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The Effect of Extremely Small Price Limits: Evidence from the Early Period of the Chinese Stock Market

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ABSTRACT: This article studies the effect of the extremely small price limits on market quotation with an agent-based model. Considering the early government intervention in the Chinese stock market as a natural experiment, we provide explanations for exotic empirical features of the Chinese stock market in specific periods. We argue that such atypical market results from the behavioral consensus among heterogeneous traders, which is facilitated by the extremely small price limits. Paradoxically, the price limits designed to stabilize prices actually exacerbate price volatility from a longer-term perspective.

KEY WORDS: agent-based modeling, Chinese stock market, extremely small price limits, unilateral trend

1. Introduction

Price limits are usually used in financial markets to avoid severe fluctuations in daily stock prices. In 1987, the Dow Jones Industrial Average fell approximately 500 points, equivalent to 22%. After this crisis, some scholars thought that price limits should be used in the American stock market to stabilize market volatility. However, others thought that price limits would cause a series of problems. Since that time, there has been significant debate around this issue. The fundamental question is, do price limits make financial markets more stable or more volatile?

Supporters think that utilizing price limits in the market will have a positive effect, reducing volatility and curbing excessive speculation in the market (Brennan 1986; Kodres and O'Brien 1994). Additionally, when the price hits the limit, traders will have more time to rethink and evaluate relevant information, this is referred to as the cooling-off effect (Chung and Gan 2005; Fernandes and Aurélio 2007; Greenwald and Stein 1991). Wong, Liu and Zeng (2009) find that the price limit rule is designed to provide a cooling off period and hence prevent excessive price movements. Some scholars also think that price stability mechanisms can push society toward the Pareto optimality and increase social welfare (Armstrong and Vickers 1991; Ippolito 1991; Timberlake 1984). Contrarily, there are many critics of price limits. They fall into four main categories. First, they claim that price limits can cause higher volatility levels on subsequent trading days (Volatility Spillover). Second, price limits can also prevent prices from reaching their equilibrium level efficiently (Delayed Price Discovery). Third, price limits may interfere with trading activities (Trading Interference). Fourth, as a stock price approaches its limit, traders fear being locked out of positions and trade quickly, potentially resulting in a magnet effect (Abad and Pascual 2007; Cho et al. 2003; Hsieh, Kim, and Yang 2009). Kim and Rhee (1997) used a combination of the event study method and the group comparison method to examine the effect of volatility spillover, delayed price discovery and trading interference. After that, many studies focused on this issue (Berkman and Lee 2002; Bildik and Gülay 2006; Huang, Fu, and Ke 2001).

Price limits are a powerful policy tool and an exogenous variable. Understanding the type of reaction that traders will have in defense of this kind of policy signal and establishing proper price limits are very important. Without price limits, the financial market may experience sharp and

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undesired fluctuations of stock prices that may result in a serious financial crisis. However, if the price limits are extremely small, what kind of impact will they have? Will the stock price fluctuate smoothly, or will it have some other kind of other characteristics? Currently, the Chinese stock market uses a 10% price limit for both upward and downward movements. Interestingly, in the early stages of the Chinese stock market, from December 19, 1990 to December 25, 1996, there was a habit of adjusting price limits very frequently and maintaining very small limits. At this time, the stock price usually appeared to have risen or fallen unilaterally. This period provides us with a good natural experiment testing the effects of extremely small price limits. Natural experiments may have many possibilities. No matter how policies are formulated, we are mainly concerned about the observable consequences of the policies. We refer to natural experiments mainly to emphasize the frequent changes of the price limit and the rare minimal price limit. Unilateral stock price patterns are rare in world financial markets. Some scholars have focused on this period of the Chinese stock market. Su and Fleisher (1998) find that the government's market intervention policies have affected stock market volatility in China. Mookerjee and Yu (1999a, 1999b) find that the Chinese stock market has significantly negative weekend effects and positive holiday effects and that price limits exert an effect on the daily pattern of returns. Los and Yu (2008) find that the Chinese stock market lacks stationarity, ergodicity and independence both before and after the various deregulations and reregulations. However, most of these studies have focused on the impact of price limits on the efficiency of financial markets. Few studies have focused on extremely small price limits. Actually, the extremely small price limit is the regulator price limit. However, there are obvious differences between the effect of extremely small price limits and that of general price limits. Accordingly, our article mainly focuses on the effect of extremely small price limits.

Actually, most of the studies above are focused on empirical research studying the impact of price limits on financial markets. The main research methods are a combination of the event study method and the group comparison method (Chari and Inamdar 2017; Kim 2001; Kim and Rhee 1997) and the autoregressive conditional heteroskedasticity (ARCH) model or the generalized autoregressive conditional heteroskedasticity (GARCH) model (Chang and Hsieh 2008; Ohuche and Ikoku 2014). Empirical research is usually done by an event study method due to data dependence. Although we use the same study method, the results may be completely different due to the selection of different data, including the characteristics of stock markets, selection periods, and market sizes. An alternative approach is agent-based modeling, which is a bottom-up approach. We can build a model to conduct a numerical simulation of an artificial financial market. Agent-based modeling can also be used to analyze the effect of price limits. Westerhoff (2003, 2006) build an agent-based model with a market-making mechanism, and finds that price limits have the effect of reducing volatility and increasing the efficiency of price discovery. Additionally, Yeh and Yang (2010) examine the effectiveness of price limits in an artificial market with bounded rational and heterogeneous traders. The results of the studies conducted by Westerhoff (2003) and Yeh and Yang (2010) are very similar. Yeh and Yang (2013) and Zhang et al. (2016) use agent-based modeling to analyze the effect of price limits, and they also use the empirical research method to examine the results. In our article, we adopt agent-based modeling to explore the issue of extremely small price limits used in the stock market.

We establish an agent-based market model under a continuous double auction mechanism in limit order markets. Each agent may have liquidity trading demands or strategy demands. The interaction of traders forms the stock price. Under the parameter settings, we conduct a number of simulations. Our model setting is inspired by Chiarella and Iori (2002), Chiarella, Iori, and Perellló (2009), and Chiarella, He, and Pellizzari (2012). The results of the model show that the unilateral trends of stock prices are consistent with the empirical analysis of the early period of the Chinese stock market. We explore whether the reason behind this phenomenon is the buyer or seller dominating the market; that is, supply and demand are seriously out of balance. We argue that this kind of one-sided market is due to a behavioral consensus among the traders. In particular, the extremely small price limit may help

achieve this behavioral consensus. At this time, the price limits that are designed to control the excess volatility of the stock price may cause the price to continue to rise or fall over a longer time horizon, even beyond the larger scale of the so-called volatility spillover effect.

This remainder of this article is organized as follows. Section 2 is an empirical analysis, and Section 3 introduces our agent-based model with price limits. In Section 4, we provide the model simulation and analyze the effect of extremely small price limits. Finally, in Section 5, we conclude our article.

2. Empirical Analysis

The Chinese stock market is an emerging stock market. On November 26, 1990, the Shanghai Stock Exchange was established, and it officially opened on December 19 of the same year. The Shanghai Stock Exchange is an important institution that safeguards the stable development of the Chinese financial system. It actively raises funds for construction services for the country and enterprises, promotes healthy investment behavior, and prohibits speculative short selling. From December 1990 to March 2018, the Shanghai Stock Exchange increased from an initial 8 stocks and 22 bonds to a stock market with 1,412 listed companies, 1,456 stocks, and 32.38 trillion renminbi (RMB) in stock market value. It has many types of financial products, including government debt, corporate bonds, funds, repurchases, warrants, and others. The Shanghai Composite Index is the first index issued by the Shanghai Stock Exchange. This index is a weighted, comprehensive stock price index with all the shares listed on the Shanghai Stock Exchange as the calculation range and the issue amount as the weight. The base date of the Shanghai Composite Index is set as December 19, 1990, and the base day index is set at 100 points. In the early period of the Chinese stock market, there was a tendency to use policies to regulate the market. The main manifestation of this is the use of price limits to control the price of every individual stock. The price limit is frequently changed and the Price Index shows the characteristics of a unilateral rise or fall, and the trading volume is very small. Table 1 shows that price limits have been implemented in the Shanghai Stock Exchange since its opening and continue to the present. The data in our article comes from the China Stock Market and Accounting Research (CSMAR) database. The sample is the daily closing price and trading volume of the Shanghai Composite Index from December 19, 1990 to December 30, 1999, a total of 2,254 trading days.

2.1. The Price Index under Different Price Limits

Figure 1a illustrates that there were six trading days with a 5% price limit from December 19 to December 26, 1990. The price of the Shanghai Composite Index continued to rise within this range, and the returns were all greater than 4%, close to the upper limit. It is worth noting that, since the price limit is for individual stocks, it is difficult for the Price Index to reach the upper or lower limit. In terms of trading volume, the trading volume on the first day was relatively large, but afterwards it

Table 1. Price limits and turnover ratio requirements of the Shanghai Stock Exchange.

Time period	Trading days	Price limit	Turnover ratio requirement
12.19.1990–12.26.1990	6	5%	None
12.27.1990–01.04.1991	6	1%	0.3%
01.07.1991–04.25.1991	77	0.5%	0.3%
04.26.1991–05.20.1992	271	1%	0.3%
05.21.1992–12.25.1996	1162	None	None
After 12.25.1996	–	10%	None

Note: All the price limits are for both upward and downward movements.

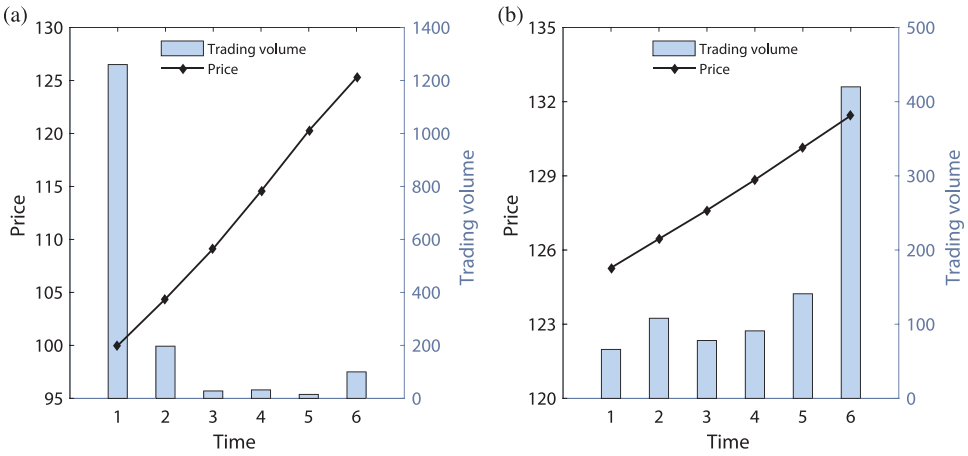

Figure 1. From December 19, 1990 to January 4, 1991, the price and trading volume of the Shanghai Composite Index. (a) From December 19 to December 26, 1990, there were six trading days with a 5% price limit. (b) From December 27, 1990 to January 4, 1991, there were six trading days with a 1% price limit.

was relatively stable. Traders showed bullish expectations for emerging stock markets, and their demand was strong during this period, so the characteristics of the market at this time showed that demand exceeded supply. To control market risk, from December 27, 1990 to January 4, 1991, the price limit was adjusted from 5% to 1%. Figure 1b illustrates that, similar to the implementation of 5% price limits, the Price Index pattern showed a unilateral upward trend of almost a 1% increase on every trading day. In addition, the trading volume of previous periods was relatively stable, and then it increased, relative to preceding days, on the last trading day. People still had bullish expectations of the stock market, and market demand remained strong during this period. During these two periods, the Price Index showed characteristics of rising unilaterally.

To prevent the rapid rise of the stocks' prices, the Shanghai Stock Exchange further narrowed the price limits to 0.5%. Figure 2 shows that from January 7, 1991 to April 25, 1991, a total of 77 trading days, the Chinese stock market used a price limit of 0.5%. During the initial stage of implementation

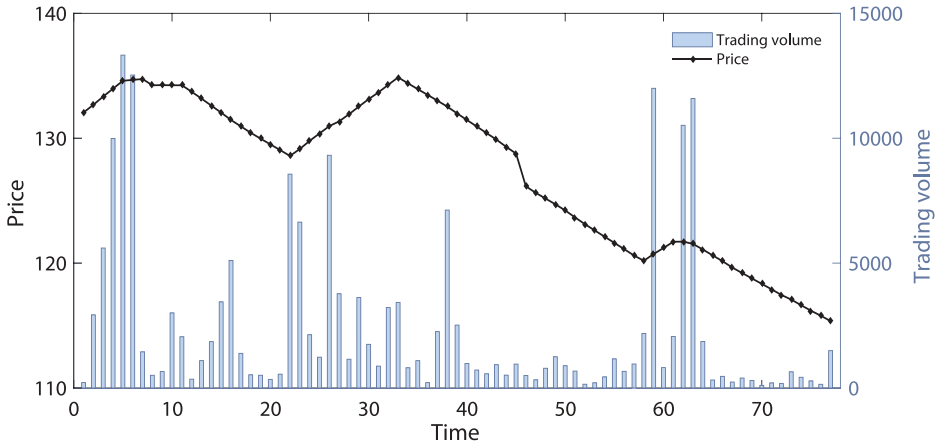

Figure 2. From January 7 to April 25, 1991, a total of 77 trading days, the price and trading volume of the Shanghai Composite Index with the price limit of 0.5%. The Price Index could also rise, but the dominant trend was a near-continuous decline.

of the 0.5% price limits, the Index could still increase sharply. By mid-January 1991, the Price Index had risen to 134.74 points, but subsequent to that increase there was a long period of adjustment. Since then, the Index could also rise, but the dominant trend was a near-continuous decline. On April 25, 1991, the Index closed at 115.36 points, down nearly 15% compared with mid-January 1991. The price limits were adjusted from 5% to 1% to 0.5%, mainly to prevent the stock index from rising too fast. However, after the middle of January 1991, the Index always showed a downward trend. The decline in price was the reaction of traders to the narrowing price limits; that is, the narrowing of price limits was a negative market signal to traders.

A continuous fall was not a good trend for the Price Index. Therefore, on April 26, 1991, the Shanghai Stock Exchange resumed 1% price limits. Figure 3 illustrates that the market soon saw the return to 1% price limits as a positive signal, and the Index showed an upward trend. In May 1991, the price of the Index gradually came out of the trough, and in July of the same year the Price Index returned to the same level as January. Since then, the Price Index continued to rise. By March 2, 1992, the Index closed at 365.39 points. At that time, the Chinese stock market developed rapidly, and transactions were active. The 1% price limits continued until May 20, 1992.

Subsequently, the Shanghai Stock Exchange fully liberalized the price and allowed stock prices to be determined by the market. Figure 4 shows the price and trading volume of the Index from May 21, 1992 to December 25, 1996. There were 1,162 trading days, more than 4 years, during which the Chinese stock market was not bound by daily price limits. The volatility of the Price Index increased significantly. We can clearly see that the Price Index had periodic sharp rises and falls during this period. On May 21, 1992, on the first day of liberalization, the Price Index rose from 616.99 points to 1266.49 points, more than double. However, on July 29, 1994, the Price Index fell to 333.92 points.

After December 25, 1996, the Chinese stock market implemented 10% price limits that remain in effect today. Figure 5 illustrates 732 trading days with 10% price limits, from December 26, 1996 to December 30, 1999. At that time, the policy of the Chinese stock market was similar to the policy in effect today. The volatility of the Price Index was significantly less than in previous periods.

2.2. The Descriptive Statistics of the Index Returns

Table 2 shows the descriptive statistics of the returns of the Shanghai Composite Index from January 7, 1991 to December 30, 1999 with price limits of 0.5%, 1%, no price limit, and 10%. We chose to analyze these four stages because there were only 6 days that used 5% and 1% price limits in

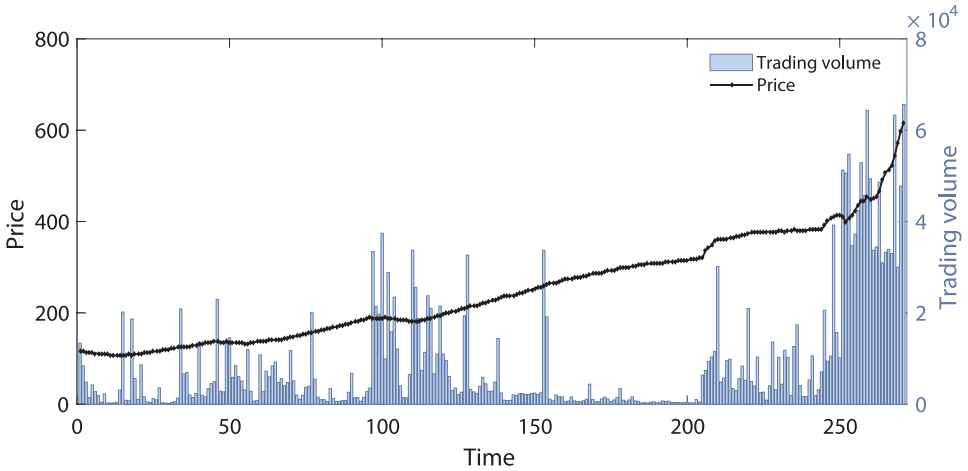

Figure 3. From April 26, 1991 to May 20, 1992, there were 271 trading days with a 1% price limit. The Price Index showed an upward trend.

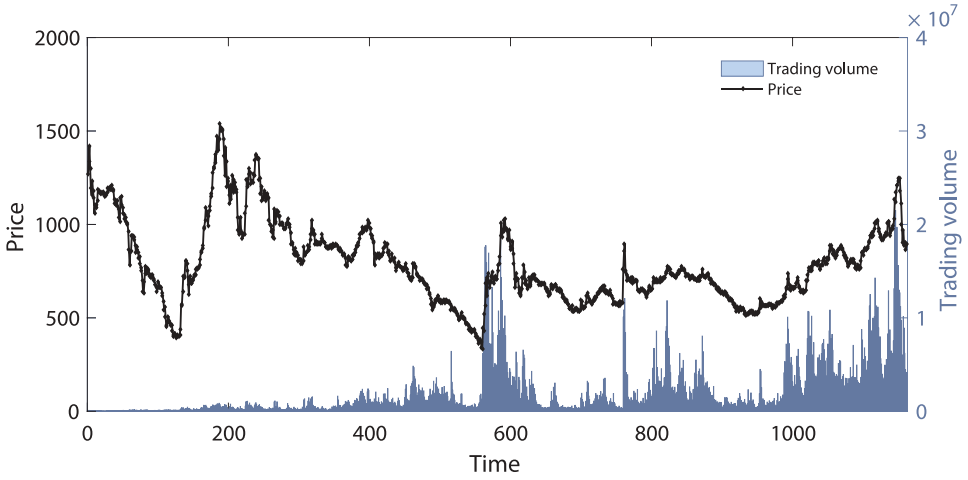

Figure 4. From May 21, 1992 to December 25, 1996, there were 1162 trading days without daily price limits. The volatility of the Price Index increased significantly.

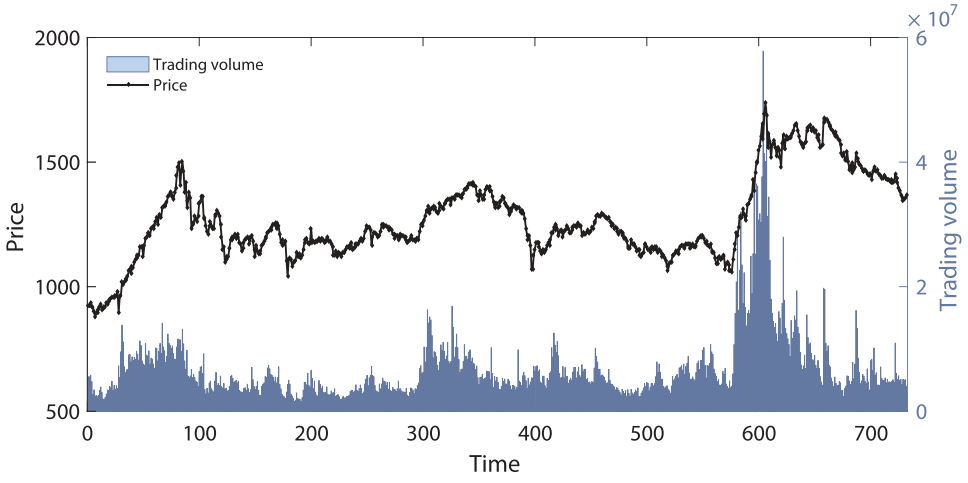

Figure 5. There were 732 trading days with a 10% price limit, from December 26, 1996 to December 30, 1999. At that time, the policy of the Chinese stock market was similar to the policy in effect today. The volatility of the Price Index was significantly less than in prior periods.

the first two stages, and we can intuitively see their price characteristics in Figure 1. In this article, all the returns represent logarithmic returns $r_t = ln(P_t/P_{t-1})$. From the chart, we can see that the smaller the price limits, the smaller the standard deviation of returns. That is, price limits can indeed restrain the fluctuation of the Price Index. It is worth emphasizing that the maximum or minimum value of the index's return exceeds the range of price limits when the value of the price limits is 0.5% and 1%. This is because some stocks in the market would take the initiative to open up the price limits during the transitional period when the policy changes with respect to price limits. The rise or fall of these initiative stocks' prices would drive the Index returns to exceed the range of price limits.

Figure 6 illustrates the density of the Index and a normal distribution with the same mean and variance during the same four periods. When Figure 6 is combined with Table 2, we find that Figure 6a–b, which shows the density of returns with 0.5% and 1% price limits, respectively, illustrate that the density of its returns presents as a multimodal distribution rather than a fat-tailed distribution,

Table 2. Descriptive statistics of the returns of the Shanghai Composite Index from January 7, 1991 to December 30, 1999 with price limits of 0.5%, 1%, none and 10%. In this article, all the returns represent logarithmic returns $r_t = ln(P_t/P_{t-1})$.

Price limit	Trading days	Max	Min	SD	Skew	Kurt
0.5%	76	0.0050	−0.0206	0.0042	−0.5115	6.9365
1%	270	0.0528	−0.0251	0.0093	1.5941	9.5231
None	1161	0.2886	−0.1791	0.0379	1.2854	12.8302
10%	731	0.0731	−0.0933	0.0180	−0.6186	7.8565

Note: We removed all implementation days of new price limits because the implementation day of the new price limits is usually the adjustment period of the stock price.

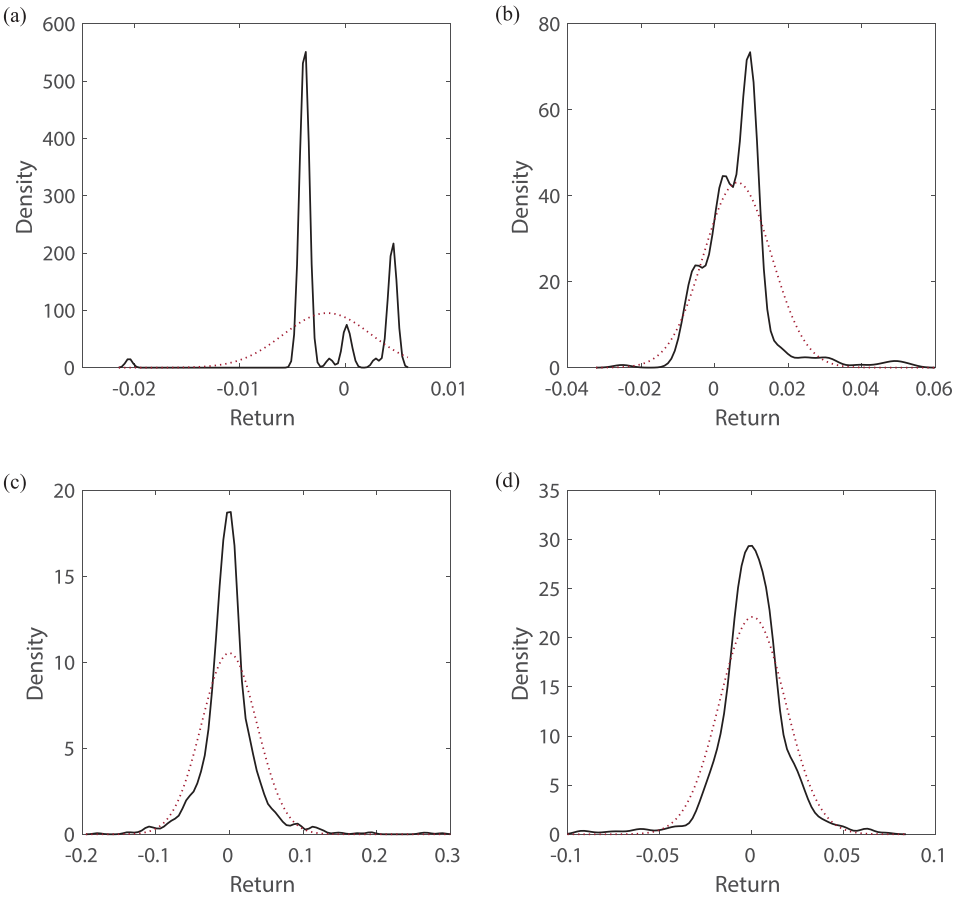

Figure 6. The density of returns of the Shanghai Composite Index is plotted using a solid black line, and a normal distribution with the same mean and variance is plotted with a dotted red line, which represent: (a) density of returns with 0.5% price limits, (b) density of returns with 1% price limits, (c) density of returns without price limits, and (d) density of returns with 10% price limits. The corresponding Price Indices of (a), (b), (c) and (d) are shown in Figures 2–5, respectively.

which is typical of financial markets. At the same time, we can also see that the peaks are concentrated near the price limits. This result powerfully demonstrates that extremely small price limits do make the Price Index rise or fall unilaterally without fluctuation. Figure 6c–d shows the

density of the Index returns under no price limits and 10% price limits, which presents as a fat-tailed distribution. Moreover, without price limits, the value of kurtosis is relatively large, as high as 12.83, which means that the Index returns easily possess extreme values. This result indicates that there will be violent fluctuations in the financial market without price limits. Choosing the right price limits can maintain the stable development of the financial market.

From the early stage of the Chinese stock market, we can see that there are obvious differences in the Index's price pattern and the descriptive statistics of the returns under the extremely small price limits and the general price limits. First, from the perspective of stock price patterns, the unilateral trend of the stock price shown in Figure 2 with the price limit of 0.5% is a typical price pattern caused by extremely small price limits. In contrast, with the price limit of 10%, the continuous nonunilateral fluctuation of the stock price is a typical price pattern under the general price limits, as shown in Figure 5. Second, from the descriptive statistics of the returns, the standard deviation of the first row with a 0.5% price limit is obviously smaller than the standard deviation of the fourth row with a 10% price limit, as shown in Table 2. Additionally, in Figure 6, it is illustrated that the density of the returns presents as a multimodal distribution with the extremely small price limits of 0.5% and 1%, as shown in Figure 6a–b, rather than a fat-tailed distribution with a general price limit of 10%, as shown in Figure 6d. Moreover, from the perspective of volatility measurement, the long-term unilateral trend brought by extremely small price limits does not mean a small fluctuation, as shown by daily volatility, because the weekly volatility and monthly volatility are higher than that brought by general price limits.

From December 1990 to January 1991, during the implementation of smaller price limits, the trading volume was extremely small. Sometimes, a stock might not trade for several days. There were two main reasons for this. First, the Chinese stock market was a pilot institution at that time, and many people took a wait-and-see attitude to securities in the emerging market. Second, the excessively small price limits restrained the momentum of stock prices and restrained transaction activity. This made traders generally reluctant to sell stocks, and the volume of transactions was relatively small. To avoid the stock price rising with extremely small volume, there were not only price limits but also a 0.3% turnover ratio requirement. Only when the turnover ratio reached 0.3% would the stock price be allowed to rise or fall by 1% or 0.5%. At that time, that was a rare spectacle in the global stock market. Securities companies were filled with people who watched a representation of the market on a big screen and waited for the trading volume to reach the 0.3% turnover ratio. When the stock price rose to a certain amount, everyone was ecstatic and applauded.

Under relatively small price limits, it was difficult for stock prices to fluctuate sharply. Additionally, the stock market was limited in its size and the number of alternative securities was very small, so the holders were more optimistic about their stocks. Most of the holders rejected selling, and this created a situation of no market. If someone expects the stock in their hands to rise by 10%, they will not sell the stock when the stock price rises by only 1%. If there are many investors with such ideas, the demand for stock will be very strong and the supply will be small; that is, the phenomenon of supply shortage will occur.

3. Model

There are N agents in our artificial stock market, and all the traders must have a liquidity trading demand or strategy demand. The strategy demand is divided into fundamentalist strategy demand and chartist strategy demand. All the traders have only one chance to enter the market, and they do so in a random order; they submit limit orders based on their strategy during each trading period t, which represents one trading day in the real stock market. At the beginning of each trading day, agents may have a liquidity trading demand with the probability of ρ_{ε}. Then, if agents do not have a liquidity trading demand, there are ρ percentage of the traders that will take the fundamentalist strategy and $(1-\rho)$ percentage of the traders that will take chartist strategy. The trading mechanism in our artificial market is a continuous double auction. Traders submit limit orders that contain order price $y_{it\tau}$ and order quantity $q_{it\tau}$ at time $\tau(t<\tau<t+1)$, and $p_{t\tau}$ is the stock's price at time τ.

3.1. Liquidity Trading Demand

When traders have a liquidity trading demand, we assume that they submit buy orders or sell orders with the same probability. The expected order price is near the stock price and is modeled by:

$$\tilde{y}_{it\tau} = p_{t\tau} + \sigma_\varepsilon z_{t\tau} \tag{1}$$

where σ_ε>0 is a given constant measuring the volatility of liquidity trading, and $z_{t\tau} \sim N(0,1)$ is a standard normal distribution. The expected order quantity $\tilde{q}_{it\tau}$ of liquidity trading is a random number in the set of $\{1, 2, \cdots, 5\}$.

3.2. Fundamentalist Strategy Demand

The fundamentalist strategy asserts that the stock price will fluctuate based on its fundamental value. The fundamental value evolves according to:

$$p^*_{t+1} = p^*_t e^{\sigma_f v_t} \tag{2}$$

where $\sigma_f \geq 0$ is a given constant volatility of fundamental return, and $v_t \sim N(0,1)$ obeys a standard normal distribution. The order type of this strategy is modeled as follows:

$$g_{it\tau} = sgn\left(p^*_t - p_{t\tau}\right) \tag{3}$$

$g_{it\tau}$ is a signal by traders to ask or bid. When $g_{it\tau} = +1$, fundamentalists want to buy the stock at time τ, because they think the stock price is undervalued and that it will go up within the next trading period when the stock price is above the fundamental value. When $g_{it\tau} = -1$, they calculate that the stock price is overestimated, so they choose to sell the stock. Next, the expected order price of fundamentalists obeys a uniform distribution:

$$\tilde{y}_{it\tau} = \begin{cases} U\left(p^*_t, p_{t\tau}\right) & \left(p^*_t \leq p_{t\tau}\right) \\ U\left(p_{t\tau}, p^*_t\right) & \left(p^*_t > p_{t\tau}\right) \end{cases} \tag{4}$$

The expected order volume of fundamentalists is modeled as follows:

$$\tilde{q}_{it\tau} = \left\lfloor \theta \left| p^*_t - p_{t\tau} \right| \right\rfloor \tag{5}$$

where θ>0 is a given constant of the reaction coefficient for fundamentalists to measure the sensitivity to the price spread.

3.3. Chartist Strategy Demand

Chartists are those who use the moving average price to make decisions. The moving average price is calculated by:

$$m_{it} = \frac{\sum_{j=1}^{d_i} p^{close}_{t-j}}{d_i} \tag{6}$$

Different traders refer to different d_i, which is the length of the moving average windows, and p^{close}_t is the closing stock price of one trading day; that is, p^{close}_t is also the stock price of trading day t. The order type of chartists is calculated by:

$$g_{it\tau} = sgn(p_{t\tau} - m_{it}) \tag{7}$$

When $g_{it\tau} = +1$, chartists want to buy the stock at time τ because they believe the stock price will go up when the stock price is over the moving average of the price. When $g_{it\tau} = -1$, they think there will be a decline in the stock value, so they choose to sell the stock. The expected order price of chartists is modeled as follows:

$$\tilde{y}_{it\tau} = p_{t\tau}(1 + \sigma_c z_{t\tau}) \tag{8}$$

where σ_c>0 is a given constant to measure the aggressiveness of chartists, and $z_{t\tau} \sim N(0,1)$ follows a standard normal distribution. The expected order volume of chartists is related to the spread of the stock price and the moving average of price that is modeled by:

$$\tilde{q}_{it\tau} = \lfloor \mu | p_{t\tau} - m_{it} | \rfloor \tag{9}$$

where μ>0 is a given constant of the reaction coefficient for chartists.

3.4. Price Limits and Wealth Constraints

For all the traders in the market, no matter which kind of strategies they have, the order price is subject to price limits and order volume is subject to wealth constraints. The allowed order price $y_{it\tau}$ is usually equal to the expected order price $\tilde{y}_{it\tau}$. However, if the expected order price $\tilde{y}_{it\tau}$ is above the highest limit price $p_{t-1}^{close}(1+L)$, the allowed order price $y_{it\tau}$ should be changed to $p_{t-1}^{close}(1+L)$. Similarly, if the expected order price $\tilde{y}_{it\tau}$ is below the lowest limit price $p_{t-1}^{close}(1-L)$, the allowed order price $y_{it\tau}$ should be changed to $p_{t-1}^{close}(1-L)$.

Additionally, we do not allow short selling, and each trader's order volume is limited by the wealth constraint, which refers to the amount of stock and cash they own at time t. Additionally, the order volume must be an integer. Therefore, the real order volume of traders is modeled as follows:

$$q_{it\tau} = \begin{cases} \lfloor min(\tilde{q}_{it\tau}, S_{it}) \rfloor & (g_{it\tau} = -1) \\ \left\lfloor min\left(\tilde{q}_{it\tau}, \frac{C_{it}}{y_{it\tau}}\right) \right\rfloor & (g_{it\tau} = +1) \end{cases} \tag{10}$$

4. Simulation Results

For each simulation, we assume that there are 1,000 agents in the market and the transaction length is 1,200. The first 100 iterations of the stock price are provided and are close to the fundamental values. This aims to provide initial data to calculate the moving averages. Therefore, the actual trading process is after the 100th trading day. To prevent transient effects, we only observe the trading time T from 201 to 1,200. The parameters of simulations are listed in Table 3. The simulation shows that, if $\rho_\varepsilon = 0$ (i.e. all the traders choose between the fundamentalist strategy and chartist strategy), then there will only be a few short-term transactions. After that, the trading stops. If $\rho_\varepsilon = 1$ (i.e. all the traders have a liquidity trading demand), the stock price is independent of the fundamental value and fluctuates around a mean value. Finally, $\rho_\varepsilon = 0.05$ is selected in our model.

We choose parameters in Table 3 for two considerations: one is to conform to the stylized facts, the other is that this set of parameters can show the following five stock patterns, which also shows that our model can be used as a reasonable explanation. For the first reason, we set price limit $L = 1$. Under the other parameters setting in Table 3, we run 100 simulations and observe the time series of the stock price and returns. We examine that the simulation results are corresponding with a series of stylized facts, such as volatility clustering, fat-tailed distribution, insignificant autocorrelations of

Table 3. Parameters used in the simulation.

Parameter	Value	Description
N	1000	Number of agents
T	1200	Trading period
S_{i0}	$\{1, 2, \cdots, 9\}$	Initial stock endowment
C_{i0}	$1000S_{i0}$	Initial cash endowment
p_0^{close}	1000	Initial stock price
p_0^*	990	Initial fundamental value
σ_f	0.002	Volatility of fundamental value
θ	0.05	Reaction coefficient for fundamentalists
μ	0.1	Reaction coefficient for chartists
d_i	$\{20, 21, \cdots, 100\}$	Length of moving average windows
σ_c	0.0005	Aggressiveness parameter
ρ_ε	0.05	Probability of having a liquidity trading demand
ρ	0.5	Percentage of the traders with fundamentalist strategy
σ_ε	$\sigma_f p_0^*$	Volatility of random offset of liquidity trading
L	$\{0, 0.1\%, \cdots, 1\}$	Price limits

returns, and significant slowly decaying autocorrelations of the absolute returns. All of these characteristics show that our model can better reflect the stylized facts of the financial market. For the second reason, we actually achieve the strict unilateral increase or decrease stock patterns when we use this model to verify the effect of extremely small price limits.

4.1. The Effect of Price Limits

We calculate the stock price, volatility of returns, and trading volume with different price limits. Price limits L range from 0% to 10%, at an interval of 0.5%. This is because when the price limit goes beyond this range, it has almost no effect on the stock price. For each price limit, we run 10 times with different seeds of random variables. Volatility and trading volume are calculated from 1,000 observations, which is the trading period from 201 to 1,200. Parameters are set in Table 3. We use the standard deviation of returns to measure the volatility V and the average trading volume to measure the liquidity Q (Q_t represents daily trading volume). Figure 7 shows the simulation result.

$$V = \sqrt{\frac{1}{T}\sum_{t=201}^{T}(r_t - \bar{r})^2} \tag{11}$$

$$Q = \frac{1}{T}\sum_{t=201}^{T} Q_t \tag{12}$$

From Figure 7a, with the increase of price limits, volatility continuously increases until it reaches its no-price-limit value. That is, effective price limits can truly restrain the market volatility. From Figure 7b, we see that liquidity increases with the price limit increase from 0% to 2% and then goes smoothly from 2% to 10%. In other words, small price limits can also restrain the trading volume. This result corresponds to the typical fact that, in the early period of Chinese stock market, trading volume was very small under the extremely small price limits.

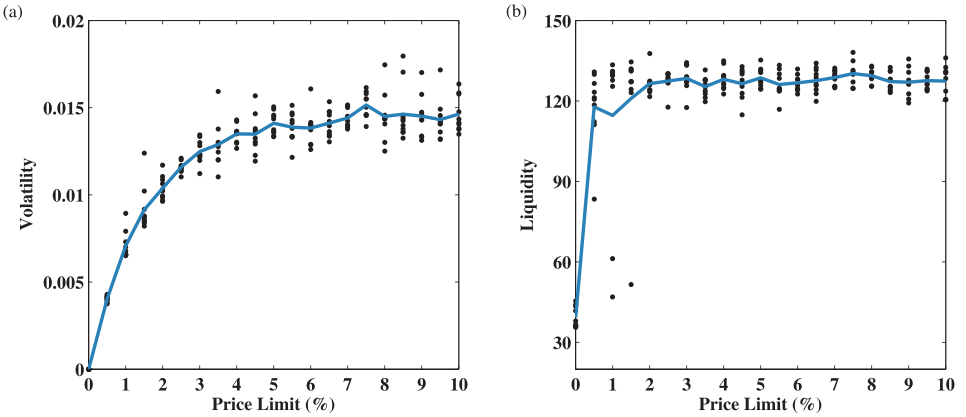

Figure 7. The effect of price limits. Price limits range from 0 to 10%, at an interval of 0.5%. For each price limit, we run 10 times with different seeds of random variables. Parameters are set in Table 3. (a) Volatility; (b) Liquidity. The solid lines indicate the averages.

4.2. The Effect of Extremely Small Price Limits

We mainly analyzed stock price patterns under extremely small price limits. We simulated 100 times under the parameters of Table 3 with a 0.1% price limit, and then found five typical stock patterns: a strict unilateral increase, a strict unilateral decrease, an uptrend after a downtrend, a downtrend after an uptrend and stable fluctuations, as shown in Figure 8. Other price patterns can be regarded as the combination of these five typical patterns. We find that the main reason for different price patterns is the traders' behavioral consensus when the stock price deviates from the fundamental value. It is worth emphasizing that we think that the fundamental value represents the intrinsic value of the stock in our model.

Figure 8a shows that the stock price is continuously increasing. At this time, the fulfillment ratio of ask orders continues to be 1, which means that all the limit ask orders can be traded, and the market is dominated by buyer power. In this situation, the stock price is below the fundamental value, so those embracing the fundamentalist strategy believe that the stock price is undervalued and they will submit bid orders. Additionally, the stock price keeps rising, so those embracing the chartist strategy also think the stock price will continue to go up and they will submit bid orders. At this time, the fundamentalist strategy and chartist strategy conform to one another. Relatedly, the number of ask orders submitted by liquidity trading demand is very small compared with bid orders, and there is a serious imbalance between supply and demand in the market. Accordingly, all the ask orders can be realized. The buyers completely dominate the market. Figure 8b shows that the stock price is continuously decreasing. At this time, the fulfillment ratio of bid orders continues to be 1, which means that all limit bid orders can be traded, and the market has been dominated by sellers. In this situation, the fundamentalist strategy and the chartist strategy conform to each other by submitting ask orders. The stock market has a supply surplus during this time, so all the bid orders can be realized. We infer that, in the market with extremely small price limits, once the intrinsic value of the stock cannot respond effectively, as in Figure 8a,b, the market will continuously have a volatility spillover effect in the long run. Figure 8c,d show the stock price patterns of an uptrend after a downtrend and a downtrend after an uptrend, which reveals price reversal. The deviation between stock price and fundamental value arouses changes in traders' behavior. As shown in Figure 8c,d, when the stock price reaches the fundamental price, the stock price will continue to fall or rise for a while because of the momental effect of the chartist strategy. Based on this point, we infer that the stock price continues to rise or fall for a longer time and with an even bigger range compared to the volatility spillover effect. Figure 8e shows stable fluctuations of the stock price. At this time, the stock

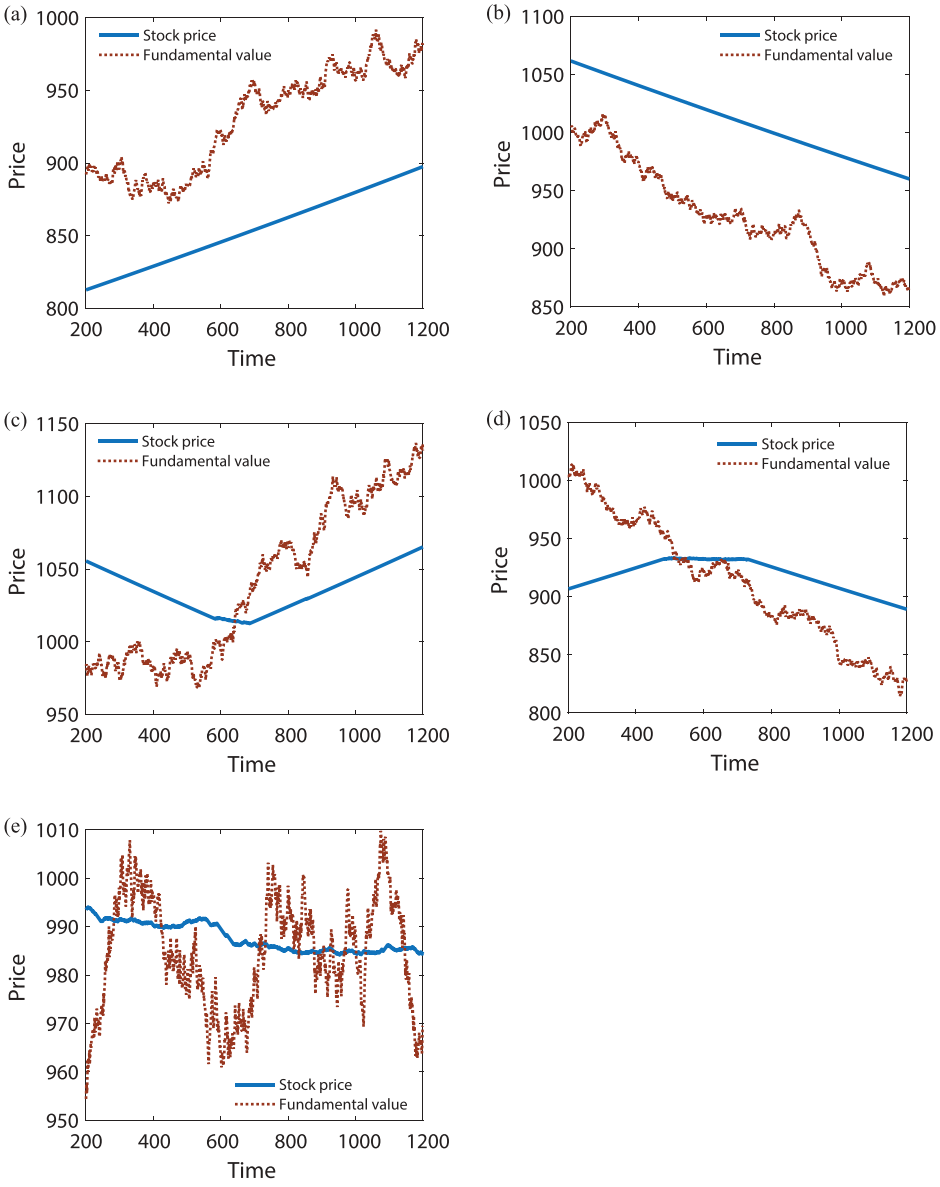

Figure 8. There are five main price patterns: (a) strict unilateral increase; (b) strict unilateral decrease; (c) uptrend after downtrend; (d) downtrend after uptrend; (e) stable fluctuations.

price is close to the fundamental value, which makes the supply and demand balanced, so the fluctuation of the stock price is relatively small.

Combined with Figures 7 and 8, we find that, in our model, there are extremely small price limits nearly at 0% to 1.5%, accompanied by the unilateral trend. And there are effective price limits nearly at 1.5% to 5%, because these price limits can truly restrain market volatility, and the stock price shows normal fluctuations with a rare unilateral trend at this range of price limits. Finally, there is almost no effect on stock price and volatility with price limits above 5%.

5. Conclusions

We have found that there was a policy of using price limits to prevent stock prices from rising too rapidly in the early period of the Chinese stock market. Especially during the period from December 19, 1990 to May 20, 1992, the Shanghai Stock Exchange used price limits of 5%, 1%, 0.5%, and 1%, which were adjusted very frequently and the value of which was very small. We find that, with extremely small price limits, the Shanghai Composite Price Index shows a unilateral trend close to the value of the price limits rather than a stable fluctuation. We used a model to explain this phenomenon. We establish an agent-based market model under the continuous double auction mechanism in limit order markets to explore the effect of extremely small price limits. Under these parameter settings, we conducted a number of simulations. The results of the stock price patterns can be divided into five types that include a strict unilateral increase, a strict unilateral decrease, an uptrend after a downtrend, a downtrend after an uptrend and stable fluctuations. Specifically, this result is consistent with the empirical analysis of the early period of the Chinese stock market. The empirical data provide a good natural experiment to support the results of our model.

Additionally, we find that the unilateral stock price is the result that the buyer or seller dominants the market. That is, supply and demand are seriously out of balance. This is because the traders' behavioral consensus (i.e. the fundamentalists and chartists both have the same trading direction [buy or sell]). This behavioral consensus emerges more easily when the stock price persistently deviates from the fundamental value that represents the intrinsic value of the stock in most traders' minds. In the actual financial market, the intrinsic value of stocks is not observable, so the trader estimates the fundamental value based on available information, including the current stock market price; even the price limits themselves are a signal that could affect the traders' judgement of the stocks' intrinsic value. Therefore, the traders' reaction to market information may change the stock's fundamental value, and there may be a sudden reversal of fundamental value in traders' minds. If the stock price deviates too much from the fundamental value in most traders' minds, it may cause a behavioral consensus between the fundamentalist traders and chartist traders. For example, from January 7 to April 25, 1991, with 0.5% price limits, the time series of the Price Index showed a unilateral increase or a unilateral decrease with small fluctuations, and the price sometimes experienced a sudden reversal. At that time, price limits acted as a signal to affect traders' judgement of the stocks' intrinsic values, thus affecting their trading behavior and finally affecting the stock price patterns, rather than stabilizing the market.

Overall, the cognitive effect of the fundamentalist strategy on the fundamental value and the positive feedback characteristics of the chartist strategy make the traders become conformist, which leads to a unilateral market, where the stock price continues to rise or fall for a longer time and with an even bigger range compared to the volatility spillover effect. Moreover, from the perspective of volatility measurement, the long-term unilateral trend brought by extremely small price limits may have bigger volatility than an average market brought by general price limits when we use weekly or monthly volatility. Things go awry, and the extremely small price limits that are designed to stabilize the market may cause the price fluctuation to continue even longer and be even greater.

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References

Abad, D., and R. Pascual. 2007. On the magnet effect of price limits. *European Financial Management* 13:833–52. doi:10.1111/j.1468-036X.2007.00399.x.

Armstrong, M., and J. Vickers. 1991. Welfare effects of price discrimination by a regulated monopolist. *The RAND Journal of Economics* 571–80. doi:10.2307/2600990.

Berkman, H., and J. B. T. Lee. 2002. The effectiveness of price limits in an emerging market: Evidence from the Korean stock exchange. *Pacific-Basin Finance Journal* 10:517–30. doi:10.1016/S0927-538X(02)00040-9.

Bildik, R., and G. Gülay. 2006. Are price limits effective? Evidence from the Istanbul stock exchange. *Journal of Financial Research* 29:383–403. doi:10.1111/j.1475-6803.2006.00185.x.

Brennan, M. J. 1986. A theory of price limits in futures markets. *Journal of Financial Economics* 16:213–33. doi:10.1016/0304-405X(86)90061-9.

Chang, C. H., and S. L. Hsieh. 2008. Is the daily price limit of the Taiwan stock exchange effective? Fundamentals of listed stocks and investors perception of fair price. *Asia-Pacific Journal of Financial Studies* 37:675–726.

Chari, L., and M. M. Inamdar. 2017. Impact of price limit on stock performance. *Research Bulletin* 43:114–22.

Chiarella, C., X. Z. He, and P. Pellizzari. 2012. A dynamic analysis of the microstructure of moving average rules in a double auction market. *Macroeconomic Dynamics* 16:556–75. doi:10.1017/S136510051000074X.

Chiarella, C., and G. Iori. 2002. A simulation analysis of the microstructure of double auction markets. *Quantitative Finance* 2:346–53. doi:10.1088/1469-7688/2/5/303.

Chiarella, C., G. Iori, and J. Perelló. 2009. The impact of heterogeneous trading rules on the limit order book and order flows. *Journal of Economic Dynamics and Control* 33:525–37. doi:10.2139/ssrn.893087.

Cho, D. D., J. Russell, G. C. Tiao, and R. Tsay. 2003. The magnet effect of price limits: Evidence from high-frequency data on Taiwan stock exchange. *Journal of Empirical Finance* 10:133–68. doi:10.1016/S0927-5398(02)00024-5.

Chung, J., and L. Gan. 2005. Estimating the effect of price limits on limit-hitting days. *The Econometrics Journal* 8:79–96. doi:10.1111/j.1368-423x.2005.00153.x.

Fernandes, M., and M. Aurélio. 2007. Are price limits on futures markets that cool? Evidence from the Brazilian mercantile and futures exchange. *Journal of Financial Econometrics* 5:219–42. doi:10.1093/jjfinec/nbm001.

Greenwald, B. C., and J. C. Stein. 1991. Transactional risk, market crashes, and the role of circuit breakers. *Journal of Business* 443–62. doi:10.1016/0167-6687(93)91051-u.

Hsieh, P. H., Y. H. Kim, and J. J. Yang. 2009. The magnet effect of price limits: A logit approach. *Journal of Empirical Finance* 16:830–37. doi:10.1016/j.jempfin.2009.06.002.

Huang, Y. S., T. W. Fu, and M. C. Ke. 2001. Daily price limits and stock price behavior: Evidence from the Taiwan stock exchange. *International Review of Economics & Finance* 10:263–88. doi:10.1016/S1059-0560(00)00082-4.

Ippolito, P. M. 1991. Resale price maintenance: Empirical evidence from litigation. *The Journal of Law & Economics* 34:263–94. doi:10.1086/467226.

Kim, K. A. 2001. Price limits and stock market volatility. *Economics Letters* 71:131–36. doi:10.1016/S0165-1765(00)00403-1.

Kim, K. A., and S. G. Rhee. 1997. Price limit performance: Evidence from the Tokyo stock exchange. *Journal of Finance* 52:885–901. doi:10.1111/j.1540-6261.1997.tb04827.x.

Kodres, L. E., and D. P. O'Brien. 1994. The existence of pareto-superior price limits. *The American Economic Review* 84 (4):919–32.

Los, C. A., and B. Yu. 2008. Persistence characteristics of the Chinese stock markets. *International Review of Financial Analysis* 17:64–82. doi:10.1016/j.irfa.2006.04.001.

Mookerjee, R., and Q. Yu. 1999a. Seasonality in returns on the Chinese stock markets: The case of Shanghai and Shenzhen. *Global Finance Journal* 10:93–105. doi:10.1016/S1044-0283(99)00008-3.

Mookerjee, R., and Q. Yu. 1999b. An empirical analysis of the equity markets in china. *Review of Financial Economics* 8:41–60. doi:10.1016/S1058-3300(99)00006-3.

Ohuche, F. K., and A. E. Ikoku. 2014. Financial management focus on price volatility and circuit breakers in the Nigerian equity market implications for monetary policy. *Journal of Financial Management & Analysis* 27:1.

Su, D., and B. M. Fleisher. 1998. Risk, return and regulation in Chinese stock markets. *Journal of Economics and Business* 50:239–56. doi:10.1016/S0148-6195(98)00002-2.

Timberlake, W. 1984. A temporal limit on the effect of future food on current performance in an analogue of foraging and welfare. *Journal of the Experimental Analysis of Behavior* 41:117–24. doi:10.1901/jeab.1984.41-117.

Westerhoff, F. 2003. Speculative markets and the effectiveness of price limits. *Journal of Economic Dynamics and Control* 28:493–508. doi:10.1016/S0165-1889(02)00185-9.

Westerhoff, F. H. 2006. Technical analysis based on price-volume signals and the power of trading breaks. *International Journal of Theoretical and Applied Finance* 9:227–44. doi:10.1142/S0219024906003512.

Wong, W., B. Liu, and Y. Zeng. 2009. Can price limits help when the price is falling? Evidence from transactions data on the shanghai stock exchange. *China Economic Review* 20:91–102. doi:10.1016/j.chieco.2008.09.002.

Yeh, C. H., and C. Y. Yang. 2010. Examining the effectiveness of price limits in an artificial stock market. *Journal of Economic Dynamics and Control* 34:2089–108. doi:10.1016/j.jedc.2010.05.015.

Yeh, C. H., and C. Y. Yang. 2013. Do price limits hurt the market? *Journal of Economic Interaction and Coordination* 8:125–53. doi:10.1007/s11403-012-0107-4.

Zhang, X., J. Ping, T. Zhu, Y. Li, and X. Xiong. 2016. Are price limits effective? An examination of an artificial stock market. *Plos One* 11:e0160406. doi:10.1371/journal.pone.0160406.