

Research Article

The Behavior and Impact of Heterogeneous Investors in China's Stock Index Futures Market: An Agent-Based Model on Cross-Market Trades

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Since the period of unusual volatility in China's A-share market in 2015, there has been an ongoing discussion about the role of stock index futures in the A-share market. There is no unified consensus among academics and industry insiders on whether stock index futures affect spot market volatility. Using agent-based modeling, we construct a theoretical model of the order book of the stock index futures market to assess the microbehavior of speculators, arbitrageurs, and hedgers in this market. We then calibrate the link between the futures and spot models to explore the respective influences of heterogeneous investors in the two markets. We find that speculators, arbitrageurs, and hedgers all play different roles and have varying effects on the two markets. While speculators serve as the foundation for other investors to participate in trading activities, both arbitrageurs and hedgers affect the spot market by significantly reducing volatility, enhancing price efficiency, and playing a positive role in the operation of this market. We develop our model from the perspective of investor behavior and explain why the stock index futures market can reduce spot market volatility. In addition, our conclusion may help regulators understand the roles played by different types of investors in the Chinese stock index futures market.

1. Introduction

From June to August 2015, the Chinese stock market experienced a period of rare and unusual volatility. During this period, public opinion tended to cite stock index futures as the culprit for this unusual spot volatility, and there were even calls for the suspension of stock index futures trading. In addition, the China Financial Futures Exchange made five adjustments (the five adjustments were made on August 26, 27, 28, and 31 and September 7, 2015). The last adjustment resulted in the following: the trading margin for nonhedging positions is 40% of the contract value, the trading margin for hedging positions is 20% of the contract value, the intraday transaction fee for opening and closing positions is 23% per 10,000, and the single product opening and trading volume

of more than 10 lots in a single day is considered abnormal behavior of “large intraday opening and trading volume”) to trading margin, intraday position opening volume, and same day closing costs in the stock index futures market in a short period. Since the occurrence of this unusual volatility, researchers have continued to explore the performance of stock index futures and their role in this rare event [1–4], and similar conclusions have been reached in studies by scholars such as Huang et al. [5], Wang et al. [6], Mou and Yuan [7], and Jian et al. [8].

A 2015 report issued by the National Institute of Finance at Tsinghua University, titled “Improving Institutional Design and Enhancing Market Confidence—Building a Capital Market for Long-Term Healthy and Stable Development,” cites the reutilization of the investor structure, a

short-sighted and weakened value investment philosophy, and a significant herd effect in the Chinese spot market as the underlying causes of this abnormal volatility [9]. The report also concludes that investors in the stock index futures market played an active role in causing this volatility, as the risk management function of stock index futures was insufficient during the period. At the same time, the report attests to the positive effects of diverting selling pressure away from spot markets.

In response to the report's findings, a research question has arisen. The Chinese market is dominated by retail investors with heterogeneous beliefs and driven by the adaptive asset allocation strategy of "chasing ups and downs" what kind of cross-market impact will different types of investors in the stock index futures market have on the spot market? Several researchers conducted studies on the impact of the stock index futures market on spot market volatility in the Chinese market. For example, Wang et al. [10] analyzed the basic characteristics of market yield volatility based on the five-minute trading data of the Chinese CSI 300 stock index futures. Cao et al. [11] found strong evidence that the measure of Chinese investor sentiment drives abnormal fluctuations on the basis of China's stock index futures. However, relevant studies fall into three broad categories due to differences in research methods and data selection intervals: stock index futures reduce spot market volatility [12–15], stock index futures increase volatility in the spot market [16, 17], and stock index futures have no significant impact on the volatility of the spot market [17, 18]. Overall, the numerous studies on the topic do not form a consistent view.

Modeling of similar markets such as stock index futures falls into two main categories: one uses statistical empirical models to predict the future based on large amounts of historical data, but the disadvantage of such models is that they become ineffective when the market is hit by a catastrophic event in the short term; the other type of model forms what appears to be a perfect economic world, but none of its assumptions are true. Financial crises and other "black swan" events have shaken the understanding of conventional models. Agent-based modeling is an attempt to model the complexity of the financial system and the micro-participant behavior of investors. According to Zhang et al. [18], the approach is to view the financial market as a system comprised of multiple adaptive heterogeneous subjects, to use intelligent information technology to micromodel the catering learning behavior of these subjects and their interactions under a given market structure, thereby forming a simulated financial market, and to explain the dynamic characteristics of the market and its causes by simulating the market and conducting microscopic experiments. NASDAQ was the first organization to use agent-based modeling as a method for financial regulation. Darley et al. [19] developed an agent-based model to investigate the mechanism design problem of adjusting the minimum quotation unit from 1/8 to 1/16, which provides decision support for NASDAQ market policymaking. In recent years, several agent-based modeling studies on institutional design, such as Li et al. [20], Wei et al. [21], and Zhang et al. [22], have emerged

based on the specific context of the trading system in the Chinese market. Accordingly, agent-based modeling is widely used to explore the design of trading systems and the impact of investor behavior on market trends [23–25]. We use the agent-based modeling to construct a theoretical model of the order book of the stock index futures market, and then we calibrate the microbehavior of speculators, arbitrageurs, and hedgers in the market to match the trading mechanism, investor behavior, and investor structure of the real stock index futures market. We then calibrate the link between the futures market and spot market models and explore the influence of heterogeneous investors in the two markets. We find that speculators, arbitrageurs, and hedgers each play different roles in the stock index futures and spot markets, thereby exerting different influences on the operation of these two markets. While speculators serve as the foundation for other investors to participate in trading, both arbitrageurs and hedgers significantly reduce volatility and enhance price efficiency in the spot market, thereby playing a positive role in the operation of this market. From the perspective of investor behavior, we develop a model and explain how the stock index futures market can reduce spot market volatility. Our results may help regulators better understand the roles played by different types of investors in China's stock index futures market.

Given the unique benefits of agent-based modeling, we employ this methodology in our research. Our principal contributions are the following: First, our work is founded on a computational experimental methodology to model the stock index futures order book market and investigate the impact of various types of investors on the quality of futures in the stock index futures market. Second, our work is the first to model speculators, arbitrageurs, and hedgers in two markets and to model their trading behavior. Third, to accurately portray investor behavior, we conducted a linkage test between the futures market and the spot market. Fourth, we also evaluated the impact of the behavior of three types of investors in two markets. Our research contributes to the expanding body of knowledge on agent-based modeling approaches to trading system design and serves as a point of reference for similar studies being conducted in other nations' capital markets.

The remainder of the paper is structured as follows: In the second section, we separately model the spot and futures markets. In the third section, the cross-market benchmark model is calibrated. The fourth section contains the primary results and the discussion. The conclusion is the fifth section.

2. An Agent-Based Model of the Futures Market and Spot Market

2.1. Underlying Assets and Trading Mechanism of the Spot Market

2.1.1. Spot Market's Underlying Assets. In this paper, we design three spot underlying assets: fundamental value low volatility Stock L , fundamental value medium volatility Stock M , and fundamental value high volatility Stock H . The equity is set to 2,000,000,000 shares, the initial price is set to

20 yuan, and the volatility of the fundamental value is set to 4 basis points (bps), 8 bps, and 12 bps, as shown in Table 1. The investor also has cash assets with a daily risk-free interest rate of $r = 4\%/360$.

2.1.2. Order Book for the Spot Market. To make the model more consistent with the characteristics of the real market, we present a pure limit that meets the following characteristics:

- (1) Each stock has an independent order book, and the market contains a total of three order books.
- (2) There is no price limit.
- (3) The minimum quotation unit is set to 1 cent.
- (4) After the close of each trading day, the order book is cleared.
- (5) The opening price of the stock on each trading day is the closing price of the stock on the previous trading day, and the current price is the most recent transaction price. If there is no transaction in the current period, the current price is equal to the previous price.

Each simulation cycle represents 5 minutes in the real market. As the trading time of each trading day in the Chinese stock market is 4 hours, there are 48 simulation cycles in the model corresponding to one trading day.

2.2. Underlying Assets and Trading Mechanism of the Stock Index Market

2.2.1. Stock Index Market's Underlying Assets. The purpose of a continuous futures contract is to connect all main contracts to facilitate a continuous analysis of contract data. This main continuous contract has the characteristics of high activity, large positions, and high turnover. As such, our paper establishes a stock index continuous futures contract model with specific parameters designed to meet the basic parameter characteristics of the CSI 300 stock index futures contract, as shown in Table 2.

2.2.2. Order Book for the Stock Index Market. The stock index futures market designed in our paper adopts a limit order book mechanism. The basic trading rules conform to the main characteristics of the Chinese stock index futures market. The specific trading rules are as follows:

- (1) $T + 0$ trading, no price limit (to exclude the effect of the different trading regimes in the two markets on the results, both the spot and stock index futures markets use the $T + 0$ trading mechanism, and neither of them sets the price limit. A study on the impact of different trading mechanisms on market quality can be found in the groundwork of this paper's study [26]).
- (2) Cash delivery.
- (3) No position limit.

TABLE 1: Design of the spot underlying assets in the agent-based model.

Assets	Equity (shares)	Initial price (yuan)	Value fluctuations (bps)
L	2,000,000,000	20	4
M	2,000,000,000	20	8
H	2,000,000,000	20	12

TABLE 2: Stock index futures contract in the agent-based model.

Mechanism	Parameter design
Quotation unit	Index points
Contract multiplier	300 yuan per point
Tick size	0.2 yuan
Margin level	15% of the contract value
Contract duration	50 trading days

- (4) Minimum order size of 1, with no limit on the maximum order size.
- (5) Adopting margin and mark-to-market systems.

Each simulation period corresponds to 5 minutes in the real market, and each trading day has 4 hours of trading. As such, one trading day equates to 48 simulation periods.

2.3. Modeling Spot Market Investors. Based on the method of Chiarella et al. [27], we model the mixed heterogeneous beliefs of spot market investors and draw on the practice of Zhao et al. [24]. We forecast and modeled spot market investors' wealth for adaptive asset allocation. In the model, the investor's order placing process still considers retained earnings μ . The order prices are all predicted prices based on retained earnings, and the order types are mainly determined based on both the investor's predicted price for the stock and the actual state of the order book. The investor's specific order placing rules are shown in Table 3.

The size of an investor's order submission is determined primarily by the investor's adaptive asset allocation process and the price at which the investor places an order. The order size submitted by investor i for asset j is the ratio of the absolute value of the current period's wealth change in asset j , $|w_{t+\tau}^{i,j} - w_t^{i,j}|$, to the investor's order placement price, $p_{\text{sub}}^{i,j}$, as shown in

$$q_t^{i,j} = \frac{|w_{t+\tau}^{i,j} - w_t^{i,j}|}{p_{\text{sub}}^{i,j}}. \quad (1)$$

2.4. Modeling Investors in the Stock Index Futures Market. Based on their roles in the stock index futures market, we divide investors into three categories: speculators, arbitrageurs, and hedgers. Speculators only trade in the stock index futures market, whereas arbitrageurs and hedgers trade in both the spot market and the stock index futures market. This section focuses on modeling speculators, and Section 3 models the other two types of investors.

TABLE 3: Investors' order.

Direction	Order conditions	Order type	Price
Buy	Seller's order book is not empty and $p_{t+\tau}^{i,j} - \mu \geq \alpha_t^j$	Market order	$p_{\text{sub}}^{i,j} = p_{t+\tau}^{i,j} - \mu$
	Other types	Limit order	$p_{\text{sub}}^{i,j} = p_{t+\tau}^{i,j} - \mu$
Sell	Buyer's order book is not empty and $p_{t+\tau}^{i,j} + \mu \leq b_t^j$	Market order	$p_{\text{sub}}^{i,j} = p_{t+\tau}^{i,j} + \mu$
	Other types	Limit order	$p_{\text{sub}}^{i,j} = p_{t+\tau}^{i,j} + \mu$

As there is no dividend in the stock index futures market, speculators try to make a profit by taking the risk of investing in volatile markets. Indeed, in our model, speculators look for investment opportunities in a market that exhibits volatility.

2.4.1. Modeling Speculators' Price Forecasting Behavior.

Let S_t be the stock index at time t , T is the duration of the stock index futures contract, d is the number of days the current contract has been traded, and r is the daily market risk-free rate. As a result, the theoretical value of stock index futures at time t , C_t , can be calculated as follows:

$$C_t = S_t \times (1 + r^{(T-d)}). \quad (2)$$

We distinguish between optimistic and pessimistic speculators, with optimistic speculators making bullish judgments on the futures market and pessimistic speculators making bearish judgments on the futures market. The predicted return r_t^0 of optimistic speculators for stock index futures at time t is

$$r_t^0 = \ln\left(\frac{C_t}{F_t}\right) + \theta + \varepsilon. \quad (3)$$

The predicted return r_t^p of pessimistic speculators for stock index futures at time t is

$$r_t^p = \ln\left(\frac{C_t}{F_t}\right) - \theta + \varepsilon, \quad (4)$$

where F_t is the price of stock index futures at time t , θ is investor sentiment, and ε is the noise term, which follows a uniform distribution of $[0, 0.005]$.

2.4.2. Speculators' Order Placing Rules. The direction of a speculator's order is determined by both the direction of their position and the forecasted return. When speculators' forecasted return is 0, they will buy when their position is greater than or equal to 0. The order placing rules are shown in Table 4.

The speculators' closing operations are based on their respective positions. As stock index futures trading is based on a margin trading system, speculators need to retain a certain amount of cash to deal with the risk of forced liquidation that may arise because of fluctuations in the futures market. In our model, the speculator opens a position using only a ω percentage of their cash assets (in our simulation experiment, ω is temporarily set to 30%), and the remaining cash assets are mainly used to deal with the risk of closing the

TABLE 4: Speculators' order placing rules.

Forecasted return	Position direction	Order direction
> 0	≥ 0	Buy open position
> 0	< 0	Buy close
< 0	≤ 0	Sell open position
< 0	> 0	Sell close

position. Therefore, the volume of open orders q_t^i for speculator i at time t can be calculated as follows:

$$q_t^i = \frac{\omega * c_t^i / p_{\text{sub}}^i}{\text{CM/ML}}, \quad (5)$$

where c_t^i is the cash assets of investor i at time t , p_{sub}^i is the order price of investor i , CM is the index futures contract multiplier, and ML is the margin ratio.

The speculator's order price p_{sub}^i is the investor's forecast price after considering retained earnings. The investor's market order and limit order are determined by a combination of the speculator's forecast price for the stock and the actual state of the order book.

2.5. Modeling Cross-Market Investors

2.5.1. Arbitrageurs' Behavior. As a typical cross-market investor, an arbitrageur seeks price deviations and carries out risk-free arbitrage by comparing the theoretical price of stock index futures with the actual price. As there is no securities lending mechanism in the Chinese market (due to factors such as high thresholds for securities lending transactions, scarcity of securities lending targets, and high handling fees, securities lending transactions are more difficult to complete), we assume that an arbitrageur can only carry out positive arbitrage (i.e., sell short stock index futures and buy stock spot).

When an arbitrageur finds that the actual price F_t of stock index futures is higher than the theoretical price C_t and can cover its arbitrage cost μ , as shown in equation (6), it will enter the market to begin an arbitrage trade.

$$F_t > C_t(1 + \mu), \quad (6)$$

where μ is the arbitrage cost and follows a uniform distribution of $[0, 0.05]$ to reflect the different arbitrage costs.

Because of the low risk of futures arbitrage transactions, investors are not required to retain cash for the time being. In the model, an arbitrageur uses 50% of their cash assets to sell short stock index futures. Therefore, the quantity s_t^i of investor i short selling stock index futures at time t can be calculated as follows:

$$s_t^i = \frac{50\% * c_t^i / F_t}{CM/ML}. \quad (7)$$

At the same time, the arbitrageur uses 50% of their cash assets to buy the corresponding number of components of the spot index so that the number $b_t^{i,j}$ of stocks j bought by investor i at time t is

$$b_t^{i,j} = 50\% \frac{* c_t^i * \text{Cap}^j}{\sum_{j=L,M,H} \text{Cap}^j} / p_t^j, \quad (8)$$

where c_t^i is the cash assets of investor i at time t , Cap^j is the equity of stock j , and p_t^j is the price of stock j at time t .

To assess the profit-taking exit of the arbitrageur, two scenarios are considered. First, the futures-spot spread in the market converges, and the arbitrageur leaves the market early by reaching its preset profit level. When arbitrageur i reaches their profit expectation η in advance at time t , as shown in equation (9), they consider closing their position early at that time.

$$W_t^i > W_{t_0}^i * (1 + \eta^i), \quad (9)$$

where t_0 denotes the start time of this arbitrage transaction, $W_{t_0}^i$ denotes the total wealth of investor i at time t_0 , W_t^i denotes the total wealth of investor i at time t , and η^i denotes the predetermined profit expectation of arbitrageur i , which follows a uniform distribution of $[0, 0.05]$ reflecting its heterogeneity.

Second, if the arbitrageur does not reach their expected profit level, they will maintain their position until the contract expires and will end their arbitrage by taking delivery. In addition to modeling the main index futures contract, we model the delivery mechanism of the index futures market, which is a fundamental guarantee for risk-free arbitrageurs to take advantage of the futures market. During the contract settlement date (every 50 trading days), the stock index futures price will converge on the spot price. At this point, if an arbitrageur still has a position, they should buy and close the position and sell the spot position during the settlement date. Because the arbitrageur seeks immediate opportunities, all orders placed by that arbitrageur are market orders. In addition, to accurately record each gain of the arbitrageur, multiple simultaneous arbitrage transactions by a single arbitrageur are not allowed in the model.

2.5.2. Hedgers' Behavior. In addition to the cross-market investors discussed so far, we assess the role of hedgers. These actors focus on the spot market and trade in the stock index futures market primarily to hedge their spot positions. When a spot investor wants to hold a stock for a long time, they can use futures to hedge the downside risk and lock in their return.

Based on the mixed heterogeneous belief model proposed by Chiarella et al. [27], our model reflects the notion that an investor will engage in a future hedging transaction when their fundamental beliefs exceed a certain threshold ($y^i > a$). Furthermore, in our model, we assume that

TABLE 5: Order placing rules for hedgers.

Position	Order direction	Order quantity
$P_t^i > Q_t^i$ and $Q_t^i < 0$	Sell and open position	$P_t^i - Q_t^i$
$P_t^i < Q_t^i$ and $Q_t^i < 0$	Buy and close position	$Q_t^i - P_t^i$
$P_t^i < Q_t^i$ and $Q_t^i > 0$	Buy and open position	$Q_t^i - P_t^i$
$P_t^i > Q_t^i$ and $Q_t^i > 0$	Sell and close position	$P_t^i - Q_t^i$
$P_t^i > Q_t^i$ and $Q_t^i = 0$	Sell and close position	P_t^i
$P_t^i < Q_t^i$ and $Q_t^i = 0$	Buy and close position	$-P_t^i$
$P_t^i = Q_t^i$	No operation	0

investors in this scenario pay more attention to the fundamental information of the stock in question and wish to hold the stock in the long term. As such, in this section, we model the trading behavior of hedgers in three steps.

First, we measure the risk exposure of hedgers. We choose β based on the capital asset pricing model (CAPM) to measure the risk exposure of a hedger's portfolio. As investors can hold multiple stocks simultaneously, we use the weighted average market value to calculate the overall β of the investor's portfolio, after calculating β of each stock. β of the portfolio held by investor i at time t can be calculated in the following way using β of each stock β_t^j ($j = L, M, H$) and the position:

$$\text{portfolio-}\beta_t^i = \sum_{j=L,M,H} \beta_t^j * \text{rate}_t^{i,j}, \quad (10)$$

where $\text{rate}_t^{i,j}$ is the ratio of the value of stock j held by investor i to the value of all stocks held by investor i at time t .

Second, we specify the hedger's asset allocation strategy. When investor i plans to buy stock j with a market value of $W^{i,j}$ at time t , hedging a transaction can be calculated to require the short sale of stock index futures worth $W^{i,j} * \beta_t^j * ML$. However, the investor may submit a limit order. If that limit order cannot be filled immediately, the corresponding hedging transaction cannot take place at that time. Furthermore, given budget constraints, the investor must set aside the cash needed for the hedging transaction at the time the spot order is placed to ensure that the transaction can proceed. Therefore, the actual amount of the investor's stock purchase is $W^{i,j} - W^{i,j} * \beta_t^j * ML$.

Third, we design the hedger's asset allocation. Based on the total value of the spot portfolio held by the hedger and its β , the position in the stock index futures market that should be held to hedge the spot position can be calculated as Q_t^i :

$$Q_t^i = -\text{portfolio-}\beta_t^i * \left[\frac{W_t^i}{(F_t * CM)} \right], \quad (11)$$

where W_t^i is the total value of the spot portfolio held by investor i at time t .

In addition, as the spot position of the hedger changes over time, it is necessary to adjust their position in the stock index futures market to reflect the actual situation. Table 5 compares the hedger's current position in the stock index futures market, P_t^i , with the position in the stock index futures market Q_t^i that the hedger should hold and determines the direction and volume of orders to be placed by the hedger.

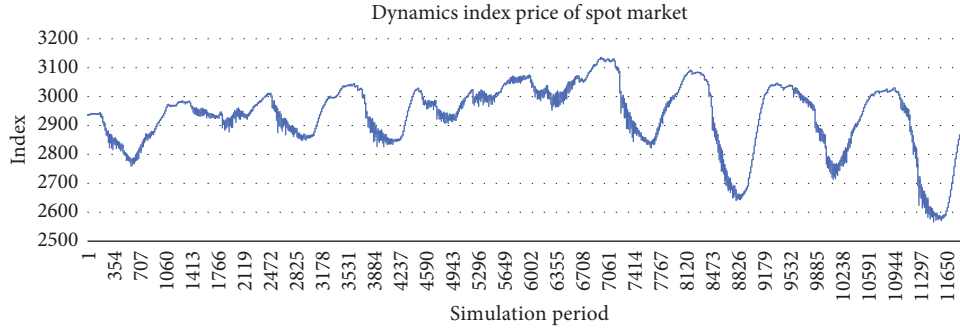


FIGURE 1: Dynamics index price of the spot market benchmark model.

When the investor's current position P_t^i is compared with Q_t^i , they will have the following operations: when the position is insufficient, the opening operation is carried out; if the position is found to be too large, the closing operation is carried out. Furthermore, depending on the investor's current position, the process of opening and closing a position is accompanied by varying buy and sell directions. For example, if the investor's current position is negative, the opening position will be a sell operation, and the closing position will be a buy operation. If the investor's current position is positive, the opening position will be a buy operation, and the closing position will be a sell operation. In addition, to ensure that the hedging transaction plays a real-time hedging role, the order types submitted by the hedger are market orders.

2.6. Model Specification and Simulations. Investors in our spot benchmark model all have heterogeneous beliefs, demonstrating 60% fundamental beliefs, 30% technical beliefs, and 10% noise beliefs, with the investor's adaptive transformation intensity set to 4. We use the initialization specification of spot market investors (including hedgers) suggested by Zhao et al. [24], and the initial cash availability of speculators and arbitrageurs is set to 1,000,000 yuan. Based on the spot benchmark model, we use an agent-based model to construct a stock index futures market. Experiment 1 simulates the investor structure of the stock index futures market to explore the cross-market quality impact of the stock index futures market on the spot market. Experiment 2 simulates a risk scenario with extreme volatility in the spot market and explores whether there is an asymmetric cross-market quality impact of stock index futures on the spot market under different risk conditions.

Each set of experiments in our work contains 30 simulations, each lasting 72,000 periods. One period in the simulated market corresponds to 5 minutes in the real stock market and the stock index futures market. Meanwhile, we select the data after a warmup; that is, we select the data of the last 12,000 periods in each simulation experiment, which is equivalent to 1 year (250 trading days) of trading data in the real market.

3. Cross-Market Benchmark Model Calibration

3.1. Spot Market Benchmark Model. In our study, a stock index is formed based on a multiasset spot, and a stock index futures market is then constructed based on the stock index.

TABLE 6: Market quality analysis using the spot market benchmark model.

	Stock L	Stock M	Stock H	Index
Volatility (bps)	42	47	62	32
Liquidity (yuan)	111,097,579	95,454,864	110,967,226	/
MAE (cents)	53	64	93	/
MRE (%)	2.63	3.23	4.42	/

Before analyzing the impact of the stock index futures market on the spot market, a benchmark model of the spot market is to develop first. Figure 1 shows the index series of the spot market benchmark model. The figure confirms the smooth running of the spot index.

In this section, we analyze the market quality of the benchmark spot market model from three perspectives: market volatility, market liquidity, and market price efficiency, respectively. The volatility indicator uses the standard deviation of the 5-minute price return, the liquidity indicator uses the Shanghai Stock Exchange liquidity index, and the market price efficiency indicator uses the absolute deviation (MAE) and relative deviation (MRE). Table 6 reports the results of the market quality analysis using the benchmark spot market model.

3.2. Investor Behavior Calibration. In the research about the stock index futures market, the behavior of arbitrageurs and hedgers is relatively objective, whose behavior is modeled consistently. In addition to arbitrageurs and hedgers, there is another key category of investors in the index futures market, known as speculators. Investors in this third category trade in a variety of ways, and their erratic behavior makes it difficult to use a standard model. In addition, speculators trade frequently and hold positions for short periods. As a result, this section focuses on calibrating the behavior of speculators.

Based on the modeling process of speculators described in the previous section, speculator sentiment θ is a key factor that dominates their trading behavior. As such, we focus on the analysis of this factor to test whether it can characterize, to some extent, the behavior of speculators. This section examines the impact of speculators with varying degrees of sentiment (0, 0.1%, 0.2%, 0.5%, 1%, 2%, 3%, 4%, and 5%) on the quality of the stock index futures market, and the

TABLE 7: The impact of speculator sentiment on the quality of the stock index futures market.

θ	Liquidity (yuan)	Volatility (bps)	MAE	MRE (%)
0	4,602,322	47	1,680	0.58
0.001	5,323,527	47	1,687	0.59
0.002	5,417,582	48	1,752	0.62
0.005	7,302,046	47	2,432	0.85
0.01	4,091,684	49	3,587	1.24
0.02	3,548,942	52	5,842	2.02
0.03	3,456,699	61	8,867	3.06
0.04	3,281,070	63	11,998	4.13
0.05	3,277,045	66	14,398	4.97

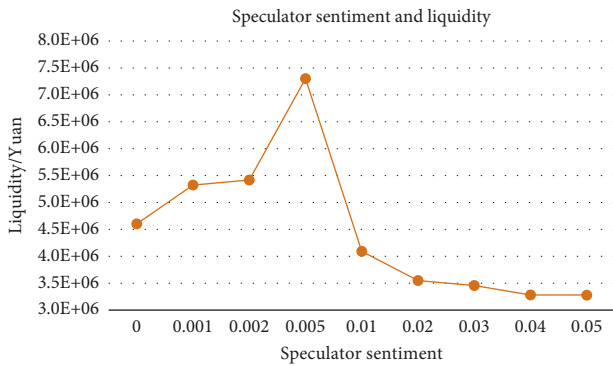


FIGURE 2: Trends in speculator sentiment and market liquidity.

statistical results are shown in Table 7. We find that the volatility of the stock index futures market significantly increases while market price efficiency significantly decreases as speculator sentiment increases.

Interestingly, as speculator sentiment increases, market liquidity first increases and then decreases, reaching its maximum when speculator sentiment arrives at 0.005, as shown in Figure 2. This phenomenon indicates that although moderate speculator sentiment can increase market liquidity, excessive speculator sentiment leads conversely to a decrease in liquidity.

In summary, when θ is 0.005, the stock index futures market features the lowest level of volatility, excellent liquidity levels, and the most efficient pricing. Given these results, the model effectively reflects the characteristics of the influence of speculators on market quality. As such, in all subsequent experiments in our work, $\theta = 0.005$ is used as the benchmark sentiment parameter.

3.3. Modeling the Investor Structure of the Stock Index Futures Market. Given that domestic stock index futures trading was launched only recently in China, it is currently difficult to obtain perfect data on the investor structure of the stock index futures market. According to the evolution process of investor types in HSI stock index futures proposed by Ding and Feng [4] in the 2005/2006 HSI stock index futures market, the proportions of speculators, hedgers, and arbitrageurs were 51.8%, 39.5%, and 8.7%, respectively. In the 2014/2015 HSI stock index futures market, the proportions

of speculators, hedgers, and arbitrageurs were 44%, 42%, and 14%, respectively. These statistics demonstrate that, after nearly 10 years of development, the investment philosophy of investors in the HSI stock index futures market has become rational, with the proportion of speculators decreasing by 7.8%, the proportion of hedgers increasing by 2.5%, and the proportion of arbitrageurs fluctuating around 10%. Based on these numbers, we design the investor structure of the stock index futures model concerning the investor structure data of the HSI stock index futures market in 2014/2015. Based on the total number of investors in the model, the number of investors in each category is then calculated, as shown in Table 8.

3.4. Link Test of the Cross-Market Benchmark Model.

Many studies show the existence of a bidirectional link between the stock index futures market and the spot market. For example, Yan et al. [28] find short-term two-way Granger causality between stock index futures prices and spot prices. Using 1-minute data from the first 2 months of the listings of the CSI 300 stock index futures as a sample, Hua and Liu [29] find a cointegration relationship and a bidirectional price guidance relationship between stock index futures prices and spot index prices. Based on daily data, Zhang et al. [30] find a bidirectional influence relationship between the spot and futures markets. Therefore, the relationship can be used as a formatting feature of the model in the construction phase. If the constructed stock index futures market and spot market can reproduce a formatting feature similar to that of the futures link, it indicates the model's high accuracy levels. This section, therefore, examines the modeled link between the spot market and the stock index futures market using Granger causality tests (before performing Granger tests, we conduct a unit root test on each data set and find them all to be first-order smooth series).

Figure 3 illustrates the price dynamics of the spot index and stock index futures. The price dynamics show a strong link between the two markets. We test this link further using Granger causality tests. While we mainly focus on the short-term relationship for high-frequency data, the 5th-order lags are used in this section. Table 9 reports the results of the Granger causality tests for stock index futures market returns and spot index returns. We find that both stock index futures market returns and spot index returns have Granger causality, which demonstrates the two-way link between the modeled stock index futures and spot markets.

4. Results

4.1. Impact of Speculators on the Quality of the Two Markets.

This section discusses the results of five separate sets of experiments, each containing a different number of speculators: 500, 1,000, 2,000, 3,000, and 4,000, respectively. Each group contains 50% optimistic and 50% pessimistic investors, and speculator sentiment is set to 0.5%. As speculators only trade in the stock index futures market, we exclusively analyze the impact of speculators on the quality of this

TABLE 8: Design of the investor structure of the stock index futures model.

Percentage of investors (%)			Number of investors (persons)		
Speculators	Hedgers	Arbitrageurs	Speculators	Hedgers ¹	Arbitrageurs
44	42	14	2,200	2,100 (0.637)	700

¹When the fundamental beliefs of spot investors are higher than a certain threshold, they engage in simultaneous futures hedging transactions. Therefore, the number of people engaging in futures hedging transactions has a one-to-one relationship with this threshold. In our paper, we first present the number of hedgers and then obtain the threshold value by inverse extrapolation from simulation experiments.

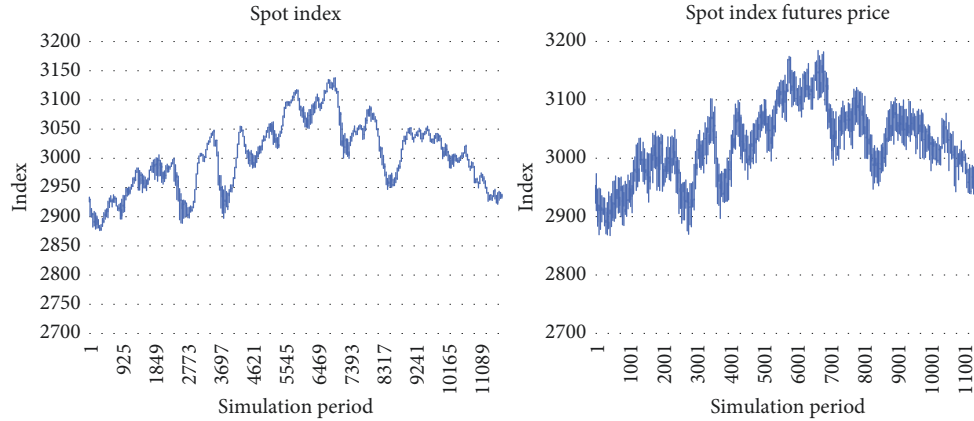


FIGURE 3: Price dynamics of the spot index and stock index futures.

TABLE 9: Granger causality tests for the two market returns.

H0	Lag order	F-statistic	P value	Judgment
Index \rightarrow future	1	369.307	0.000***	Reject H0
Future \rightarrow index	1	16.303	0.000***	Reject H0
Index \rightarrow future	2	237.352	0.000***	Reject H0
Future \rightarrow index	2	4.937	0.007***	Reject H0
Index \rightarrow future	3	164.444	0.000***	Reject H0
Future \rightarrow index	3	7.937	0.000***	Reject H0
Index \rightarrow future	4	128.414	0.000***	Reject H0
Future \rightarrow index	4	6.443	0.000***	Reject H0
Index \rightarrow future	5	104.899	0.000***	Reject H0
Future \rightarrow index	5	2.447	0.0318**	Reject H0

The symbols ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

TABLE 10: Impact of speculators of the stock index futures market.

Number of speculators	Liquidity (yuan)	Volatility (bps)	MAE (cents)	MRE (%)
500	3,627,883	45	2,803	0.99
1,000	4,890,928	47	2,724	0.95
2,000	7,302,046	47	2,432	0.85
3,000	9,634,527	48	2,404	0.83
4,000	10,881,574	48	2,395	0.83

market by assessing market liquidity, market volatility, and market price efficiency.

Table 10 reports the statistical results of the impact of the number of speculators on the quality of the stock index futures market. The results show that when the number of speculators increases, the volatility of the stock index futures market does not change much, and market price efficiency increases slightly. However, market liquidity increases

significantly when the number of speculators increases, as shown in Figure 4.

We, therefore, argue that the presence of speculators leads to an increase in market price efficiency because an increase in the number of speculators leads to increased market competition, which in turn leads to an increase in market price efficiency (it is important to note that the results of this experiment do not take into account the effects

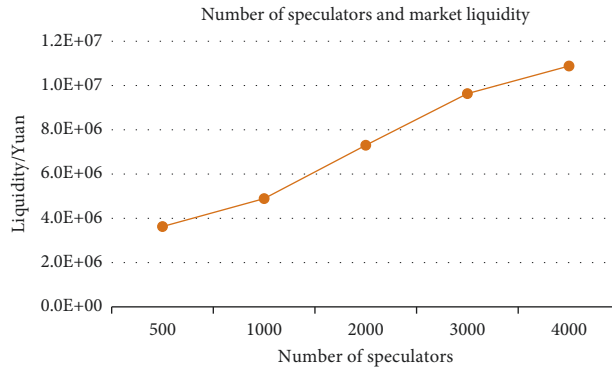


FIGURE 4: Trends in the number of speculators and market liquidity.

TABLE 11: Impact of arbitrageurs of the stock index futures market.

Number of arbitrageurs	Liquidity (cents)	Volatility (bps)	MAE (cents)	MRE (%)
0	7,302,046	47	2,432	0.85
500	7,405,144	47	2,377	0.82
1,000	7,288,207	47	2,377	0.82
2,000	7,341,010	46	2,362	0.82
3,000	7,584,439	45	2,335	0.81

TABLE 12: Impact of futures and cash arbitrageurs on spot market liquidity and volatility.

Numbers	Liquidity (\$)			Volatility (bps)			Index
	Stock <i>L</i>	Stock <i>M</i>	Stock <i>H</i>	Stock <i>L</i>	Stock <i>M</i>	Stock <i>H</i>	
0	111,097,579	95,454,864	110,967,226	42	47	62	32
500	111,239,784	94,649,690	107,848,768	41	47	62	32
1,000	110,102,254	93,648,873	106,502,589	39	46	60	31
2,000	104,892,338	91,866,062	105,252,790	35	42	58	29
3,000	101,004,576	88,170,781	105,128,544	33	39	56	28

of speculator sentiment. The results of the previous experiments show that an increase in speculator sentiment leads to a decrease in market price efficiency). At the same time, an increase in the number of speculators significantly increases the liquidity of the stock index futures market. Then, we note that speculators play a positive role by injecting liquidity into the market, which in turn informs regulators' view of speculators in the stock index futures market.

4.2. Impact of Arbitrageurs on the Quality of the Two Markets.

This section investigates the effect of arbitrageurs on the quality of the futures market. To this end, five separate experiments are designed, each containing a different number of arbitrageurs: 0, 500, 1000, 2000, and 3000. As speculators provide basic liquidity to the market to ensure its proper functioning, the experiments in this section are conducted in a market based on 1,000 speculators.

Table 11 reports the results of the experiment assessing the impact of the number of arbitrageurs on the quality of the stock index futures market. As the number of arbitrageurs increases, we note a trend of monotonic changes in both volatility and market price efficiency in the stock index

futures market. This trend is evidenced by the fact that arbitrageurs reduce market volatility and enhance the price efficiency of the stock index futures market, but the extent of their effects on both variables is relatively small. As such, we speculate that this trend may be related to arbitrage opportunities in the market: if arbitrage opportunities are limited, arbitrageurs have little impact on the market. It is also important to note, however, that the arbitrage opportunities in the experiment are strongly related to the behavior of speculators (we do not believe that it is necessary to add the number of speculators to the market to increase the arbitrage opportunities in the market to study the arbitrage behavior of investors, because the arbitrage opportunities in the real market are extremely limited). Our results are not consistent with the findings of Xiong et al. [31], who find that arbitrageurs significantly affect the volatility of the stock index futures market. However, in their model, all investors except arbitrageurs are modeled from a spot market perspective, which differs significantly from how investors are modeled in our paper.

Table 12 reports the statistical results of the impact of the number of arbitrageurs on the liquidity and volatility of the spot market. The results show that the liquidity of the spot

TABLE 13: Impact of futures and cash arbitrageurs on price efficiency in the spot market.

Numbers	MAE (cents)			MRE (%)		
	Stock <i>L</i>	Stock <i>M</i>	Stock <i>H</i>	Stock <i>L</i>	Stock <i>M</i>	Stock <i>H</i>
0	53	64	93	2.63	3.23	4.42
500	52	64	91	2.60	3.26	4.35
1,000	49	61	90	2.52	3.08	4.30
2,000	43	55	83	2.15	2.78	3.94
3,000	39	49	78	1.95	2.48	3.72

TABLE 14: Impact of hedgers on the quality of the stock index futures market.

Numbers	Liquidity (\$)	Volatility (bps)	MAE (cents)	MRE (%)
0	7,302,046	47	2,432	0.85
1,000 (0.748)	4,817,474	49	2,040	0.69
2,000 (0.644)	3,335,129	49	1,757	0.59
3,000 (0.547)	2,036,627	50	1,484	0.50

TABLE 15: Impact of hedgers on spot market liquidity and volatility.

Numbers	Liquidity (\$)			Volatility (bps)			
	Stock <i>L</i>	Stock <i>M</i>	Stock <i>H</i>	Stock <i>L</i>	Stock <i>H</i>	Stock <i>H</i>	Index
0	111,097,579	95,454,864	110,967,226	42	47	62	32
1,000 (0.748)	104,466,915	97,801,384	118,416,850	23	31	49	23
2,000 (0.644)	93,847,230	10,2856,000	121,473,796	11	20	38	16
3,000 (0.547)	96,902,078	11,3637,018	124,186,136	11	19	37	15

market does not change much as the number of arbitrageurs increases. We argue that as arbitrageurs exploit the timeliness of arbitrage opportunities, they use market orders, a practice that affects market liquidity. The weak change in market liquidity can therefore be explained by the fact that arbitrageurs essentially provide liquidity to the market, which is consumed by the market-priced orders they place. At the same time, as the number of arbitrageurs increases, market volatility decreases significantly, and arbitrageurs serve to stabilize the spot market. Table 13 reports the statistical results on the impact of the number of futures arbitrageurs on the pricing efficiency of the spot market. The results show that, with the increase in the number of futures arbitrageurs, the pricing efficiency of the spot market increases significantly, and the futures arbitrageurs have a positive impact on the spot market.

4.3. Impact of Hedgers on the Quality of the Two Markets. In this section, four separate sets of experiments are designed to explore the effect of hedgers on the quality of the futures market. Each experiment contains a different number of hedgers: 0, 1000, 2000, and 3000. The experiments in this section are also conducted in a market based on 1,000 speculators.

Table 14 reports the results of the effect of the number of hedgers on the quality of the stock index futures market. An increase in the number of hedgers significantly reduces the liquidity of the stock index futures market, which indicates that hedgers are liquidity consumers in the stock index futures market. At the same time, the price efficiency of the stock index futures market significantly increases when the number of hedgers increases.

Table 15 reports the statistical results of the impact of the number of hedgers on the liquidity and volatility of the spot market. The results show that spot market volatility decreases significantly when the number of hedgers increases and that hedgers play a stabilizing role in the market.

Table 16 reports the statistical results of the impact of the hedgers' number on price efficiency in the spot market. The results show that hedgers significantly improve price efficiency in the spot market.

In Table 17, "+" indicates that this category of investors has a positive impact on market quality, "-" demonstrates that this category of investors hurts market quality, and "/" illustrates that this type of investor has little influence on market quality. It is clear from the table that both arbitrageurs and hedgers have a positive effect on the spot market by reducing market volatility and improving market price efficiency.

TABLE 16: Impact of hedgers on price efficiency in the spot market.

Numbers	MAE (cents)			MRE (%)		
	Stock <i>L</i>	Stock <i>M</i>	Stock <i>H</i>	Stock <i>L</i>	Stock <i>M</i>	Stock <i>H</i>
0	53	64	93	2.63	3.23	4.42
1,000 (0.748)	22	33	63	1.11	1.68	3.00
2,000 (0.644)	9	19	41	0.45	0.93	1.94
3,000 (0.547)	8	16	38	0.45	0.86	1.82

TABLE 17: Impact of different types of investors on the quality of the futures and cash markets.

		Liquidity (\$)	Volatility (bps)	Price efficiency
Speculators	Stock index futures market	+	/	+
	Stock market	/	+	+
Arbitrageurs	Stock index futures market	/	/	/
	Stock market	/	+	+
Hedgers	Stock index futures market	-	/	+

5. Conclusion

We use agent-based modeling to construct an order book model for stock index futures and investigate the impact of different types of investors in the stock index futures market on the quality of the two markets. Our study is the first to comprehensively model the trading behavior of speculators, arbitrageurs, and hedgers in the stock index futures market. In addition, in terms of investor behavior calibration, we calibrate speculators whose trading behavior is more subjective. In terms of model calibration, we perform the first link test on the cross-market model. Through simulations, we find that speculators, arbitrageurs, and hedgers play different roles in the market and that they have different effects on the operational quality of the futures market. While speculators provide liquidity to the stock index futures market and form the basis for other investors to participate in market transactions, both arbitrageurs and hedgers have various effects on the spot market, including significantly reducing volatility, enhancing price efficiency, and playing a positive role in operational quality. It is hoped that our results will help regulators understand the roles played by different types of investors in the stock index futures market from the perspective of market participants' behavior. Our research contributes to the expanding body of knowledge on agent-based modeling approaches to trading system design and serves as a point of reference for similar studies being conducted in other nations' capital markets.

Data Availability

Our research methodology can be simply understood as a "simulation" and does not involve real market data.

Disclosure

The views expressed in this paper are those of the authors and do not necessarily represent the views of the Shenzhen Stock Exchange.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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