38)		
	Upper	Lower	Total		Upper	Lower	Total
A	2721	1800	4521	A	2116	1574	3690
B	1157	906	2063	B	728	582	1310
Total	3878	2706	6584	Total	2844	2156	5000

Panel C: Chi-squared test

	Upper	Lower	Total	Marginal Probability		Upper	Lower	Total	Marginal Probability
A	4837	3374	8211	0.7088	SSE	3878	2706	6584	0.5684
B	1885	1488	3373	0.2912	SZSE	2844	2156	5000	0.4316
Total	6722	4862	11584		Total	6722	4862	11584	
Marginal Probability	0.5803	0.4197			Marginal Probability	0.5803	0.4197		
Expected values	Upper	Lower	Total	p-value	Expected values	Upper	Lower	Total	p-value
A	4765	3446	8211	0.0027	SSE	3821	2763	6584	0.0291
B	1957	1416	3373		SZSE	2901	2099	5000	
Total	6722	4862	11584		Total	6722	4862	11584	
chi-squared statistics = 8.9757					chi-squared statistics = 4.7628				

Panel D: Summary Statistics[a]

	SSE A			SSE B		
	Upper	Lower	Days Between[b]	Upper	Lower	Days Between
Mean	62	41	39	26	21	75
SD	37	26	27	16	12	37
Min	8	9	8	7	6	17
Median	54	38	31	22	16	68
Max	187	130	152	74	58	166

	SZSE A			SZSE B		
	Upper	Lower	Days Between	Upper	Lower	Days Between
Mean	49	37	49	17	14	124
SD	35	27	36	14	12	97
Min	4	5	7	3	1	11
Median	34	27	45	11	10	109
Max	128	103	182	61	54	479

a A detailed number of price-limit-hits for individual shares are available upon request.
b The number of days between consecutive limit-hits.

and

$$\sigma_t^2 = \beta_9 + \beta_{10}\varepsilon_{t-1}^2 + \beta_{11}\sigma_{t-1}^2 + \beta_{12}U_{t-1} + \beta_{13}L_{t-1} + \beta_{14}U9_{t-1} + \beta_{15}L9_{t-1} \tag{3}$$

R_t is the daily stock return on day t. T_{t-1} is the daily negotiable turnover ratio on day $t-1$, which is measured by daily negotiable turnover divided by daily negotiable market value. U_{t-1} ($U9_{t-1}$) and L_{t-1} ($L9_{t-1}$) are upper (90% upper) and lower (90% lower) price limit hits dummy variables taking value of one on day t if a share reaches the limit (90% of the limit) on day $(t-1)$ and zero otherwise. The model parameters are estimated by maximising the log-likelihood function *logL*. Under the truncated model *logL* has two components

$$log\ L = log\ L_1 + log\ L_2, \tag{4}$$

where

$$log\ L_1 = \sum_{t'=1}^{n'} \log\left\{\varnothing\left(r_{t'}, \mu_{t'}, \sigma_{t'}^2\right)\right\} - \sum_{t'=1}^{n'} \log\left\{\Phi\left(\frac{U_{t'} - \mu_{t'}}{\sigma_{t'}}\right) - \Phi\left(\frac{L_{t'} - \mu_{t'}}{\sigma_{t'}}\right)\right\}, \tag{5}$$

and

$$log\ L_2 = \sum_{tl=1}^{nl} \log\left\{\Phi\left(\frac{L_{tl} - \mu_{tl}}{\sigma_{tl}}\right)\right\} + \sum_{tu=1}^{nu} \log\left\{1 - \Phi\left(\frac{U_{tu} - \mu_{tu}}{\sigma_{tu}}\right)\right\}, \tag{6}$$

where $n' + nl + nu = N$, the total number of observations, n' is the number of values which lie between the upper and lower limits, nl and nu are respectively the number of values which are truncated at the lower limit and upper limit. The notation $\varnothing\ (x, \mu, \sigma^2)$ denotes the probability density function of a normally distributed variable with mean μ and variance σ^2 evaluated at x and Φ denotes the standard normal distribution function. The variables in the three summations are indexed by t', tl and tu respectively. Return is denoted by r, U and L are the upper and lower limits. μ_t and σ_t^2 are the mean and conditional volatility at time t. Estimated parameters are denoted with the $\wedge$ symbol

In Equation (2), the estimated coefficient $\widehat{\beta}_2$ measures the relationship between current return and its previous value without price-limit-hit, while $\widehat{\beta}_2 + \widehat{\beta}_5$ $(\widehat{\beta}_2 + \widehat{\beta}_6)$ measures the correlation between current return and its previous value when the price hits upper (lower) limits. $\widehat{\beta}_3$ and $\widehat{\beta}_4$ measure how the negotiable turnover ratio and conditional standard deviation would affect stock return autocorrelations. In Equation (3) $\widehat{\beta}_{12}$ and $\widehat{\beta}_{13}$ measure the volatility after upper- and lower-limit-hits. In order to show the effects that indeed come from price limits rather than extreme price movements, it is necessary to compare the estimated coefficients between limit-hits and near-hits dummies. For example, if upper price-limit-hit induces price continuation, $\widehat{\beta}_2 + \widehat{\beta}_5$ needs to be significantly greater than 0 and $\widehat{\beta}_5$ also needs to be significantly greater than $\widehat{\beta}_7$. detailed constructions of the hypotheses are illustrated below.

The null hypotheses for upper price limits that are tested are as follows:

Price continuation (PC): $H_0 : \beta_2 + \beta_5 = 0\ vs\ H_1 : \beta_2 + \beta_5 > 0$ and $H_0 : \beta_5 = \beta_7\ vs\ H_1 : \beta_5 > \beta_7$.

Price reversal (PR): $H_0 : \beta_2 + \beta_5 = 0\ vs\ H_1 : \beta_2 + \beta_5 < 0$ and $H_0 : \beta_5 = \beta_7\ vs\ H_1 : \beta_5 < \beta_7$.

Table 4

Models Estimation for subsample A-shares with corresponding B-shares on the SSE The abbreviations are as follows: PC = price continuation, PR = price reversal, VI = volatility increase, VD = volatility decrease.

	SSE N = 41 (out of 45)				SZSE N = 38 (out of 45)				
5% significant results									
SSE A (41)	PC	PR	VI	VD	SZSE A (38)	PC	PR	VI	VD
Upper	8	1	1	2	Upper	9	1	3	1
Lower	1	2	0	0	Lower	2	5	0	0
SSE B (41)	PC	PR	VI	VD	SZSE B (38)	PC	PR	VI	VD
Upper	4	5	0	0	Upper	10	5	2	2
Lower	3	2	0	0	Lower	5	5	0	0
1% significant results									
SSE A (41)	PC	PR	VI	VD	SZSE A (38)	PC	PR	VI	VD
Upper	8	0	1	2	Upper	8	1	2	1
Lower	1	0	0	0	Lower	1	3	0	0
SSE B (41)	PC	PR	VI	VD	SZSE B (38)	PC	PR	VI	VD
Upper	4	3	0	0	Upper	10	4	2	1
Lower	3	1	0	0	Lower	4	3	0	0
0.1% significant results									
SSE A (41)	PC	PR	VI	VD	SZSE A (38)	PC	PR	VI	VD
Upper	6	0	1	2	Upper	7	1	2	1
Lower	1	0	0	0	Lower	1	3	0	0
SSE B (41)	PC	PR	VI	VD	SZSE B (38)	PC	PR	VI	VD
Upper	3	1	0	0	Upper	7	4	1	1
Lower	3	1	0	0	Lower	4	2	0	0

Volatility increase (VI): $H_0 : \beta_{12} = 0$ *vs* $H_1 : \beta_{12} > 0$ and $H_0 : \beta_{12} = \beta_{14}$ *vs* $H_1 : \beta_{12} > \beta_{14}$.
Volatility decrease (VD): $H_0 : \beta_{12} = 0$ *vs* $H_1 : \beta_{12} < 0$ and $H_0 : \beta_{12} = \beta_{14}$ *vs* $H_1 : \beta_{12} < \beta_{14}$.

There is a similar set of hypotheses for lower price limits, which are omitted in the interests of brevity.

The truncated GARCH model allows the computation of tail probabilities; that is, the estimated probability that the price would move beyond the limit after a price-limit-hits under the circumstance that the limit was not in place. The mean and conditional variance can be estimated from Equations (1)–(3). The upper and lower tail probabilities are calculated as

Table 5
Summary of truncated-GARCH-M model' parameters SSE.

SSE(N = 41)	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{11}	β_{12}	β_{13}	β_{14}	β_{15}
5% significance															
SSE A Total	5	4	9	9	12	11	12	12	35	31	22	25	23	25	26
Positive	5	2	0	6	6	7	10	9	35	31	22	24	23	25	26
Negative	0	2	9	3	6	4	2	3	0	0	0	1	0	0	0
SSE B Total	4	8	7	13	10	10	10	4	25	11	10	6	6	9	6
Positive	2	4	5	8	4	3	8	2	25	11	10	6	6	9	6
Negative	2	4	2	5	6	7	2	2	0	0	0	0	0	0	0
1% significance															
SSE A Total	2	3	6	8	10	9	8	8	34	29	20	17	16	15	16
Positive	2	1	0	5	5	5	7	8	34	29	20	16	16	15	16
Negative	0	2	6	3	5	4	1	0	0	0	0	1	0	0	0
SSE B Total	3	5	7	13	10	9	8	4	25	11	10	6	5	9	5
Positive	1	2	5	8	4	3	7	2	25	11	10	6	5	9	5
Negative	2	3	2	5	6	6	1	2	0	0	0	0	0	0	0
0.1% significance															
SSE A Total	0	2	2	4	7	5	7	4	34	28	19	12	12	11	12
Positive	0	0	0	3	2	3	6	4	34	28	19	11	12	11	12
Negative	0	2	2	1	5	2	1	0	0	0	0	1	0	0	0
SSE B Total	3	5	6	11	7	8	8	4	24	11	9	4	3	7	3
Positive	1	2	4	7	4	3	7	2	24	11	9	4	3	7	3
Negative	2	3	2	4	3	5	1	2	0	0	0	0	0	0	0
SZSE(N = 38)	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{11}	β_{12}	β_{13}	β_{14}	β_{15}
5% significance															
SZSE A Total	5	8	8	12	11	16	9	20	34	30	20	21	19	22	23
Positive	5	3	0	10	8	10	5	16	34	30	20	20	14	22	23
Negative	0	5	8	2	3	6	4	4	0	0	0	1	5	0	0
SZSE B Total	6	15	8	14	10	17	17	10	26	12	14	8	7	6	7
Positive	6	7	3	9	10	11	6	8	26	12	14	7	6	6	6
Negative	0	8	5	5	0	6	11	2	0	0	0	1	1	0	1
1% significance															
SZSE A Total	1	6	3	11	10	13	7	13	34	28	16	20	17	18	19
Positive	1	1	0	10	8	8	3	10	34	28	16	19	13	18	19
Negative	0	5	3	1	2	5	4	3	0	0	0	1	4	0	0
SZSE B Total	6	15	8	13	10	14	16	9	26	12	14	6	7	4	7
Positive	6	7	3	8	10	9	5	7	26	12	14	5	6	4	6
Negative	0	8	5	5	0	5	11	2	0	0	0	1	1	0	1
0.1% significance															
SZSE A Total	0	4	2	8	9	10	5	9	33	26	15	15	13	15	15
Positive	0	0	0	7	7	7	2	6	33	26	15	14	9	15	15
Negative	0	4	2	1	2	3	3	3	0	0	0	1	4	0	0
SZSE B Total	5	14	8	12	8	11	12	8	26	11	14	6	6	4	6
Positive	5	7	3	8	8	6	5	6	26	11	14	5	5	4	5
Negative	0	7	5	4	0	5	7	2	0	0	0	1	1	0	1

This table summarises the number of estimated parameters, which are significant at 0.1%, 1% and 5% from the truncated-GARCH-M model. The model parameters are as defined for the following equations.

$\mu_t = \beta_1 + (\beta_2 + \beta_3 T_{t-1} + \beta_4 \sigma_{t-1} + \beta_5 U_{t-1} + \beta_6 L_{t-1} + \beta_7 U9_{t-1} + \beta_8 L9_{t-1}) R_{t-1},$

$\sigma_t^2 = \beta_9 + \beta_{10} \varepsilon_{t-1}^2 + \beta_{11} \sigma_{t-1}^2 + \beta_{12} U_{t-1} + \beta_{13} L_{t-1} + \beta_{14} U9_{t-1} + \beta_{15} L9_{t-1}$

$$P(x > U_t) = 1 - \int_{-\infty}^{U_t} \frac{1}{\sqrt{2\pi}\widehat{\sigma}_t} exp^{\left\{-\frac{1}{2\widehat{\sigma}_t^2}(x-\widehat{\mu}_t)^2\right\}} dx, \tag{7}$$

and

$$P(x < L_t) = \int_{-\infty}^{L_t} \frac{1}{\sqrt{2\pi}\widehat{\sigma}_t} exp^{\left\{-\frac{1}{2\widehat{\sigma}_t^2}(x-\widehat{\mu}_t)^2\right\}} dx, \tag{8}$$

where in Equations (7) and (8) x denotes the return on the day of a price-limit-hit for which the upper and lower limits are U_t and L_t respectively. Using standard features of GARCH models implies that these computations may be performed either contemporaneously or to compute a prediction of the tail probability for a future time period. In China, the price change limit is 10%. To illustrate the use of computed tail probabilities, if the estimated tail probability of exceeding the 10% limit is high, 90% for example, the implication is that absent price limit regulation the price may keep moving in the same direction. These computations thus offer useful information about the effect of price limits and could contribute to the construction of decision rules for trading.

4. Empirical results

4.1. Analysis of price discovery and volatility spillover for AB-shares

Table 4 contains the empirical analysis of price discovery and volatility spillover for AB-shares on the SSE and SZSE exchanges. Results are reported at 5%, 1% and 0.1% levels of significance based on the daily data used.

At the 5% significance level, there are 8 (1) out of 41 A-shares showing price continuation after upper (lower) price-limits-hits, while the number of stocks is 4(3) for B-shares on the SSE. On the SZSE, A- and B-shares show similar patterns: 9 (2) out of 38 A-shares and 10 (5) out of 38 B-shares show price continuation after upper (lower) price-limit-hits. The number of shares showing price continuation does not change substantially at the 1% or 0.1% significance levels. At the 5% significance level, for price reversal, 3 (7) SSE A- (B-) shares show such behaviour. For the SZSE exchange, the corresponding number of A- (B-) shares is 6 (10). For SSE AB-shares, the number of reported price reversals declines at the 1% and 0.1% significance levels: at the 0.1% level, the price reversal effect has all but vanished. On the SZSE, however, the number of price reversals does not decline substantially at the more stringent levels of significance. Overall, the empirical results suggest that there are more price reversals in B-shares than A-shares after upper-limit-hits. There is evidence of price continuation for A-shares only after upper-limit-hits. For B-shares, the evidence suggests price continuation after both upper- and lower-limit-hits. For price reversals, the empirical evidence is more complex. For the SSE, evidence of price reversal largely disappears at the more stringent levels of significance. On the SZSE, the evidence of price reversal persists for A-share lower-limit-hits, but for both upper- and lower-limit- hits for SZSE B-shares.

In general, the empirical evidence suggests that price limits delay price discovery on A-shares and that there are more price reversals in B-shares on both exchanges after upper-limit-hits. The A-shares results are consistent with those in Adcock et al. (2019), which indicates that price limits calm the market by reducing over selling behaviour caused by panic, but are less effective in dealing with over-enthusiastic buying. The larger number of price reversals in B-shares results show that price limits works more efficiently for this class of shares. SSE B-shares also show less evidence of price continuation after upper price-limit-hits. The results suggest a greater degree of effectiveness of price limits for B-shares when compared to A-shares. This may be explained by the higher proportion of institutional investors who are active in the B-shares markets.

By contrast, there is a very small number of shares that show either increasing or decreasing volatility after either upper or lower price-limit-hits. None of the shares on either exchange experience significant volatility change after a lower price-limit-hit. On the SSE, 1 (2) A-shares experience higher (lower) volatility after upper price-limit-hits, with this limited effect persisting at the 1% and 0.1% significance levels. None of the B-shares exhibit either higher or lower volatility at any significance level. For the SZSE, at the 5% level there are 3 (1) A-shares and 2 (2) B-shares with volatility increases (decreases) after upper price-limit-hits. These effects decline slightly at the higher significance levels.

Table 5 contains a summary of the numbers of estimated model parameters that are significantly different from zero at the 5%, 1% and 0.1% level of significance. Examination of individual model parameter estimates reveals that turnover ratio (β_3) has a negative effect on stock return autocorrelation for A-shares. For example, at the 5% significance level there are respectively 9 out of 41 A-shares on the SSE and 8 out of 38 A-shares on the SZSE for which the estimated value of β_3 is less than zero. This finding is consistent with Campbell, Grossman and Wang (1993), who suggest that heterogeneous investors tend to change to a different direction with high turnover. This further indicates the conflicting feature of the A-share market due to the composition of its investors, who are polarised by differing ability to access information. However, this effect does decline in importance at the 1% and 0.1% level. Interestingly, B-shares exhibit some positive effect on autocorrelation arising from turnover. Furthermore, this effect is more persistent at higher significance levels. We suggest that this can be explained by the likelihood that B-share investors are more homogeneous compared to their A-share counterparts. For some stocks, conditional volatility (σ_{t-1}) induces a change in stock return autocorrelation. Such changes can be either positive or negative. For example, at the 5% level 6 (8) and 10 (9) A (B)-shares on the SSE and SZSE show a positive effect. These effects are more persistent at 1% and 0.1%. As expected from daily data, there are significant GARCH effects ($\beta_{9,10,11}$) shown by the majority of stocks. These persist at all three levels of significance. Notablely, the number of B-shares which do not show significant GARCH effects is higher than that for A-shares, providing more evidence to support the view that B-share investors form a more homogeneous group. For A-shares, in both markets at 5% level, there is a significant number of stocks for which the price limit dummies ($\beta_{12,13,14,15}$) have an effect on conditional volatility. This effect, however, declines in importance at 1% and 0.1%. For B-shares, a significant effect of price limit dummies is less common.

To summarise, price limits work more efficiently with B-shares, especially SSE B-shares, in terms of price continuation.

4.2. Tail probabilities

Table 6 reports the tail probabilities on the day of a price-limit-hit. There is a vertical panel for each exchange. In each panel, there are four columns. These columns contain results for upper- and lower-limit-hits for AB-shares on each of the two exchanges. The contents of the table are explained as follows using A-shares on the SSE to illustrate the computations. For SSE A-shares, there are approximately 2500 upper price-limit-hits. The tail probabilities are computed for each price-limit-hit, and a histogram is constructed. Corresponding to the 75% vigintile, for upper-price-limits for SSE A-shares, 25% of the right hand tail probabilities are greater than 0.57. That is, given 2500 upper price-limit-hits, there are 625 occasions on which the price has an estimated probability of 0.57 of exceeding the upper limit. For SSE A-shares lower limits, 25% of the left hand tail probabilities are greater than 0.58. For SSE B-shares, the results for the same vigintile exhibit less symmetry. The upper and lower exceedance probabilities are, respectively, 0.54 and 0.62. For both A- and B-shares on SZSE there is a greater degree of asymmetry at the same vigintile.

Fig. 2 shows a graphical visualisation of the tail probabilities for SSE A-shares. The horizontal axis shows the probability of exceeding the upper limit from 0.1 to 0.9 in steps of 0.1. The vertical axis shows the frequency of occurrence of the exceedance. The values used to construct the bar chart are derived from the entries in Table 6 using linear interpolation. Using the bar chart, when there is an upper-limit-hit, there is a 60% [28.5%] chance that the percentage increase will be 10% [50%] or greater in the absence of the price limit. The results between A- and B-shares on the SSE do not display great numerical differences. For the SZSE, however, B-shares show higher tail probabilities after both upper and lower price-limit-hits. This suggests that without price limits in place, there would be a greater degree of price continuation for SZSE B-shares. Taken in conjunctions with the results from Section 4.2, we suggest that price limits more efficiently reduce the price continuation of SZSE B-shares to a level that is similar to that of A-shares.

5. Conclusions

This study utilizes a GARCH model with a doubly truncated distribution to investigate the difference of price discovery and volatility spillover after price limit hits between Chinese A- and B-share market. Using daily data from 2004 to 2018, we find that there is still a considerable amount of divergence, especially in terms of price discovery, between A and B-shares. From this analysis, price limits work more efficiently in B-share market from the price discovery point of view. Results show B-share market tend to be more homogenous. A reduction in market heterogeneity may improve the efficacy of price limits.

Table 6
Summary of Tail Probability This table summarises the computed tail probabilities on the days of upper (U) and lower (L) price-limit-hits. The vigintiles are reported. The explanation of the table entries is as follows. There are about 2500 upper price-limit-hits in A-shares on the SSE and the tail probabilities are computed for each price-limit-hit. For the Truncated-GARCH model for upper price limits in SSE A, about 25% of the tail probabilities are greater than 0.50. That is, given 2500 upper price-limit-hits, there are about 625 times that the price has a probability of 0.50 of exceeding the restricted level.

	SSE				SZSE			
	SSEA		SSEB		SZSEA		SZSEB	
Vigintiles	U	L	U	L	U	L	U	L
5%	0.00	0.03	0.00	0.01	0.00	0.02	0.00	0.01
10%	0.00	0.04	0.00	0.04	0.01	0.03	0.00	0.04
15%	0.01	0.07	0.01	0.07	0.02	0.05	0.01	0.07
20%	0.02	0.12	0.01	0.12	0.03	0.09	0.02	0.12
25%	0.03	0.19	0.03	0.15	0.04	0.12	0.04	0.20
30%	0.04	0.26	0.06	0.20	0.07	0.17	0.08	0.23
35%	0.06	0.30	0.09	0.24	0.10	0.23	0.13	0.28
40%	0.10	0.34	0.14	0.28	0.16	0.28	0.20	0.33
45%	0.17	0.37	0.19	0.32	0.24	0.35	0.26	0.38
50%	0.23	0.4	0.24	0.36	0.28	0.40	0.33	0.44
55%	0.28	0.44	0.29	0.40	0.34	0.44	0.39	**0.50**
60%	0.34	0.47	0.35	0.44	0.40	0.48	0.46	0.55
65%	0.40	**0.51**	0.40	**0.50**	0.47	**0.52**	**0.51**	0.61
70%	0.47	0.55	0.47	0.56	**0.53**	0.57	0.57	0.69
75%	**0.57**	0.58	**0.54**	0.62	0.62	0.61	0.63	0.72
80%	0.65	0.63	0.60	0.67	0.71	0.67	0.72	0.80
85%	0.78	0.68	0.68	0.72	0.77	0.71	0.77	0.94
90%	0.88	0.72	0.75	0.75	0.82	0.76	0.95	0.96
95%	0.92	0.78	0.82	0.81	0.92	0.91	0.98	0.98

Note: Values are shown rounded to two decimal places.

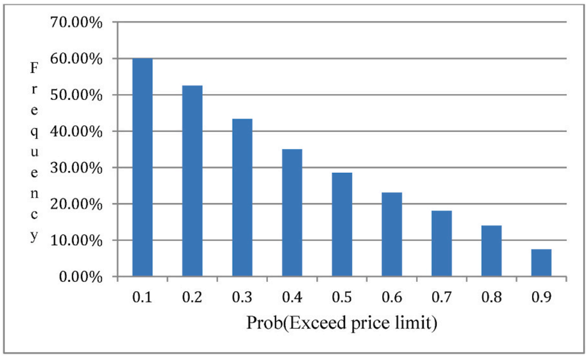

Fig. 2. Price limit exceedance probabilities for SSE A shares.
The figure shows a graphical visualisation of the tail probabilities for SSE A-shares. The horizontal axis shows the probability of exceeding the upper limit from 0.1 to 0.9 in steps of 0.1. The vertical axis shows the frequency of occurrence. The values used to construct the bar chart are derived from the entries is Table 6 using linear interpolation. Using the bar chart, when there is an upper limit hit, there is a 60% [28.5%] chance that the percentage increase will be 10% [50%] or greater.

Author statement

Author statement for manuscript "Are Chinese B-shares dead? An analysis of price limits on AB-shares on the Shanghai and Shenzhen Stock Exchanges".

Chris Adcock: Conceptualization, Methodology, Supervision, Writing-Review and Editing, Visualisation. Caiwei Ye: Software, Data curation, Writing- Original draft preparation, Formal Analysis, Methodology. Shuxing Yin: Conceptualization, Supervision, Writing-Review and Editing, Visualisation. Dalu Zhang: Software, Data curation, Writing-Review and Editing, Formal Analysis, Methodology, Visualisation.

Data availability

The authors do not have permission to share data.

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