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Research Article

Shock Transfer in Futures and Spot Markets: An Agent-Based Simulation Modelling Method

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There have been heated debates about the role of stock index futures in the financial market, especially during the crash periods. In this paper, a multiagent spot-futures market model is developed to analyze the micromechanism of shock transfer across spot and futures markets. We assume that there are two stocks and one stock index futures contract in the spot-futures market. Agents are heterogeneous, including fundamentalists, chartists, noise traders, and arbitragers. The spot market and the futures market are linked by arbitragers. The simulation results show that our spot-futures market model can reproduce various important stylized facts, including the price co-movement between stock index prices and index futures prices and the fat-tailed distribution of the returns of risky assets and the basis. Further analysis shows that when we introduce an exogenous fundamental shock to one of the stocks, the backwardation phenomenon appears in the futures market and the shock is widespread across the whole market by means of index futures. Moreover, the backwardation gradually disappears when the number of arbitragers increases. Besides, when there are few arbitragers or when there are sufficient arbitragers, shocks cannot be transferred to other stocks via the futures market, while an intermediate level of arbitrage will amplify the shock transfer and hurt market stability. These findings underscore that arbitragers play an important role in spot-futures market interaction and shock transfer, and adequate arbitrage trading during crises may help eliminate the positive basis and halt the further spread of the crises.

1. Introduction

In 2015, China's stock market experienced a roller coaster ride. From mid-July 2014 to mid-June 2015, the CSI 300 index climbed almost 150%, reaching a seven-year high of 5380. The bubble, however, broke on June 12, 2015, and the stock market collapse began. Within a month, A-shares lost about a third of their value. Following that, large aftershocks occurred around "Black Monday" on July 27 and August 24, 2015. From mid-June to mid-September, more than 1,000 stocks plummeted by the daily limit of 10% every four trading days on average. Selling index futures was blamed for the crash. Stock index futures are cash-settled future contracts on the value of stock index. On 16 April 2010, the CSI 300 index futures, known as the first stock index futures contract in China, were launched. During the market crises in 2015, the daily turnover in CSI 300 index futures rocketed up to 2 million. Besides, during this crash, stock index futures prices dropped lower than stock index prices and this backwardation anomaly persisted for a long time.

It has been debated for a long time about the role of stock index futures in the financial markets, especially during the crash period. After the October 1987 stock market crash, the well-known Brady Commission report stated that the interaction of index arbitrage and portfolio insurance across the spot and futures markets was the cause of this collapse. As stock prices sank, the portfolio insurance programs sold index futures to limit losses, resulting in the backwardation. This backwardation encouraged arbitragers to sell stocks and purchase index futures, further depressing spot prices. This view has become known as the *cascade theory*. However, opponents argue that there is no direct evidence that the futures market should be responsible for this crash, and measures such as increasing margin requirements and the circuit breaker mechanism could not play a preventive role (see Miller et al. [1]; Becketti and Roberts [2]; and Antoniou and Garrett [3]). The controversy still remains.

2. Literature Review

There is a series of empirical studies focusing on the impact of the index futures on the underlying assets but drawing inconsistent conclusions (see Edwards [4]; Wade [5]; Baldauf and Santoni [6]; Pericli and Koutmos [7]; Darrat et al. [8]; Antoniou and Holmes [9]; Antoniou et al. [10]; Fan and Du [11]; and Gulen and Mayhew [12]). In the futures market, all transactions are conducted through leverage trading. Advocates believe that the futures market's high liquidity can facilitate the flow of information into the stock market, hence improving the market's pricing efficiency and stability, while opponents argue that excessive speculation in futures market might introduce unstable elements into the stock market, thereby impairing market efficiency. Antoniou et al. [13] asserted that empirical studies' conflicting findings are attributable to the fact that the proportion of feedback traders differs among markets. This conclusion is compatible with the theoretical research results of Weller and Yano [14].

There are also some works focusing on the backwardation anomaly, which frequently happens and plays an important role during crises, as *cascade theory* described. It is a widely accepted principle that, considering the carry cost, the spot price should not be persistently higher than the futures price in the frictionless market; otherwise, buying a futures contract and selling spot would yield a profit. But a series of empirical studies observed the mispricing phenomenon in financial markets around the world, including the United States, Europe, Japan, and India (see Chung [15]; Klemkosky and Lee [16]; Yadav and Pope [17]; Białkowski and Jakubowski [18]; Marcinkiewicz et al. [19]; and Kadapakkam and Kumar [20]). Further research showed that the mispricing phenomenon in futures markets may result from stock dividends, short selling restrictions, illiquidity, market sentiment, and so on (see Modest and Sundaresan [21]; Marcinkiewicz [19]; Gay and Jung [22]; Kempf [23]; Fung and Draper [24]; Fung and Jiang [25]; Roll et al. [26]; and Kadapakkam and Kumar [20]).

Most of the studies above are empirical research studies, which have limited ability to analyze cross-market risk from micromechanisms such as cross-market traders' behavior. Meanwhile, the theoretical models based on traditional economic and finance theory are always established under some unrealistic assumptions, such as the rational expectations of traders. The theoretical models of King and Wadhwani [27]; Yuan [28]; and Gromb and Vayanos [29] provide us with a framework for understanding the micromechanism of risk transfer but ignore some important features of real-world financial market. For example, the investors are heterogeneous and have bounded rationality. The agent-based modelling method, which is a hot topic and has been used in multiple fields and disciplines in recent years (see Li et al. [30]; Li et al. [31]; Sena et al. [32]; Zhao et al. [33]; Rupnik et al. [34]; Fragapane et al. [35]; and Yang et al. [36]), provides us with an alternative approach. Agent-based modelling is a bottom-up approach with more realistic bottom settings and can produce much more stylized facts than theoretically oriented models.

Recently, there have been several studies using the agent-based modelling method to analyze the interaction between spot and futures markets. Ohi et al. [37] built an agent-based multimarket model to simulate the spot-futures market and found out that the two-market model performed better in terms of reproducing the typical statistical properties of Nikkei 225 index futures prices than one-market model. Torii et al. [38] investigated shock transfer through multiple assets caused by arbitragers and the effect of circuit breakers. Besides, Wei et al. [39, 40] built a multiagent model based on empirical data in the CSI 300 index futures market and, respectively, examined the tick size effect and position limit effect in stock index futures market. Xu et al. [41] constructed an artificial spot-futures market model with cross-market traders and successfully reproduced the typical characteristics of Chinese stock market and the CSI 300 index futures market. After that, Xiong et al. [42]; Liang et al. [43], and Xiong et al. [44] did further research based on the model of Xu et al. [41]. Xiong et al. [42] focused on the price limits level in futures market and found that enhancing or removing price limits could both hurt market stability. Liang et al. [43] analyzed the effects of $T+1$ trading rule on futures market. Xiong et al. [44] evaluated the trading strategies in stock index futures market based on their artificial cross-market platform. Moreover, there are also some agent-based simulation platforms, such as the SumWEB in Cappellini [45] and the U-Mart in Shiozawa et al. [46], combining the simulation platform with real financial market so that human agents can trade with machine agents on these platforms.

Torii et al. [38] established a spot-futures market model with multiassets that has some similarities to our model. Their work, however, is more focused on how fundamental weight and chartist weight impact on the shock transfer progress, and they assume that every local agent uses a strategy that blends three components (fundamentalist, chartist, and noisy). Instead, we set the traders in our model to be fully fundamentalist or chartist as Chiarella et al. [47] and change the experiment environments by changing the number of different types of agents, which is more intuitive and realistic. We have proved that our model can reproduce some important stylized facts in the real financial market. Moreover, we not only analyze the micromechanism of market risk diffusion but also analyze how the number of arbitragers impacts the risk diffusion process. As far as we know, the existing relevant agent-based research pays more attention to whether regulatory measures, such as price limits and circuit breakers, are effective to maintain market stability or halt the further spread of the crisis. But due to the fact that regulatory measures affect market quality by influencing trader's investment behavior, we believe it is certainly worth checking how different types of traders, especially arbitragers, who are cross-market traders and may play an important role in the risk diffusion process, influence market first. Hence, we change the number of arbitragers in our artificial spot-futures market and conduct simulations to figure out whether arbitrage trading should be encouraged or restricted during crises, which can offer some meaningful suggestions for policy formulation at the qualitative level.

This paper is organized as follows. Section 3 introduces the spot-futures market model. In Section 4, we provide an analysis of the simulation results of the model. Finally, in Section 5, we present our conclusion.

3. The Model

Inspired by Ohi et al. [37] and Torii et al. [38], we built an order-driven cross-market model based on the same framework as Chiarella et al. [47]. The salient features of the model of Chiarella et al. [47] can be briefly outlined as follows: heterogeneous agents trade based on a fundamentalist or chartist strategy or noise trading strategy occasionally in the continuous double auction stock market where only one stock is traded. With a realistic market microstructure, their model can reproduce plenty of stylized facts in stock market, including the fat-tailed distribution of the stock's returns and the volatility clustering. In order to analyze how shocks to a single stock spread throughout the entire stock market by futures market and figure out the role of stock index futures during the crash periods, we extended the single-asset single-market model of Chiarella et al. [47] to a multiasset multimarket model and introduced cross-market traders into our artificial spot-futures markets. Most of the model structure is retained from the model of Chiarella et al. [47] in terms of fundamentalists, chartists, and noise traders' trading strategies. The detailed structure of our model is shown in Figure 1.

Firstly, there exist a futures market where the stock index futures are traded and a spot market (also called the stock market) where the stocks are traded. We suppose there are two stocks (marked as stock 1 and stock 2) in the spot market, giving a minimal multiasset model. Besides, there exists a stock index (also called the stock market index), which is a collection of stocks and gives an overview of how the spot market performs. In the futures market, there is one stock index futures contract (marked as asset f) whose underlying asset is the stock index. Each risky asset has its own fundamental value, which is different from its market price. The former reflects the present value of a risky asset's future cash flows and is considered to be the true value, while the latter is determined by transactions and reflects traders' perception of the risky asset's value. The fundamental values are exogenous given in our model, while the market prices are determined by the transactions between the traders in our artificial spot-futures market.

Secondly, the trading mechanism in our artificial spot-futures market is continuous double auction (CDA), which is widely used in modern financial exchanges around the world, including China. In a CDA market, traders can enter the market and submit orders at any time during the trading periods. Traders in the CDA markets usually submit limit orders. A limit order is a type of order to buy (sell) a specified quantity of security at a specified price or lower (higher). Hence, a limit order (H, l, q) consists of three elements: the order direction (i.e., buy or sell) H, the limit price l, and the order volume q. The orders in the CDA market are executed based on price-time priority. The details of the CDA trading mechanism and the limit order can be found in Chiarella et al. [47] and our previous work (Zhou and Li [48]).

Thirdly, we consider each trading step t in our model as a trading day. During each trading day, all traders enter the market randomly and can only submit one order into the spot market or/and the futures market. In the following, we suppose a trader i enters the market at time $\tau (t < \tau < t + 1)$, which is an intraday time subscript that will be used with variables that can assume different values in the same trading day, such as the price of a risky asset traded in any continuous auction. For example, $p_{a,t\tau}$ is the last market price of asset a when the trader enters the market at time τ. Traders submit orders according to their heterogeneous trading strategies. We classify traders into four types by their trading strategies: fundamentalists, chartists, noise traders, and arbitragers. Fundamentalists, chartists, and noise traders are local traders who can only trade on one specific asset, while arbitragers are cross-market traders who submit orders both in the spot market and the futures market. The spot market and the futures market can be linked through arbitragers' trading behaviors.

Finally, in the spot market, short selling and buying on margin are forbidden, while in the futures market, all transactions are executed through margin trading (also called leverage trading). Hence, traders are subject to different degrees of wealth constraints in the spot market and the futures market. The details of our multiasset multimarket model are described as follows.

3.1. Assets in Spot-Futures Market

3.1.1. Stocks in Spot Market. Following the assumption in Chiarella et al. [47], the fundamental value of stock 1 and stock 2 $p^*_{s,t}$ $(s \in \{1, 2\})$ of trading day t in our model is set to evolve as

$$p^*_{s,t} = p^*_{s,t-1} \exp(\sigma_s \nu_t), \tag{1}$$

where $\nu_t \sim N(0, 1)$ is subject to the standard normal distribution and $\sigma_s \geq 0$ is the constant volatility of the fundamental returns.

3.1.2. Stock Index in Spot Market. In spot market, the stock index cannot be traded directly, and its price is calculated as a weighted sum of the market prices of underlying stocks (see Hull [49]). Given a set of underlying stocks $s \in \mathbb{S}$, the price-weighted stock index $I_{t\tau}$ can be calculated as

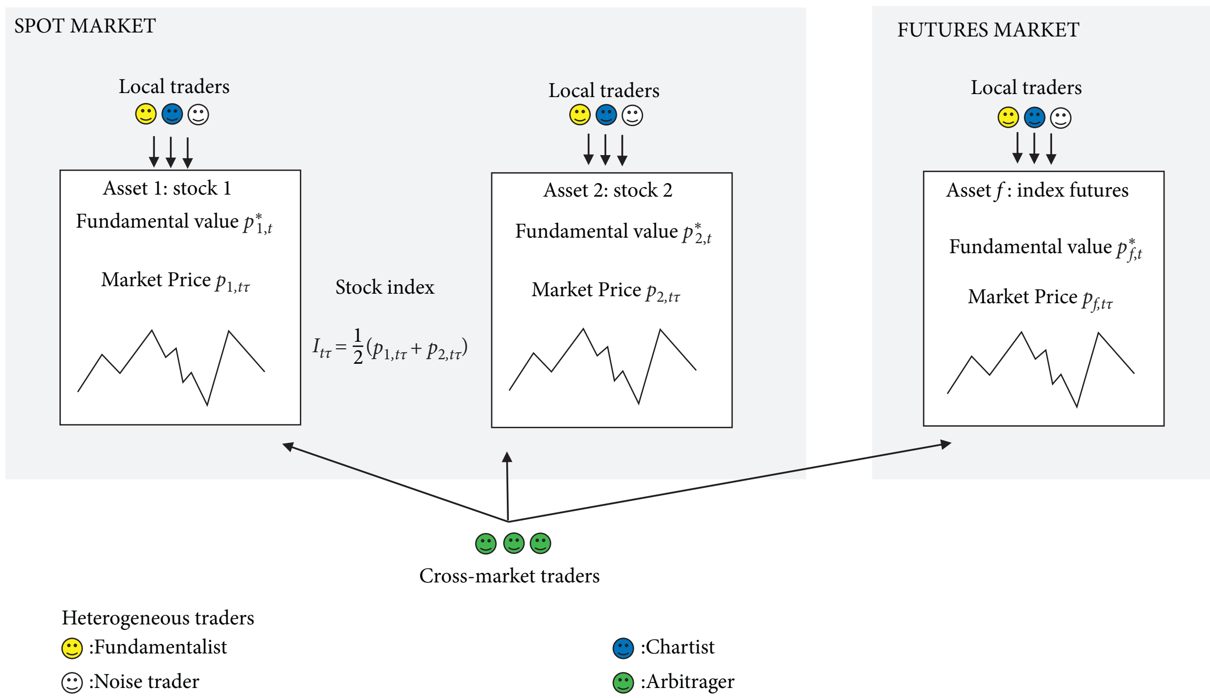

Figure 1: The multiasset multimarket model: stocks and stock index in spot market, stock index futures in futures market, and heterogeneous traders.

$$I_{t\tau} = \frac{1}{|\mathbb{S}|} \sum_{s \in \mathbb{S}} p_{s,t\tau}, \quad (2)$$

where $p_{s,t\tau}$ is the market price of stock s at time τ in trading day t. In our model, the number of stocks is set to be 2 and $s \in \{1, 2\}$. Hence, the price of stock index is

$$I_{t\tau} = \frac{1}{2}\left(p_{1,t\tau} + p_{2,t\tau}\right). \quad (3)$$

Similarly, the fundamental value of the stock index I^*_t can be calculated in the same manner of the price-weighted stock index, using the fundamental value of the underlying stocks:

$$I^*_t = \frac{1}{2}\left(p^*_{1,t} + p^*_{2,t}\right). \quad (4)$$

3.1.3. Stock Index Futures in Futures Market. Stock index futures are future contracts to buy or sell stock index on a future date at a specific price. According to the *spot-futures parity theorem* (see Hull [49]), the theoretical price of index futures equals the underlying stock index's current price, adjusted for time plus carrying costs and benefits during the delivery period. Since stock dividends are not considered in our spot-futures market, the index futures' theoretical price $\overline{p}_{f,t\tau}$ can be calculated as the underlying stock index's current price, adjusted for time plus carrying costs:

$$\overline{p}_{f,t\tau} = e^{r(T-t)} I_{t\tau}, \quad (5)$$

where T is the delivery time of the futures contract and r is the risk-free interest rate.

Similarly, we calculate the fundamental value of stock index futures $p^*_{f,t}$ in the same manner as we do for the theoretical price, using the stock index's fundamental value:

$$p^*_{f,t} = e^{r(T-t)} I^*_t. \quad (6)$$

3.2. Trading Strategies of Heterogeneous Traders. As mentioned at the beginning of Section 3, in a CDA market, traders usually submit limit orders (H, l, q). In this section, we will introduce how a trader decides whether to buy or sell (i.e., the order direction H), the limit price l, and the desired order volume $\overline{q}$ according to his trading strategy. We will further introduce how to determine the practical order volume q in Section 3.3 ($q \leq \overline{q}$: the desired order volume $\overline{q}$ is the order volume a trader wants to submit despite the wealth constraint; hence, the practical order volume q, which is the order volume a trader can submit considering his wealth constraints, is generally less than or equal to the desired order volume).

3.2.1. Fundamentalist. Fundamentalists are informed traders who know the assets' latest fundamental value $p^*_{a,t}$ $(a \in \{1, 2, f\})$. In the financial market, fundamentalists are usually institutional investors. They pay costs to get the information about the asset's fundamental value and believe that the asset's market price will revert to its fundamental value.

Following the assumption in Chiarella et al. [47] that if asset's market price $p_{a,t\tau}$ is higher (lower) than its fundamental value $p^*_{a,t}$, fundamentalists consider this asset to be overestimated (underestimated) and tend to submit sell (buy) orders, we determine the order direction $H_{a,it\tau}$ $(a \in \{1, 2, f\})$ for fundamentalist i as

$$H_{a,it\tau} = \mathbf{sgn}\left(p^*_{a,t} - p_{a,t\tau}\right), \quad (7)$$

where **sgn** denotes the sign function and $H_{a,it\tau} = 1\,(-1)$ means that the fundamentalist tends to submit buy (sell) limit order. As for the limit price, simplifying the assumptions in Chiarella et al. [47] and Ohi et al. [37], the limit price $l_{a,it\tau}\,(a \in \{1,2,f\})$ is assumed to be close to the asset's latest market price:

$$l_{a,it\tau} = p_{a,t\tau}\left(1 + \left|\Delta z_{t\tau}\right| H_{a,it\tau}\right), \tag{8}$$

where $z_{t\tau} \sim N(0,1)$ and $\Delta > 0$ is a constant, which describe the limit price's aggressive level. A large Δ means the traders tend to submit aggressive limit orders with particularly high ask prices or low sell prices, while a small Δ will drive the limit prices very close to the latest market prices. Finally, we assume that the order volume the fundamentalist i wants to submit, i.e., the desired order volume $\overline{q}_{a,it\tau}\,(a \in \{1,2,f\})$, is proportional to the spread between the market price $p_{a,t\tau}$ and fundamental value $p^*_{a,t}$:

$$\overline{q}_{a,it\tau} = \left\lfloor \left|\alpha\left(p^*_{a,t} - p_{a,t\tau}\right)\right| \right\rfloor, \tag{9}$$

where $\alpha > 0$ is a constant measuring the trader's sensitivity to the spread (in the model of Chiarella et al. [47], traders can only submit orders with the order volume of one unit, and the probability of a trader submitting an order is assumed to increase when the price spread is large, while in our model, traders can submit limit orders with order volume of multiple units; inspired by the assumption in Chiarella et al. [47], we define the traders' desired order volume as proportional to the price spread, and this setup has been used in our previous work [48]). A bigger value of α means facing the same spread, the trader will submit a larger order.

3.2.2. Chartist. Chartists are technical analysts and make trading decisions based on asset's moving average prices. The moving average (MA) price, one of the most widely used technical analysis indicators, is the average value of the last D_i days' closing prices:

$$m_{a,it} = \frac{\sum_{j=1}^{D_i} p^{\text{close}}_{a,t-j}}{D_i}, \tag{10}$$

where $a \in \{1,2,f\}$ and $D_i > 0$ is the trader's individual length of time window, and the closing price $p^{\text{close}}_{a,t-j}$ is the last transaction price in day $t-j$.

As in Chiarella et al. [47], chartist believes that if the asset's market price $p_{a,t\tau}$ is higher (lower) than its moving average price $m_{a,it}$, the market price will rise (fall) further; hence, he will submit buy (sell) order. Therefore, the order direction for the chartist $H_{a,it\tau}\,(a \in \{1,2,f\})$ can be defined as

$$H_{a,it\tau} = \mathbf{sgn}\left(p_{a,t\tau} - m_{a,it}\right). \tag{11}$$

Besides, similar to the assumption of the fundamentalist, the limit price of a chartist's order is close to the asset's latest market price $p_{a,t\tau}$, and the order volume a chartist wants to submit is proportional to the spread between the market price $p_{a,t\tau}$ and the moving average price $m_{a,it}$. Hence, the limit price $l_{a,it\tau}\,(a \in \{1,2,f\})$ and desired order volume $\overline{q}_{a,it\tau}\,(a \in \{1,2,f\})$ of a chartist's limit order can be determined as follows:

$$\begin{aligned} l_{a,it\tau} &= p_{a,t\tau}\left(1 + \left|\Delta z_{t\tau}\right| H_{a,it\tau}\right), \\ \overline{q}_{a,it\tau} &= \left\lfloor \left|\alpha\left(p_{a,t\tau} - m_{a,it}\right)\right| \right\rfloor. \end{aligned} \tag{12}$$

3.2.3. Noise Trader. We also introduce some noise traders with zero intelligence into our model to provide market liquidity. The noise traders are all local traders and submit buy orders ($H_{a,it\tau} = 1$) and sell orders ($H_{a,it\tau} = -1$) into the market with the same probability. The limit price is close to the asset's latest market price:

$$l_{a,it\tau} = p_{a,t\tau}\left(1 + \left|\Delta z_{t\tau}\right| H_{a,it\tau}\right). \tag{13}$$

Also, the desired order volume is random between 3 and 10, i.e., $\overline{q}_{a,it\tau} \in \{3,4,\ldots,10\}$, where $a \in \{1,2,f\}$.

3.2.4. Arbitrager. Arbitragers are cross-market traders and carry out arbitrage trading between the two markets to earn the risk-free profit. Usually, arbitragers sell (buy) the futures and buy (sell) the spots when the futures' market price is higher (lower) than its theoretical price and realize profit later through closing positions in both markets when the price spread disappears.

Following the assumption in Ohi et al. [37], we introduce a threshold δ into our model and suppose that arbitragers engage in arbitrage trading only when the ratio of the spread between the market price $p_{f,t\tau}$ and the theoretical price $\overline{p}_{f,t\tau}$ to the theoretical price $\overline{p}_{f,t\tau}$ is greater than the threshold's value (in actuality, costs such as the transaction fees and the impact costs will prohibit arbitragers from completely eradicating mispricing and bringing the futures market price $p_{f,t\tau}$ to parity with the theoretical price $\overline{p}_{f,t\tau}$; hence, arbitragers often arbitrage between two markets when the spread is sufficiently large and close positions to profit when the spread becomes sufficiently narrow). Thus, arbitragers' order direction can be defined as follows:

$$\begin{aligned} H_{s,it\tau} &= \begin{cases} 1, & \left(\dfrac{p_{f,t\tau} - \overline{p}_{f,t\tau}}{\overline{p}_{f,t\tau}} > \delta\right), \\ -1, & \left(\dfrac{p_{f,t\tau} - \overline{p}_{f,t\tau}}{\overline{p}_{f,t\tau}} < -\delta\right), \end{cases} \\ H_{f,it\tau} &= -H_{s,it\tau}, \end{aligned} \tag{14}$$

where $s \in \{1,2\}$. Besides, similar to the assumptions of fundamentalists and chartists, the limit price of an arbitrager's order is close to the asset's latest market price, and the desired order volume is proportional to the spread between the futures' market price and its theoretical price. The limit prices and the desired order volumes in spot market and futures market for arbitragers can be determined as follows:

$$\begin{aligned} l_{a,it\tau} &= p_{a,t\tau}\left(1 + \left|\Delta z_{t\tau}\right| H_{a,it\tau}\right), \\ \overline{q}_{s,it\tau} &= \left\lfloor \left|\alpha\left(p_{f,t\tau} - \overline{p}_{f,t\tau}\right)\right| \right\rfloor, \\ \overline{q}_{f,it\tau} &= \sum_{s=1}^{2} \overline{q}_{s,it\tau}, \end{aligned} \tag{15}$$

where $a \in \{1, 2, f\}$ and $s \in \{1, 2\}$ (in the spot market, the stock index cannot be traded directly, so arbitragers typically trade a basket of underlying stocks, which is to buy or sell the same shares of stock 1 and stock 2 in our model (i.e., $\overline{q}_{1,it\tau} = \overline{q}_{2,it\tau}$), to track the stock index, and trade the index futures with the same shares as the stock portfolio in futures market (i.e., $\overline{q}_{f,it\tau} = \sum_{s=1}^{2} \overline{q}_{s,it\tau}$), in the opposite direction (i.e., $H_{f,it\tau} = -H_{s,it\tau}$)).

It should be noted that when the spread becomes narrow, namely, $|p_{f,t\tau} - \overline{p}_{f,t\tau}| \leq \delta \overline{p}_{f,t\tau}$, the arbitrage opportunity disappears and the arbitrager submits market orders in both markets to close his positions and realize profits.

3.3. Margin Trading and Order Volume. This section discusses how to calculate the practical order volume q for traders in the spot market and in the futures market. Due to the different leverage ratios in the spot market and the futures market, traders are subject to different degrees of wealth constraints, in these two markets. Short selling and buying on margin are prohibited in spot market, which means traders cannot enlarge their demand or supply by margin trading. However, in the futures market, all transactions are conducted via margin (leverage) trading and traders only need to deposit a proportionate amount of cash into their credit accounts as margin in accordance with the initial margin ratio (see Hull [49]). Assume that the amount of stocks s that trader i holds when he enters the market on the trading day t is $S_{s,it}$ ($s \in \{1, 2\}$), and his liquid cash (not including the cash deposited in the credit account) is C_{it}. Additionally, the initial margin ratio in futures market is set to be $\beta \in (0, 1)$. The practical order volume q for traders in the spot and futures markets can be calculated as follows.

3.3.1. Order Volume in the Spot Market. In the spot market, short selling and buying on margin are forbidden. Hence, traders cannot submit sell limit orders with the order volume beyond their stock holdings S. Similarly, if a trader submits a buy limit order with limit price l and order volume q into the spot market, he has to pay cash as much as lq, which cannot exceed the liquid cash holdings C, i.e., $lq \leq C$; otherwise, he cannot afford it. Hence, considering the order volume should be a positive integer, the order volume of a buy limit order cannot exceed the upper limit as $\lfloor C/l \rfloor$. Therefore, the order volume in the spot market $q_{s,it\tau}$ ($s \in \{1, 2\}$) is calculated as

$$q_{s,it\tau} = \begin{cases} \min\left(\overline{q}_{s,it\tau}, \left\lfloor \dfrac{C_{it}}{l_{s,it\tau}} \right\rfloor\right), & \left(H_{s,it\tau} = 1\right), \\ \min\left(\overline{q}_{s,it\tau}, S_{s,it}\right), & \left(H_{s,it\tau} = -1\right), \end{cases} \quad (16)$$

where $\overline{q}_{s,it\tau}$ is the desired order volume and $l_{s,it\tau}$ is the limit price of the limit order for stock s.

3.3.2. Order Volume in the Futures Market. When opening positions in the futures market, traders only need to pay a corresponding proportion of cash as margin according to the initial margin ratio β. Hence, if a trader submits a limit order (H, l, q) into futures market, he has to pay βql as margin into his credit account, which should not exceed the liquid cash holdings C, i.e., $\beta ql \leq C$; otherwise, he cannot afford. Considering the order volume should be a positive integer, the order volume of the limit order in futures market cannot exceed the upper limit as $\lfloor C/\beta l \rfloor$. Hence, the order volume in futures market $q_{f,it\tau}$ is calculated as

$$q_{f,it\tau} = \min\left(\overline{q}_{f,it\tau}, \left\lfloor \frac{C_{it}}{\beta l_{f,it\tau}} \right\rfloor\right), \quad (17)$$

where $\overline{q}_{f,it\tau}$ is the desired order volume and $l_{f,it\tau}$ is the limit price of the limit order for index futures.

3.3.3. Maintenance Margin Requirement in the Futures Market. It should be noted that in futures market, traders' credit accounts are marked to market daily, namely, the floating profit and loss are accounted at the end of each trading day according to the stock index futures' closing price and their position changes. Moreover, at the end of each trading day, the maintenance margin requirement, i.e., the minimum amount of cash deposited that must be maintained in credit account to hold the open positions, will be checked (see Hull [49]). Suppose the cash deposited in the credit account of the trader i at the end of trading day t is $\overline{C}_{it}^{\text{close}}$ and his futures position is $F_{it}^{\text{close}} \in \mathbb{Z}$ ($F > 0$ represents long positions, and $F < 0$ represents short positions). Besides, the index futures' closing price of day t is $p_{f,t}^{\text{close}}$ and the maintaining margin ratio in futures market is $\beta_m \in (0, \beta)$ (generally, the maintenance requirement is lower than the initial requirement; otherwise, the trader may get a margin call immediately after his initial transaction as the price moves against the margin (see Hull [49])). For every trader who holds positions in futures market, the ratio of the cash deposited to the current market value of his futures' positions must be no less than the maintaining margin ratio:

$$\frac{\overline{C}_{it}^{\text{close}}}{\left|F_{it}^{\text{close}}\right| p_{f,t}^{\text{close}}} \geq \beta_m. \quad (18)$$

Otherwise, if the maintenance margin requirement cannot be met, this trader will get a margin call and be required to add money into his credit account or be forced to close his position (see Hull [49]).

3.4. Timeline. A typical trading day t develops as described in Figure 2. Assume that there are N traders trading on asset a. At time t^-, the end of trading day $(t-1)$, the closing price $p_{a,t-1}^{\text{close}}$ and the moving average price $m_{a,it}$ for asset a are both available, and fundamentalists get the latest fundamental value $p_{a,t}^*$ of trading day t. At time t^+, the beginning of trading day t, all traders enter the market at random times $t < \tau_i < t + 1$, submitting orders based on their strategies. Match the new submitted order against the limit orders on the order book based on the CDA trading mechanism. Once transaction happens, the market price of asset a changes. At time $(t+1)^-$, the end of trading day t, the closing price $p_{a,t}^{\text{close}}$

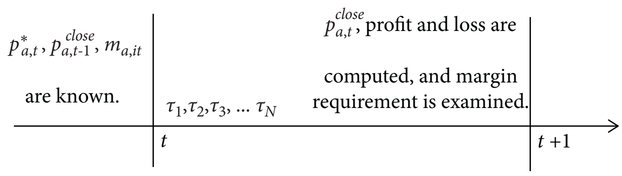

Figure 2: Schematic representation of the unfolding of a trading day.

is given, and traders can compute their profits and losses. In futures market, the margin requirement will be examined for each trader who has positions in futures market. If the requirement cannot be met, even after adding all the money into his credit account, this trader will be forced to submit market orders to close all his positions in the next trading day $t+1$. At the end of each trading day, the order book will be cleared.

4. Simulation Results

4.1. Parameter Settings. We introduce 300 fundamentalists, 150 chartists, and 150 noise traders into our artificial spot-futures market, and these local traders invest on each asset with same probability, namely, there are 100 fundamentalists, 50 chartists, and 50 noise traders trading on each risky asset. Besides, we also introduce 70 arbitragers who trade both in the spot market and futures market into our basic model. For simplicity, we consider the risk-free interest rate r to be 0. Under this assumption, the stock index's fundamental value is equal to the index futures' fundamental value, i.e., $p^*_{f,t} = I^*_t$, and the index futures' theoretical price is equal to the stock index's market price, i.e., $\overline{p}_{f,t\tau} = I_{t\tau}$. The closing prices $p^{\text{close}}_{a,0}$ at time $t=0$ are all set to be 1000, while the initial fundamental prices $p^*_{a,0}$ are all set to be 990. Besides, the stock index futures' delivery date $T = 1200$ is set to be the last trading period for each simulation. In order to initialize the moving average prices $m_{a,it}$, we set the first 240 time periods' closing prices of each risky asset to be close to the fundamental value:

$$p^{\text{close}}_{a,t} = p^*_{a,t} + \psi, \tag{19}$$

where $t = 1, 2 \ldots, 240$ and $\psi \sim U(-10, 10)$ obeys uniform distribution between -10 and 10. We remove the first 480 observations while doing simulations to avoid transitory effects. Additionally, the initial margin ratio is set to be 20% because the initial margin ratio for CSI 300 index futures range from 10% to 40% since launched. Other parameter settings are described in Table 1. The choice of most of the parameters is guided by the values used in Chiarella et al. [47] but still needs some trial and error to get realistic time series, as in most time series analysis of agent-based models.

4.2. Stylized Facts. Firstly, we run 50 repeated simulations of our spot-futures model and compare the simulation results with the empirical results to verify the reproduction of stylized facts, including price co-movement and fat-tailed distributions.

Table 1: Parameters used in the simulations.

Parameter	Value	Description
$S_{s,i0}$	{20, 21, . . ., 30}	Initial stock holdings for traders ($s \in \{1, 2\}$)
C_{i0}	$1000S_{s,i0}$	Initial cash holdings for traders
F_{i0}	0	Initial position of futures for traders
$\overline{C}_{i0}$	0	Initial credit account for traders
σ_s	0.001	Volatility of stocks' fundamental value
r	0	Risk-free interest rate
α	1	Reaction coefficient for traders
D_i	{1, 2, . . ., 240}	Length of MA windows
Δ	0.001	Aggressiveness parameter
δ	0.001	Threshold for arbitrage trading
β	0.2	Initial margin ratio
β_m	$0.75 * \beta$	Maintenance margin ratio

4.2.1. Price Co-Movement. The price co-movement between stock index and index futures is a vital stylized fact in spot-futures markets. In Figure 3, we compare the stock index and index futures' daily closing prices of one simulation, as a representative of the 50 trials, to the daily closing prices of CSI 300 index and index futures for the period from 22 June 2018 to 22 June 2021. As illustrated in Figure 3(a), the daily index futures' prices (red line) and the stock index's prices (blue line) move in lockstep, corresponding with the co-movement characteristic of the CSI 300 index and index futures in Figure 3(b). Besides, we compare the 50 times repeated simulation results to the empirical results and find that the median and mean correlation coefficients between stock index prices and index futures prices are 0.9908 and 0.9519, respectively, while the correlation coefficient between the prices of CSI 300 index and index futures is 0.9780. The results indicate that both simulation and empirical data exhibit a significant degree of price co-movement, as illustrated in Figure 3.

4.2.2. Fat-Tailed Distribution. Fat-tail distribution of basis is also a significant stylized fact in spot-futures market. In Figure 4, we present the distributions of the basis (the basis is usually defined as spot price minus futures price (see Hull [49]), but the alternative definition as future price minus spot price is also used; in this paper, we chose the former definition, which is the stock index's closing prices minus index futures' closing prices), namely, the price spread between stock index and index futures, using simulated data from one trail and empirical data from CSI 300. It is obvious that the simulation basis and empirical basis both obey a peak and fat-tailed distribution rather than a normal distribution. Besides, we calculate the kurtosis of the basis' distributions for the 50 times repeated simulations and the CSI 300 data and compare the simulated results with empirical results. The statistical values are shown in the second column of Table 2. We can see that the median and mean values of the kurtosis of the repeated simulations' basis' distribution are 4.1078 and 14.1841, respectively, while the empirical result based on CSI 300 data is 5.5282. It is clear that both the simulation results and empirical results exceed 3, showing a similar feature of the basis' fat-tail distribution.

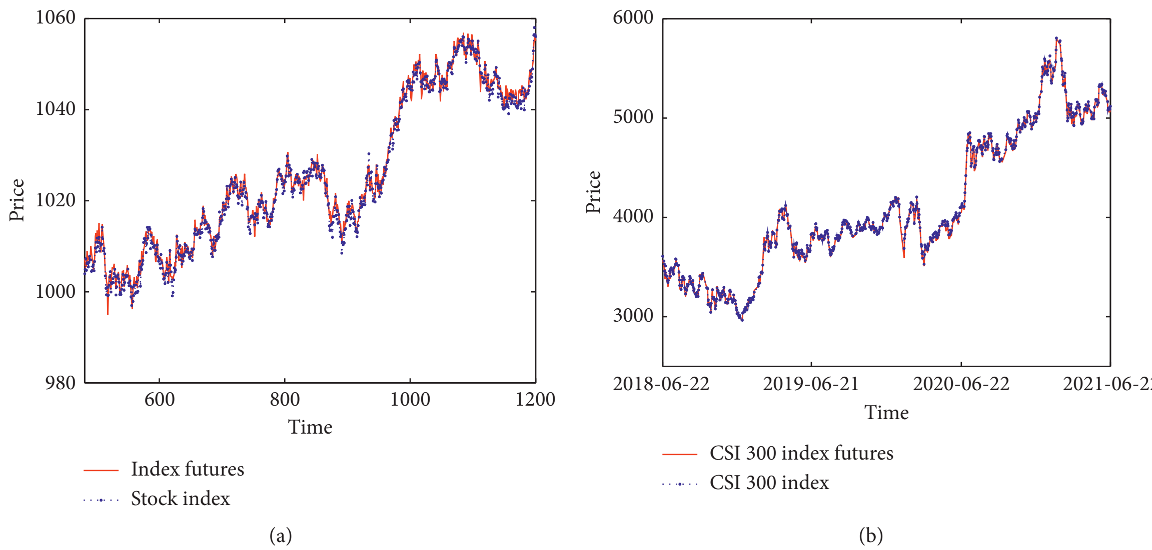

Figure 3: The time series of stock index and index futures' closing prices: (a) the simulation data for the last 720 trading days; (b) the CSI 300 data from 22 June 2018 to 22 June 2021.

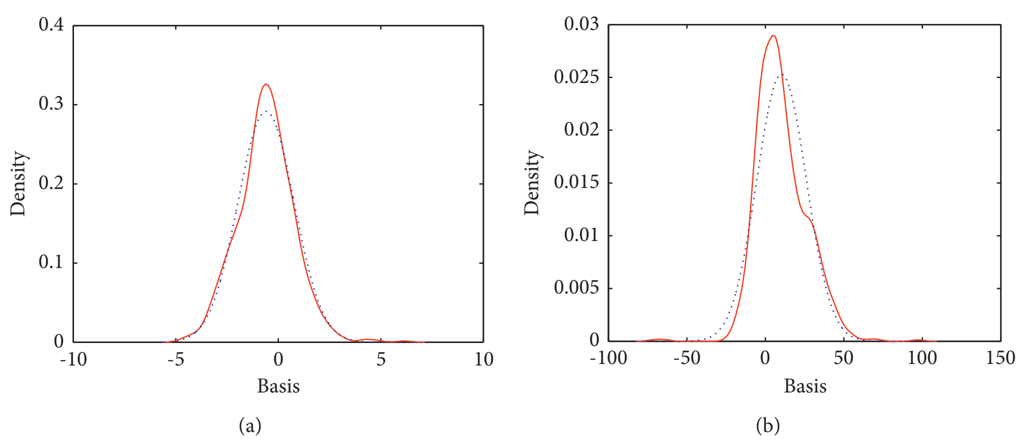

Figure 4: The density distribution of basis (with a normal distribution with the same mean and variance): (a) the simulation data for the last 720 trading days; (b) the CSI 300 data from 22 June 2018 to 22 June 2021.

Table 2: Comparison of kurtosis of basis and returns distribution.

	Basis	Stock index's return	Index futures' return
Simulation (median)	4.1078	3.3995	3.6836
Simulation (mean)	14.1841	3.5414	7.0978
CSI 300	5.5282	6.2580	9.0946

Furthermore, we focus on the fat-tail distribution of the returns of risky assets, which is one of the stylized facts in financial market. The last two columns of Table 2 provide the results of the repeated simulations and the empirical data. According to the third column of Table 2, the median and mean values of the kurtosis of stock index's returns for simulation data are 3.3995 and 3.5414, respectively, whereas the empirical result based on CSI 300 data is 6.2580. Both the simulated and empirical values exceed 3, showing a similar feature of the fat-tail distribution. The returns of index futures, as seen in the final column of Table 2, are similar to those of stock indexes.

The results above indicate that our cross-market model is capable of reproducing a number of significant stylized facts, including high correlations between stock index and index futures prices and fat-tailed distributions of basis and returns. Thus, the model can be applied to further studies of the interaction between spot and futures markets, the arbitrager investing behavior based on the basis, and the cross-market risky diffusion mechanisms.

4.3. Shock Transfer by Arbitragers. In order to analyze how shock transfers by futures market, we introduce an exogenous shock to stock 1 by dropping its fundamental value $p^*_{1,t}$ at time step $t = 720$ by 20% and observe the price changes of stock 2 and the index futures. We conduct simulations with the exogenous shock under the same parameter settings 50 times and record the time series of stock index futures and stock 2's closing prices. The median results of the time series data after the shock are shown in Figure 5. For narrative convenience, in the following context, the market price of the trading day t refers to its closing price, i.e., $p_{a,t} = p_{a,t}^{\text{close}}$. Figure 5(a) shows the result of the price changes of stock 2 after the shock. It can be seen that after the shock to stock 1 at time step $t = 720$, the market price of stock 2 (red line) falls below its fundamental value (blue dashed line) and the undervaluation persists for a while. Meanwhile, from Figure 5(b), we can find that the index futures' price (red line) falls below the stock index price (blue line) after the shock and the backwardation (i.e., the positive basis) persists for a long time, which is consistent with the empirical studies' observation we mentioned in Section 2.

To figure out the mechanism of shock transfer, we conduct additional analysis on the price data and fundamental value of stock 1, as well as the relationship between index futures' fundamental value and closing price. The results are shown in Figure 6. From Figure 6(a), we can see that as the fundamental value of stock 1 drops, its market price falls as well, which is an expected result. When fundamental value decreases, fundamentalists receive the signal and submit sell orders according to the fundamental strategy, resulting in a decrease in the market price of stock 1. Additionally, We can see in Figure 6(a) that the market price (red line) goes below its fundamental value (blue dashed line) and swiftly returns to fundamental value. This is because market price decline illuminates chartists' willingness to sell, which can drive the market price to drop through fundamental value, but the fundamentalists in stock market can submit buy orders and pull the market price back to fundamental value in time. Figure 6(b) shows the result of fundamental value and market price of index futures after the shock of stock 1. We can see from Figure 6(b) that the fundamental value of index futures also drops after the fundamental shock on stock 1, which is because the fundamental value of index futures is determined by the fundamental value of stock 1 (see equations (4) and (6)). Additionally, the index futures market price declines following the decline in fundamental value but does not recover to the fundamental value swiftly, owing to the fact that the traders in futures market can enlarge their supplies through leverage trading and submit more sell orders.

Comparing the results in Figures 6(a) and 6(b), we can infer that the backwardation phenomenon in Figure 5(b) is due to the fact that traders in futures market, who can trade with leverage, react to the fundamental shock faster and more furious than the traders in stock market. Furthermore, arbitragers sell stocks and buy futures as the futures price falls below the spot price, hence lowering the price of stock 2, as illustrated in Figure 5(a). Besides, the arbitrage intensity is insufficient to reduce the price disparity between stock index and index futures in time, resulting in the persistent backwardation in Figure 5(b). To sum up, we illustrate the mechanism of shock transfer and the backwardation phenomenon as follows:

(1) The initial decline of the fundamental value of stock 1 causes fundamentalists (informed traders) to sell stock 1, which makes the market price of stock 1 fall. The chartists sell the fall, further depressing the price of stock 1.

(2) The fundamental value of stock index and index futures declines when the fundamental value of stock 1 declines. Hence, similar to what happens in the stock 1 market, the fundamentalists and chartists in futures market both sell index futures. Due to the leverage trading in futures market, traders submit aggressive sell orders pushing the price of index futures below the price of the underlying stock index, resulting in the backwardation phenomena.

(3) Arbitragers submit buy orders into futures market and sell orders into spot market to seize the arbitrage opportunity, causing the price of stock 2 to decrease. Therefore, the shock of one stock has been transferred to another stock market by the index futures.

4.4. Influence of Arbitrage Intensity. In this section, we focus on the role of cross-market traders, i.e., arbitragers, during crises and analyze whether arbitrage trading should be encouraged or restricted during crises. We increase the number of arbitragers N_a in our artificial spot-futures market from 50 to 100 and conduct simulations with shocks of each experiment 50 times. Figure 7 shows the box plot for the average spread between stock 2's market price and its fundamental value and the average spread between index futures' price and stock index's price of the 150 trading days after the shock to stock 1.

From Figure 7(a), we can see that as the number of arbitragers increases, the spread between stock 2's market price $p_{2,t}$ and its fundamental value $p_{2,t}^*$ expands and then narrows, indicating that the impact of stock 1's fundamental shock on stock 2 is greatest when the arbitrage intensity is at an intermediate level. To a certain extent, this result is consistent with the findings of the theoretical models of Kyle and Xiong [50] and Xiong [51] that when the wealth of convergence traders, who are sometimes referred to as arbitragers, is at an intermediate level, the price volatility is the greatest. Moreover, Figure 7(b) shows that the price spread between index futures $p_{f,t}$ and stock index I_t becomes narrow, indicating that the backwardation will gradually disappear as the number of arbitragers increases. This finding is consistent with the common sense that arbitrage trading can eliminate the spread between spot market and futures market.

By comparing the results in Figures 7(a) and 7(b), we can deduce that when there are few arbitragers in the market, shocks cannot be transferred to the market of stock 2 by futures market due to a lack of cross-market traders. However, when there are enough arbitragers, the shock can be absorbed by the futures market, and the backwardation will disappear immediately. Therefore, the arbitragers will not continue to transfer the shock into the market of stock 2 by buying futures and selling stocks.

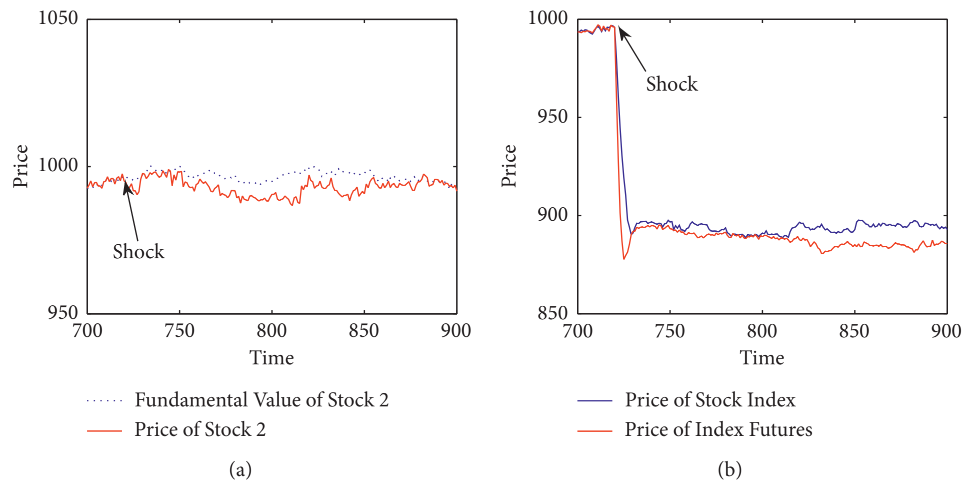

FIGURE 5: The median time series of (a) fundamental value (blue dashed) and market price (red) of stock 2 and (b) market price of stock index (blue) and index futures (red).

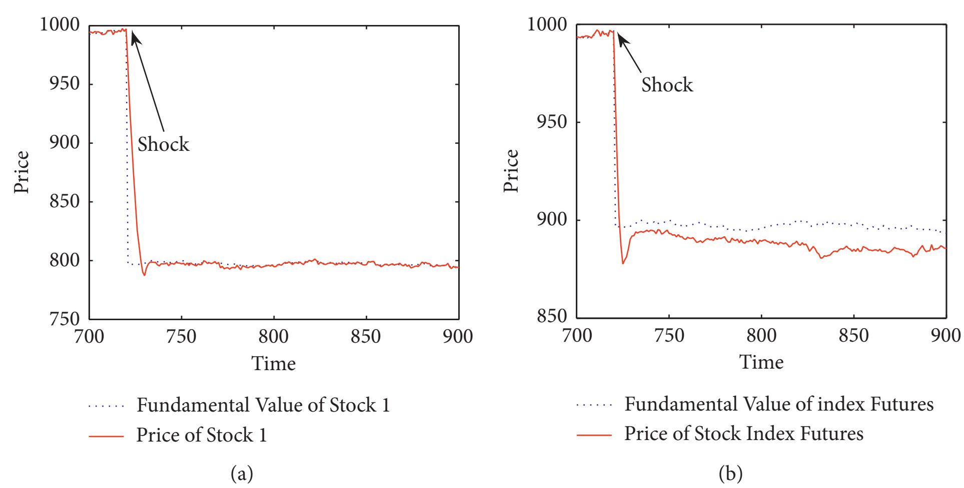

FIGURE 6: The median time series of (a) fundamental value (blue dashed) and market price (red) of stock 1 and (b) fundamental value (blue dashed) and market price (red) of index futures.

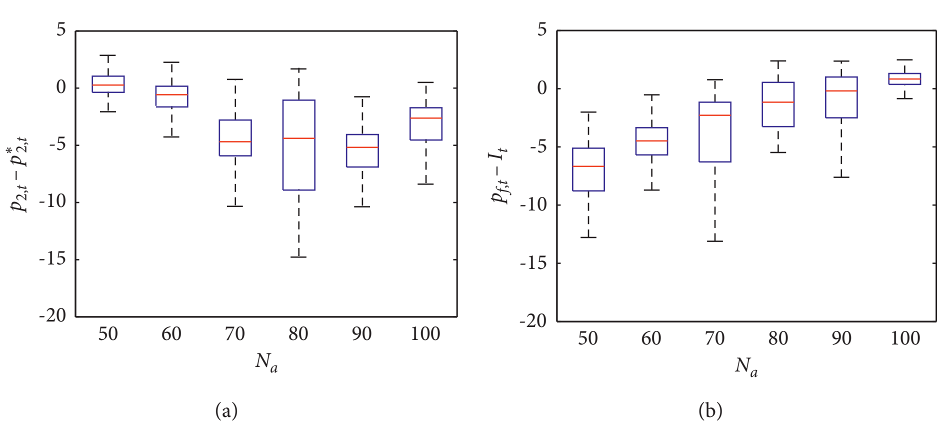

FIGURE 7: The results about how the spread between (a) stock 2's market price (closing price) and fundamental value and (b) index futures' price and stock index's price changes as the number of arbitragers increases.

5. Conclusions

We model a multiagent multiasset spot-futures market based on the CDA trading mechanism and focus on the micromechanism of shock transfer across spot and futures markets. In our model, the spot market where two underlying stocks are traded and the futures market where the index futures are traded are linked through the cross-market traders' trading behavior. We conduct simulations of our basic model and produce some important stylized facts such as the co-movement between stock index prices and index futures prices and the fat-tailed distributions of the basis and the returns of risky assets, demonstrating the effectiveness of our model.

Further analysis shows that when an external shock is applied to stock 1, the futures market exhibits backwardation, and the shock is transmitted through the entire stock market via the futures market. Additionally, to determine the effect of arbitrage intensity on the formation of backwardation anomalies and the process of market risk diffusion, we increase the number of arbitragers in our model and observe that backwardation gradually vanishes while the spread between stock 2's market price and fundamental value expands and then narrows. From the results, we conclude that an increase in arbitrage intensity could help eliminate the positive basis. Besides, when there are few arbitragers or when there are sufficient arbitragers, shocks cannot be transferred to other stocks by the futures market. The former is because cross-market traders are absent, whereas the latter is because arbitragers eliminate the price differential in time, preventing the formation of backwardation. These findings underscore that adequate arbitrage trading during crises may help eliminate the positive basis and halt the further spread of the crises, but an intermediate level of arbitrage will amplify the shock diffusion and hurt market stability. Hence, during the crisis, market liquidity supply for arbitrage trading could probably prevent risk diffusion. However, if adequate arbitrage cannot be achieved, an outright ban on arbitrage trading may be a second alternative to stop risk diffusion.

Generally, this model provides some meaningful results, and we will extend the model to conduct more analysis in the spot-futures market, such as the effects of introducing the circuit breaker regulatory measures and so on.

Data Availability

The code and simulation data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

An earlier version of the model used in this paper was presented in the Proceedings of the 7th International Conference on Industrial Economics Systems and Industrial Security Engineering (IEIS2020, see Zhou et al. [52]), and this paper is the extension and further application of the earlier work.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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