Optimization of Non-arbitrage Interval Pricing Model of Stock Index Futures and Arbitrage Analysis of SCI 300 in the Context of COVID-19

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Abstract. Stock index futures are important investment assets for small and medium investors. Under the impact of the COVID-19, the stock index futures market has been seriously impacted. The traditional non-arbitrage interval model of stock index futures has also been affected, and the pricing efficiency has been reduced. This paper introduces investor sentiment variables to improve the non-arbitrage interval pricing model under the background of the COVID-19, which improves the pricing accuracy by 30.05% and reduces the profit margin of single arbitrage. Based on the above research, this paper puts forward some suggestions for small and medium-sized investors' investment decisions in stock index futures.

Keywords: COVID-19 · CSI 300 · Non-arbitrage interval · Investor sentiment

1 Introduction

Stock index futures are important financial derivatives. When the market is depressed, stock index futures can be used to avoid risks. When the market is expected to rise, stock index futures can also enrich investors' financial tools. It is one of the most important investment tools for investors.

Stock index futures pricing theory originated in western countries. In 1983, Cornell and French [1] proposed a cost-of-carry model based on the research of Rendleman and Cox. After that, Modest and Sundarensan [2] introduced a series of practical factors such as dividends and transaction costs into Cornell and French's model and then deduced the non-arbitrage interval pricing model of stock index futures. In 1991, Klemkosky and Lee [3] took dividend, loan interest rate, transaction cost, and other factors into account, and derived the upper and lower bounds of stock index futures prices based on stock index futures and spot trading strategies, that is, Klemkosky and Lee's non-arbitrage interval pricing model.

Compared with western countries, China's stock index futures were launched late but developed rapidly. In terms of model parameters, domestic research is mainly based on Klemkosky and Lee's model and introduces new parameters according to the actual situation of China's stock index futures market. Researchers [4–7] continuously introduced some new parameters, such as impact cost, tracking error, market supervision,

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investor structure, etc., and gradually improved the non-arbitrage interval model of stock index futures. Recently, Zheng et al. [8, 9] have used empirical analysis to conclude that investor sentiment will cause the pricing bias of stock index futures. However, few studies have introduced investor sentiment indicators as parameters into the model for improvement.

COVID-19 has had a great impact on China's financial market. Liu et al. [10] have found that the expected level of stock index return has been negatively impacted by the COVID-19. Chinese investors have pessimistic expectations for the stock index futures market, and investor sentiment has been seriously affected, which also seriously affects the pricing efficiency of the traditional model. It is particularly important to draw a non-arbitrage interval model suitable for the epidemic situation and provide investment advice to small and medium-sized investors according to the empirical analysis of the new model.

The contribution of this paper is to introduce the investor sentiment parameters that have been proved to have a significant impact on the model under the background of COVID-19. To a certain extent, this fills the gap that there is still a lack of investor sentiment parameters to modify the model. By using empirical analysis to compare the pricing efficiency of the model with and without this parameter, we prove that the pricing efficiency of the model is improved after introducing this parameter. Based on the above research, we put forward some suggestions for small and medium-sized investors to make investment decisions in China's stock index futures market. It will help small and medium-sized investors to make effective investment decisions against the background that China's economy has been affected by the COVID-19 for a long time.

2 Related Works

At present, there is much research on the non-arbitrage interval of stock index futures in China, most of which is based on the non-arbitrage interval pricing model proposed by Klemkosky and Lee [3], and constantly revised in combination with the actual situation in China.

2.1 Model Parameter Selection

In terms of model parameter selection, most of the current studies are based on the parameters of Klemkosky and Lee's model and make some modifications to the model based on the current situation of China's stock index futures market. Xie and Li [4] introduced implicit transaction cost parameters such as impact cost and tracking error, Liu and Ma [5] introduced market supervision, investor structure, and behavior parameters, Liu and Chi [6] introduced margin parameters, Xu and Shi [7] introduced short-selling restriction parameters. They all proved that the newly introduced parameters improved the pricing efficiency of the model. Based on the above research, this paper considers the impact of investor sentiment on the non-arbitrage interval model and uses empirical analysis to show that the introduction of this parameter improves the pricing efficiency of the model.

2.2 Research Periods

In terms of the time range of the research data, the time interval includes different stages since the CSI 300 stock index futures were just issued. In the embryonic period of the CSI 300 stock index futures market, Liu and Ma [5] pointed out that due to the incomplete market, the pricing bias of the stock index futures continued to exist, and the arbitrage profit margin decreased as the maturity date approached. Xu and Shi [7] pointed out that in the period of stock market fluctuation, there is a positive arbitrage opportunity for stock index futures, and there is a pricing error in the pricing of stock index futures at this time. With the gradual completion of the CSI 300 stock index futures trading system, Li and Chen [11] pointed out that China's stock index futures market has entered a relatively mature operation stage. There are fewer and fewer arbitrage opportunities for stock index futures, the single arbitrage income decreases rapidly, and the duration of arbitrage opportunities is shorter and shorter. There is still a lack of relevant research on the pricing efficiency of the model under the background of events that have a great impact on the financial market. Based on the data of stock index futures under the background of COVID-19, this paper uses the improved model to analyze the arbitrage opportunities of stock index futures and gives some investment suggestions to small and medium-sized investors.

3 Method

Although many previous researchers have made some modifications to Klemkosky and Lee's model, few consider the impact of investor sentiment on the pricing efficiency of the model, this paper introduces investor sentiment parameters to modify the model based on Klemkosky and Lee's model and the improved model of previous researchers. Then we use the data to compare and analyze the pricing efficiency of the model before and after the improvement.

3.1 Symbol Description

Table 1 shows the symbols used in this article and their meanings.

3.2 Model Establishment

Previous researchers [4–7] have made some improvements based on Klemkosky and Lee's model. They introduced impact cost parameters, tracking error parameters, and margin parameters, and obtained a modified non-arbitrage interval pricing model suitable for China's stock index futures market. Based on these researchers, this paper introduces investor sentiment parameters to further modify the model.

3.2.1 Current Mainstream Non-arbitrage Interval Pricing Model

Klemkosky and Lee [3] used the strategies of cash-and-carry arbitrage (short futures and long spot) and reverse cash-and-carry arbitrage (long futures and short spot) to derive the

Table 1. Symbols and their meanings

Symbol	Meaning	Symbol	Meaning
$\mathbf{F_D}$	Lower limit of the non-arbitrage interval	$\mathbf{C_{ss}}$	The transaction cost of selling the spot
$\mathbf{F_U}$	Upper limit of the non-arbitrage interval	$\mathbf{C_{sb}}$	The transaction cost of buying spot
$\mathbf{S_t}$	Spot price at time t	$\mathbf{C_{fs}}$	The transaction cost of selling stock index futures
$\mathbf{S_T}$	Spot price at time T	$\mathbf{C_{fb}}$	The transaction cost of buying stock index futures
$\mathbf{F_t}$	Stock index futures price at time t	$\mathbf{D}$	Dividend discount value from t to T
$\mathbf{F_T}$	Stock index futures price at time T	$\mathbf{M_f}$	Margin ratio of stock index futures
$\mathbf{r_l}$	The interest rate on loans	$\boldsymbol{\gamma_U}$	The impact of consumer sentiment on the upper limit of the range
$\mathbf{r_b}$	The interest rate on borrowings	$\boldsymbol{\gamma_D}$	The impact of consumer sentiment on the lower limit of the range

upper and lower bounds of the range in which the price of stock index futures happens to be. You can refer to Klemkosky et al. [3] for more details.

Based on Klemkosky and Lee's model, domestic researchers improved it and obtained the modified model. The modified model includes 12 parameters, i.e. the price of spot and stock index futures at the initial time t and the final time t, the transaction cost, the interest rate of loans, the margin ratio of stock index futures, and the discount value of dividends. Among them, for the calculation of the transaction cost of buying and selling spot goods or stock index futures, the transaction handling fee and impact cost need to be considered in general. For spot goods, the tracking error of spot goods should be additionally considered. Specifically, when buying and selling spot goods, the transaction cost is equal to the sum of the transaction fee, impact cost, and tracking error; When trading futures, the transaction cost is equal to the sum of the transaction handling fee and the impact cost.

Buy spot goods and sell futures at time t, and sell emerging goods and buy futures at time t. Make the final return equal to 0, that is, the upper bound of the non-arbitrage interval. Under the condition of non-arbitrage, we get the upper limit of the non-arbitrage interval The basis converges at maturity, so we get the upper limit of the non-arbitrage range. We use the reverse operation to calculate the lower bound of the non-arbitrage interval, so we have Eq. (1). The meanings of symbols in the equation are given in Table 1.

$$F_U = \frac{S_t(1 + C_{sb})(1 + r_b)^{T-t} + F_T(C_{ss} + C_{fb}) - D}{1 + M_f + (M_f + C_{fs})(1 + r_b)^{T-t}}$$

$$F_D = \frac{S_t(1 - C_{ss})(1 + r_l)^{T-t} + F_T(C_{sb} + C_{fs}) - D}{1 - M_f + (M_f + C_{fb})(1 + r_l)^{T-t}} \tag{1}$$

Table 2. Monthly investor sentiment index

Date	SI	Date	SI	Date	SI
202001	-0.7784	202005	-0.42088	202009	1.71963
202002	-0.46542	202006	-0.06836	202010	-0.14437
202003	-0.79048	202007	2.3403	202011	-0.15487
202004	-0.30203	202008	1.31713	202012	1.40374
...	...	...	...	...	...

3.2.2 Construction of Investor Sentiment Indicators

The construction of investor sentiment in this paper refers to the previous research [9]. We select six original indicators that can better reflect investor sentiment (SI) in China's financial market, namely closed-end fund discount rate (DCEF), turnover rate (TURN), IPO first-day return (RIPO), IPO number (NIPO). The investor confidence index (ICI) and price-earnings ratio (PE) adopt the consumer price index (CPI), wholesale price index (PPI), industrial added value (IAV), and macroeconomic prosperity leading indicator (MPLI) to eliminate the impact of macroeconomic variables on investor sentiment, to obtain a purer indicator of investor sentiment. Using principal component analysis, we have Eq. (2). The calculated SI are shown in Table 2.

$$SI = 0.975 * TURN_{t-1} - 0.519 * ICI_{t-1} +$$

$$0.609 * RIPO_{t-1} + 0.549 * DCEF_t - 0.689 * PE_t \tag{2}$$

3.2.3 Model with Investor Sentiment

After the investor sentiment index is quantified, we introduce it into the improved model and get a non-arbitrage interval pricing model considering investor sentiment. So we have Eq. (3).

$$\begin{aligned} F_U &= \frac{S_t(1 + C_{sb})(1 + r_b)^{T-t} + F_T(C_{ss} + C_{fb}) - D}{1 + M_f + (M_f + C_{fs})(1 + r_b)^{T-t}} e_t^{\gamma_U SI} \\ F_D &= \frac{S_t(1 - C_{ss})(1 + r_l)^{T-t} + F_T(C_{sb} + C_{fs}) - D}{1 - M_f + (M_f + C_{fb})(1 + r_l)^{T-t}} e_t^{\gamma_D SI} \end{aligned} \tag{3}$$

3.3 Empirical Analysis of Pricing Efficiency of the Model

3.3.1 Source of Data and Determination of Parameters

This paper selects 484 trading days' stock index futures trading data from January 1, 2020, to December 31, 2021. The data sources of this paper are the wind database, China financial futures exchange database, and CSMAR database.

Table 3. Upper and lower limits of no-arbitrage interval

Date	**St**	SI	F_U	F_D
20200102	4152.24	-0.7784	4181.502331	4107.457345
20200103	4144.96	-0.7784	4256.195908	4100.255861
20200106	4129.3	-0.7784	4240.11565	4084.764757
...	...	...	...	...

Since the research data period of this paper is from the beginning of 2020 to the end of 2021, we select the deposit and loan interest rate of banks in the same period as the interest rate of loans and borrowings, which is 1.375% and 4.35% respectively. According to the regulations of the China Financial Futures Exchange, the margin ratio of futures is 10%. The average dividend yield during the data observation period is adopted for the stock interest rate, which is 1.8%.

Spot transaction costs include transaction handling fees, impact costs, and tracking errors. As stock index futures are generally traded in large amounts, we adopt the minimum transaction service charge of 0.03% as the transaction service charge. The impact cost and tracking error are calculated regarding the method of Xie [4], and the results are 0.18% and 0.08% respectively. The transaction cost of stock index futures mainly includes transaction fees and impact costs. Using the method similar to the spot transaction cost, it is 0.0023% and 0.17% respectively.

Through the optimization analysis of the data before 2020 by the model including investor sentiment parameters, we take the investor sentiment influence parameters as the values that make the arbitrage accuracy of historical data the highest, which are 0.12% for the upper limit and -0.15% for the lower limit respectively.

The F_U and F_D calculated by Eq. (3) are shown in Table 3.

3.3.2 Establishment of Non-arbitrage Interval

According to Eq. (1) and the above estimation of model parameters, the non-arbitrage interval under the traditional model is shown in Fig. 1. According to Eq. (3) and the above estimation of model parameters, the non-arbitrage interval under the model including investor sentiment is shown in Fig. 2.

3.3.3 Model Pricing Efficiency Comparison

Under the background of COVID-19, there is no cash-and-carry arbitrage but reverse cash-and-carry arbitrage. The modified model improves the pricing accuracy and reduces the average arbitrage points and profit margin. Specific data are shown in Table 4.

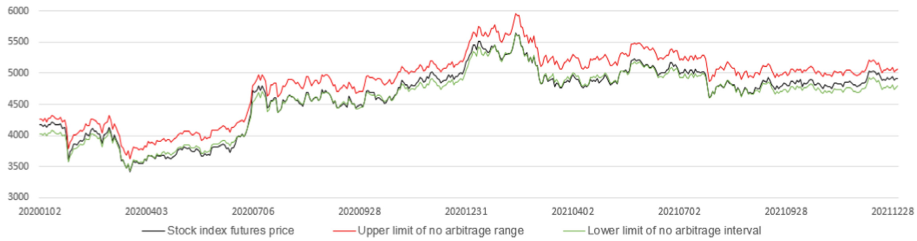

Fig. 1. No arbitrage interval before modification, the futures prices in the figure are close to the lower limit.

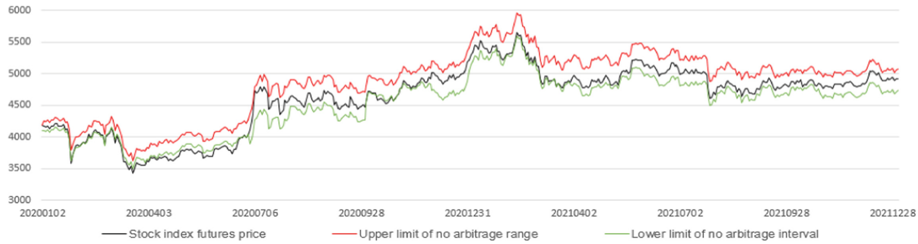

Fig. 2. No arbitrage interval after modification, the futures prices in the figure are not so close to the lower limit.

Table 4. Model pricing efficiency comparison data

Model type	Arbitrage direction	Arbitrage opportunity count	Average arbitrage points	Average arbitrage profit (%)
Before modification	Cash-and-carry Arbitrage	0	0	0
	Reverse cash-and-carry Arbitrage	203	44.76	1.12
After modification	Cash-and-carry Arbitrage	0	0	0
	Reverse cash-and-carry Arbitrage	142	30.76	0.71

4 Discussion

At present, domestic researchers have proved that investor sentiment will affect the pricing efficiency of the non-arbitrage interval pricing model, but few scholars introduce investor sentiment into the non-arbitrage interval pricing model for optimization. At the same time, the COVID-19 has caused a serious impact on China's financial market, and investors generally hold pessimistic sentiment, which further reduces the pricing efficiency of the traditional model. This paper introduces investor sentiment into the model, trying to improve the pricing efficiency of the traditional model.

This paper modifies the model by introducing investor sentiment parameters and makes a comparative analysis of the pricing efficiency of the model by using empirical data. The changes in pricing efficiency before and after model improvement is shown in Table 4. The accuracy of the pricing model has increased by 30.05% compared with that before the modification. While we improve the accuracy, we also reduce the profitability of each arbitrage opportunity. This further shows that investor sentiment does affect the pricing efficiency of the model [9], and it also shows that it is effective for us to introduce investor sentiment into the model.

The empirical analysis of this paper makes recommendations for small and medium-sized investors' investment decisions in stock index futures. When the stock market continues to rise, investors are generally optimistic, too optimistic will lead to overestimation of the price of stock index futures; The sharp drop in the stock market is easy to cause investor panic, which leads to the undervaluation of the stock index futures price. There will be some errors in arbitrage analysis only through quantifiable costs, such as transaction costs, quasi-principal parameters, etc. So, it is necessary to introduce investor sentiment parameters into the model to improve pricing efficiency.

The method in this paper does improve the pricing efficiency of the traditional model, but our research method still needs to be improved. Based on the convenience of data acquisition, we select the closing price of each trading day to represent the futures and spot prices of the day, which may ignore some arbitrage opportunities in the trading day. We can further adopt higher frequency data, such as minute-level transaction data, to optimize the model.

5 Conclusion

This paper aims to improve the efficiency of the traditional non-arbitrage interval pricing model and give some investment suggestions to small and medium-sized investors under the COVID-19. By constructing an investor sentiment index and introducing this parameter into the model, the model's accuracy is improved and the degree of arbitrage is reduced. Our research has initially mitigated the negative impact of the COVID-19 on the pricing efficiency of the traditional non-arbitrage interval model and small and medium-sized investors can refer to this article to make more effective investment decisions. We can further improve the pricing efficiency of the model by using higher frequency data.

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