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Zkoumání příležitostí arbitráže na čínském finančním trhu

Examination of Arbitrage Opportunities at Chinese Financial Market

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Contents

1 Introduction

Since China is currently in the transition period from a planned economy to a market economy, the market economy system has not been fully established. The financial system, as a deep-water area for economic reform, is even more underdeveloped and imperfect. Arbitrage is defined as the use of imperfections in the market price system to gain profits through buying and selling. Arbitrage is essentially a means of market governance. The difference between arbitrage and investment is that they have different purposes. The purpose of investment is to buy, the purpose of investing money is to gain value, and the purpose of arbitrage is to buy and sell, using the imperfect market to earn the difference. According to the journal which was published in November 2021, focusing on the China CSI 300 Index and its three exchange-traded funds (ETFs), this study examines the relationship between stock trading volume in the ETF market, the efficiency of tracking stock markets, and the role of carry trades in this association. And found that ETF stock trading volume makes a significant contribution to tracking the price efficiency of the stock market. However, this effect was blunted by arbitrage activity across the market. The estimated cumulative impulse response function confirms that the CSI 300 is increasingly informative as the market share of the CSI 300 ETF increases.

The purpose of this thesis is to study arbitrage opportunities in Chinese financial markets and study how to use stock index futures and CSI 300ETF for arbitrage. This thesis uses a variety of arbitrage strategies to study arbitrage opportunities, such as geographic arbitrage, futures arbitrage, time arbitrage and other arbitrage strategies, and focuses on statistical arbitrage opportunities in China's financial market.

In chapter 2, this thesis divides China's financial market into money market, capital market, financial derivatives market and foreign exchange market, and this thesis describes how to arbitrage in these markets. In chapter 3, this thesis describes various arbitrage strategies and defines these arbitrage strategies, which focuses on statistical arbitrage and designs statistical arbitrage models that will be used in chapter 4. In chapter 4, this thesis selects 6 CSI 300 ETFs in China, then using the method described in chapter 3, the results were calculated. And this thesis compares the 6 CSI 300 ETFs, this thesis selects the best CSI 300 ETF, and uses the OLS model and the GARCH model to conduct arbitrage research. This thesis randomly selected five trading days within a stock index futures contract to study. This thesis simulates the arbitrage opportunities of these data in the graph, and finally compares it by calculating the average return on each trading day, the annualized return and the cumulative net profit. Finally, through the combination of traditional indicators and Sharp ratio, the best arbitrage strategy is obtained. Therefore, it is recommended that arbitragers prefer the positive arbitrage operation of the GARCH model when using high-frequency data for statistical arbitrage trading strategies, followed by the reverse arbitrage of the OLS model, and finally the GARCH model reverse arbitrage.

2 Description of Strategies at Financial Markets

In China, there are different strategies in different markets. In this chapter, this thesis first introduces the strategies in the money market, then introduces the strategies in the capital market, then introduces the strategies in the financial derivatives market, and finally introduces the strategies in the foreign exchange market.

2.1 Strategies in money market

The money market is an organized exchange market where participants can lend and borrow short-term, high-quality debt securities with average maturities of one year or less. It enables governments, banks, and other large institutions to sell short-term securities to fund their short-term cash flow needs. Money market also allows individual arbitragers to invest small amounts of money in a low risk setting.

Several financial instruments are created for short-term lending and borrowing in the money market. They include Treasury bills, certificate of deposit, commercial paper and banker's acceptance.

Treasury bills are considered the safest instruments since they are issued with a full guarantee by the government. They are issued by the Treasury regularly to refinance Treasury bills reaching maturity and to finance the federal government's deficits. They come with a maturity of one, three, six, or twelve months. Chinese treasury bills have a minimum maturity of one year.

Treasury bills are sold at a discount to their face value, and the difference between the discounted purchase price and face value represents the interest rate. They are purchased by banks, broker-dealers, individual arbitragers, pension funds, insurance companies, and other large institutions.

Treasury bill interest rates are closely related to commercial paper, certificates of deposit, etc. Treasury bill futures can provide hedging for other certificates when their returns fluctuate. It is also very mobile. Treasury bills have a vast secondary market, are easy to change hands, can be cashed at any time, and have a high reputation.

Treasury bills are the direct debt of the government and are the least risky investment for arbitragers, and many arbitragers regard it as the best investment object. Although the interest rate of treasury bills is generally lower than that of bank deposits or other bonds, since the interest of treasury bills can be exempted from income tax, investment in treasury bills can obtain higher returns.

A certificate of deposit (CD) is issued directly by a commercial bank, but it can be purchased through brokerage firms. It comes with a maturity date ranging from three months to five years and can be issued in any denomination.

Most CDs offer a fixed maturity date and interest rate, and they attract a penalty for withdrawing prior to the time of maturity. Just like a bank's checking account, a certificate of deposit is insured by the Federal Deposit Insurance Corporation (FDIC).

Large-denomination certificates of deposit in China are book-entry large-denomination certificates of deposit issued by banking depository financial institutions to non-financial institutional arbitragers and denominated in RMB. They are financial products of bank deposits and are general deposits. Large-denomination certificates of deposit take the form of products with standard terms. The starting number of large-denomination certificates of deposit subscribed by individual arbitragers shall not be less than 300,000 yuan, and the starting amount of large-denomination certificates of deposit subscribed by institutional arbitragers shall not be less than 10 million yuan. Large-denomination certificates of deposit take the form of products with standard terms. The starting amount for individual arbitragers to subscribe for large-amount deposit slips is not less than 10 million yuan. The tenors of large-amount certificates of deposit include nine varieties: one month, three months, six months, nine months, twelve months, eighteen months, two years, three years and five years.

Large-denomination certificates of deposit can use fixed or floating interest rates. Interest payment methods are divided into one-time repayment of principal and interest upon maturity, regular interest payment, and principal repayment upon maturity. Before the issuance of each CD, the issuer shall specify in the issuance terms whether transfer, early withdrawal and redemption are allowed, as well as the corresponding interest calculation rules. Arbitragers purchase large deposit certificates in accordance with the real-name system.

Commercial paper is an unsecured loan issued by large institutions or corporations to finance short-term cash flow needs, such as inventory and accounts payables. It is issued at a discount, with the difference between the price and face value of the commercial paper being the profit to the arbitrager.

Only institutions with a high credit rating can issue commercial paper, and it is therefore considered a safe investment. Commercial paper is issued in denominations of $100,000 and above. Individual arbitragers can invest in the commercial paper market indirectly through money market funds. Commercial paper comes with a maturity date between one month and nine months.

Commercial paper is a credit paper, which directly reflects the issuer's commercial credit situation. Arbitragers can use the notes to raise capital. For those issuers who enter the bill market for the first time and are not familiar with arbitragers, by rating their bills, their financial strength, creditworthiness, and reliability of repayment of principal and interest can be accurately and effectively transmitted to many arbitragers, so that it becomes possible to raise more funds.

Arbitragers can obtain more interest income through the issuance of commercial paper at higher interest rates. Arbitragers can also communicate with foreign counterparts through commercial paper and can draw lessons from foreign experience and apply them in combination with the development of Chinese social economy and paper business. However, there are some problems in Chinese commercial paper. At present, China's credit rating agencies have shortcomings such as small scale, inconsistent business scope, loose organization, and low quality of personnel.

A banker’s acceptance is a form of short-term debt that is issued by a firm but guaranteed by a bank. It is created by a drawer, providing the bearer the rights to the money indicated on its face at a specified date. It is often used in international trade because of the benefits to both the drawer and the bearer.

The holder of the acceptance may decide to sell it on a secondary market, and arbitragers can profit from the short-term investment. The maturity date usually lies between one month and six months from the issuing date.

Bank Acceptance For sellers, providing long-term payment to existing or new customers can increase sales and improve market competitiveness. For arbitragers, forward payments can be used to purchase more goods with limited capital, which minimizes the occupation and demand for working capital and is conducive to expanding production scale. Compared with loan financing, arbitragers can significantly reduce financial costs by using bank acceptance. In China, acceptance bills are suitable for all kinds of state-owned enterprises, private enterprises, medical and health institutions, government institutions, schools and other units with real trade background and demand for deferred payment.

A repurchase agreement (repo) is a short-term form of borrowing that involves selling a security with an agreement to repurchase it at a higher price later. It is commonly used by dealers in government securities who sell Treasury bills to a lender and agree to repurchase them at an agreed price later.

The Federal Reserve buys repurchase agreements as a way of regulating the money supply and bank reserves. The agreements' date of maturity ranges from overnight to 30 days or more.

First, repurchase agreement borrowing is one of the favourable tools for banks to implement liability reserve management. Large banks like to use repurchase agreements to adjust their reserve positions. Second, borrowing under repurchase agreements does not require the submission of reserves, which reduces the real cost of borrowing under repurchase agreements. Third, because the repurchase agreement is backed by financial assets such as government bonds, the interest paid by banks for capital needs is slightly lower than the interbank lending rate. Fourth, the term of repurchase agreements is flexible. Although the term of the repurchase agreement is mostly one business day, it can be as long as several months, and the two parties can sign a continuous contract. In the case of no objection to the agreement, the agreement can be automatically extended. Thus, repurchase agreements provide commercial banks with an easier-to-determine tool than other controllable liability instruments.

2.2 Strategies in capital market

Capital markets are the exchange system platform that transfers capital from arbitragers who want to employ their excess capital to businesses that require the capital to finance various projects or investments.

Capital markets primarily feature two types of securities – equity securities and debt securities. Both are forms of investments that provide arbitragers with different returns and risks and provide users with capital with different obligations.

Equity securities are traded on the stock market and are essentially ownership shares of a business or venture. When you own equity securities of a company, you essentially own a portion of that company and are entitled to any future earnings that the company brings in.

However, the money that you invest in equity securities is not required to be paid back by the business.

Equity securities include common stock and preferred stock. Most of the equity securities listed in China are ordinary shares and account for most of the exchange's trading volume.

Common stock and preferred stock are shares issued by a company to shareholders. Common stockholders, as shareholders of the company, have voting rights and can receive dividends according to the company's dividends. However, a company may not necessarily declare a dividend even if it records a profit that year. Preferred stockholders are entitled to the distribution of agreed dividends in preference to common stockholders. Preferred stockholders have no voting rights but receive a fixed dividend (though the dividend will not increase as the company's earnings increase). In the unfortunate event of a company winding up, preferred shareholders can receive distributions before common shareholders and after creditors. Shareholders of dividend-paying preference shares may receive dividends if profits permit. As for holders of cumulative preference shares, if there is no dividend to be distributed in the year, the dividends that the holders should receive will be accumulated until the company has dividends to be distributed and distributed in one go.

Debt securities are traded on the bond market and are IOUs that can come in the form of bonds or notes. They essentially represent the borrowing of money that will be paid back later with interest.

Interest is the required compensation that entices lenders to lend their money. The borrowers will take the money today, use it to finance their operations, and pay back the money in addition to a prescribed rate of interest later.

Bonds are a common type of debt securities such as government bonds, corporate bonds, municipal bonds, mortgage bonds, and zero-coupon bonds.

A debt security is a financial asset created by one party lending money to another. For example, corporate bonds are debt securities issued by companies and sold to arbitragers. Corporate bond arbitragers lend money to a company in exchange for a pre-determined amount of interest payments and get back the principal when the bond matures.

Government bonds, on the other hand, are debt securities issued by the government and sold to arbitragers. Government bond arbitragers lend money to the government in exchange for interest (called a coupon payment) and to get the principal back when the bond matures. Debt securities are also known as fixed income securities because they generate regular income from the interest paid.

Because borrowers are legally required to make these payments, debt securities are generally considered a lower-risk form of investment compared to equity investments such as stocks. Of course, as is always the case in investing, the true risk of a particular security will depend on its characteristics.

For example, a company with a strong balance sheet operating in mature markets may be less likely to default on its debt than a start-up operating in emerging markets. In this case, more favourable credit ratings may be given to mature companies. To balance risk and reward, companies with higher credit ratings typically offer lower interest rates on their bonds, and vice versa.

Equity securities represent a claim on a company's earnings and assets, while debt securities are investments in debt instruments. For example, a stock is an equity security while a bond is a debt security. When arbitragers buy corporate bonds, they are effectively lending money to the company, and they are entitled to the principal and interest paid back on the bond. Conversely, when someone buys stock from a company, they are actually buying part of that company. If the company is profitable, the arbitragers will also be profitable, but if the company is losing, the stock will also lose.

2.3 Strategies in financial derivatives market

The derivatives market refers to the financial market for financial instruments such as futures contracts or options that are based on the values of their underlying assets.

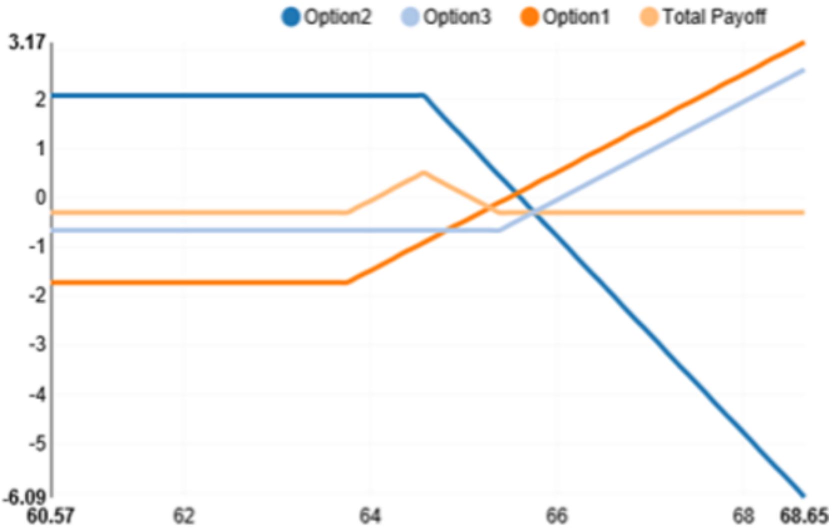
Derivative contracts can be classified into the following four types:

Options are financial derivative contracts that give the buyer the right, but not the obligation, to buy or sell an underlying asset at a specific price (referred to as the strike price) during a specific period. American options can be exercised at any time before the expiry of its option period. On the other hand, European options can only be exercised on its expiration date.

Arbitragers can use options to arbitrage, with unlimited gains and limited risks and losses. Therefore, in many cases, using options to replace futures for short-selling and arbitrage trading will have less risk and higher returns than simply using futures arbitrage.

In China, arbitragers can have a variety of arbitrage methods using various combinations of options.

Figure 2.1 Option Arbitrage



Source: Financial Decision Making Under Risk

From Figure 2.1, arbitragers can use stocks and options to arbitrage. There are two combinations: one is to buy a put warrant while longing a stock; the other is to buy a call warrant while shorting a stock, using long arbitrage and short arbitrage respectively.

Arbitragers can also switch arbitrage, for example, when an arbitrager buys a put option and sells a call option, he buys a trade in the underlying futures contract. The strike price and expiration date of the call option and the put option are the same, and the delivery month of the relevant futures contract and the expiration month of the option contract are also the same.

Arbitragers can also use two-way options to simultaneously buy or sell different types of options at the same strike price. Arbitragers can also simultaneously buy or sell call options and put options with the same underlying, the same expiration date, but different strike prices.

Arbitragers can also arbitrage by buying and selling call or put option contracts on the same commodity, the same expiry month, but at different strike prices at the same time. This arbitrage consists of two arbitrage exchanges that buy and sell in opposite directions and share the same and cantered strike price.

Arbitragers can separately sell (buy) options with two different strike prices, and simultaneously buy (sell) options with lower and higher strike prices. All options have the same type, underlying contract and expiration date, and strike prices are equally spaced.

Taking stocks as an example, suppose an arbitrager buys 5,000 shares of SAIC Motor. When the stock price is 20 yuan, the arbitrager wants to avoid the risk of falling stock prices in the market due to certain needs. If the option contract is 20 yuan, then arbitragers can choose to buy a put option that matches the time, and pay the premium according to the transaction price, if the premium of the option contract you buy is 0.5 yuan. Then arbitragers lock in the biggest risk of the stock price going down through put options. You can imagine that if the stock price continues to fall to 19 yuan or lower, after holding to maturity, arbitragers have the right to sell the stock out at the price of 20 yuan. Therefore, the more the fall, the greater the gain after the option is up. This part of the gain and the loss of holding the underlying stock can offset each other, to achieve the purpose of avoiding risks. In addition, the operation of buying put options also gives room to profit even when the stock price rises. The combined return of the underlying stock and the long-put option is like buying a call option.

In addition to buying put options to provide protection for their holdings, arbitragers can also sell call options in the market, but doing so only provides partial protection for the stock. Assume that the sold call option with a strike price of 20 yuan also trades at 0.5 yuan. When the stock price rises, the underlying stock makes a profit, but the short position of the call option begins to lose money after reaching the breakeven point 20.5.

Futures contracts are standardized contracts that allow the holder of the contract to buy or sell the respective underlying asset at an agreed price on a specific date. The parties involved in a futures contract not only possess the right but also are under the obligation, to carry out the contract as agreed. The contracts are standardized, meaning they are traded on the exchange market.

There are two types of futures: commodity futures and stock index futures. The subject matter of commodity futures is agricultural and side-line products, metals and energy and other commodities. Financial futures mainly include currency futures, interest rate futures and stock index futures. In China, there is only one stock index futures contract, namely the CSI 300 stock index futures contract, which was officially listed and traded on April 16, 2010. As a type of futures trading, stock index futures are standardized futures contracts with the CSI 300 index as the subject matter. Both parties agree to trade at a future point in time, and the determined stock price index is used as the basis for profit or loss.

For example, before the close of a certain day, the CSI 300 index in the spot market is 3500 points, and the futures market has a CSI 300 index futures contract that expires in 3 months. Very optimistic, so now the price of index futures has reached 3800 points.

If arbitragers think that after 3 months, the CSI 300 index will exceed the 3800 points, arbitragers can buy this stock index futures, that is arbitragers promise to buy the market index at a price of 3800 points after 3 months. When the stock index futures rise to 3850 points, arbitragers can choose to close the position in advance to take profit and sell the futures contract to gain a profit of 50 points, or arbitragers can choose to hold the position before closing the position. The arbitrage formula is as follows:

$$Profit = (index_1 - index_0) \times P_0 \tag{2.1}$$

Among them: $index_1$ is stock index in future, $index_0$ is the current stock index, P_0 is the profit of each lot of the stock index futures. According to the CSI 300 index contract, the price of each point is 300 yuan, and each lot of the stock index futures contract you hold will receive a profit of $300 \times 50 = 15{,}000\ yuan$ (transaction costs are not considered for the time being).

Another situation is, if everyone thinks that the stock index will rise in 3 months, the current price of index futures is 3800 points, and arbitragers are not so optimistic, arbitragers predict that the stock index will fall in 3 months, arbitragers can sell the contract at the spot price of CSI 300 at 3500 points, that is short the stock index. If the trend of the stock index after three months is really down, assuming it falls to 3200 points, then arbitragers can buy the contract at the price of 3200 points to close the position, then arbitragers can get 300 points of income per lot, that is profit of RMB 90,000, which is how the stock index is profitable when it falls.

In China's financial market, arbitragers can use stock index futures for risk-free arbitrage. Since the stock index futures contract is a financial futures contract with the stock price index as the subject matter, sometimes there is a certain deviation between the futures index and the spot index. When the deviation reaches a certain level, there may be arbitrage space. Arbitrage with the short-term irrational relationship of the spot index.

For example, on a certain day, the CSI 300 index futures contract is 4,500 points, and the CSI 300 index is 4,000 points, and the price difference between the two reaches 500 points. Since the price of each point is 300 yuan, in principle, there are 150,000 yuan arbitrage spaces in the futures and spot markets. First, sell 1 lot of stock index futures at a price of 4500 points in the stock index futures market, and the transaction price is

$4500 \times 300 = 1350{,}000\ yuan$. Then, arbitragers can choose to buy shares in the CSI 300 stock pool for the same amount. Of course, because there are too many stocks in the CSI 300 stock pool, arbitragers cannot buy them all, you can replace them with corresponding index funds (such as the SSE 50ETF index fund).

Assuming that by the settlement date, the CSI 300 index is at 4200, the profit can be divided into the following two parts. The total profit formula is as follows:

$$Profit_{total} = Profit_1 + Profit_2 \tag{2.2}$$

Among them: $Profit_1$ is the money made by shorting the futures contract, $Profit_2$ is the return of the fund. The formula for $Profit_1$ is as follows:

$$Profit_1 = index_p \times P_0 \tag{2.3}$$

Among them: $index_p$ is the point that a short-sold futures contract has a profit, P_0 is the price of each point. A short-sold futures contract has a profit of 500 points, which is converted into cash at $300 \times 300 = 90{,}000\ yuan$. The formula for the increase in the return of the buying fund is as follows:

$$r_0 = \frac{index_1 - index_0}{index_0} \tag{2.4}$$

Among them: r_0 is the increase in the return of the buying fund, $index_1$ is stock index at the settlement data, $index_0$ is the current CSI 300 index. The formula for the $Profit_2$ is as follows:

$$Profit_2 = P_t \times r_0 \tag{2.5}$$

Among them: P_t is the transaction price. Here this thesis assumes that the fund's income will rise in the same proportion, and the income of buying the fund will rise at a rate of: $(4200 - 4000) \div 4000 = 5\%$, and the fund's income will be $135{,}0000 \times 5\% = 6750\ yuan$, and the total profit: $90{,}000 + 6750 = 96{,}750\ yuan$.

If the stock index rises by more than 4,500 points and reaches 4,600 points on the settlement date, the profit situation is as follows: the short-sold futures contract loses 100 points, which is $-100 \times 300 = -30{,}000\ yuan$ when converted into cash. $(4600 - 4000) \div 4000 = 15\%$, the fund income is $1350{,}000 \times 15\% = 202{,}500\ yuan$, the total profit: $-30{,}000 + 202{,}500 = 172{,}500\ yuan$.

If the stock index falls to 3800 points on the settlement day, the profit situation is as follows: First, the short-sold futures contract is 700 points of profit, which is $700 \times 300 = 210{,}0000$ when converted into cash. The second is the income from buying the fund. Due to the decline in the index, the fund is losing money. The loss ratio is: $(4000 - 3800) \div 4000 = 5\%$, the fund loss is $1350{,}000 \times (-5\%) = -67{,}500\ yuan$, and the total profit: $210{,}000 - 67500 = 142{,}500\ yuan$.

Forwards contracts are similar to futures contracts in the sense that the holder of the contract possesses not only the right but is also under the obligation to carry out the contract as agreed. However, forwards contracts are over-the-counter products, which means they are not regulated and are not bound by specific trading rules and regulations.

Since such contracts are unstandardized, they are traded over the counter and not on the exchange market. As the contracts are not bound by a regulatory body's rules and regulations, they are customizable to suit the requirements of both parties involved.

A forward contract is the basis of a futures contract. It is a contract in which both parties agree to complete a fixed transaction volume at a fixed price at a fixed time in the future. The transaction contract is binding on both parties to the transaction, that is, both parties have the obligation to complete the transaction and must not breach the contract.

For example, the arbitrager opened a pig farm. Arbitragers thought that they could make money by raising pigs, but arbitragers soon discovered that the price of pork not only fluctuates frequently, but also fluctuates greatly. Arbitragers have calculated the cost. If the price of pork is above 8 yuan, it will make money, but the price is unstable. At this time, arbitragers found a factory that makes pig sausages. The price of sausages is linear and basically does not fluctuate. Sausage factories have the same concern, that if pork prices rise, they will lose money. The sausage factory calculated that the pork price can be profitable if it is below 12 yuan. So, the arbitrager and the sausage factory signed a contract, and the agreed price was 10 yuan, so that both parties could make a profit.

Swaps are derivative contracts that involve two holders, or parties to the contract, to exchange financial obligations. Interest rate swaps are the most common swaps contracts entered into by arbitragers. Swaps are not traded on the exchange market. They are traded over the counter, because of the need for swaps contracts to be customizable to suit the needs and requirements of both parties involved.

In August 2007, the inter-bank foreign exchange market officially launched the RMB foreign exchange currency swap business. In the first few years of business operation, due to the complex transaction elements and insufficient actual demand, the currency swap market was still in its infancy and cultivation stage, with few transactions and insufficient liquidity. In 2014, the RMB exchange rate bid farewell to the trend of unilateral appreciation and entered a two-way fluctuation. With the rise of exchange rate volatility, the demand for exchange rate hedging of foreign currency assets and liabilities has also increased. In 2014, the volume of interbank currency swaps reached US$10 billion for the first time, a leap-forward increase from the average US$5 billion volume in the previous two years. After the renminbi was officially included in the SDR in 2016, the demand for Chinese assets from overseas arbitragers exploded, and the ensuing exchange rate hedging demand made the volume of interbank currency swaps jump to more than US$20 billion in 2016. In 2016, the number of members in the interbank foreign exchange currency swap market reached 138, a significant increase from 84 and 99 in 2014 and 2015. According to the data of the foreign exchange trading center, the newly added currency swap members after 2014 are mainly foreign central bank institutions and overseas participating banks, while the domestic currency swap members have not grown significantly. It can be seen that after the domestic inter-bank bond market was officially opened to the three types of overseas institutions, the transaction demand for currency swaps mainly came from the exchange rate hedging demand of overseas members.

2.4 Strategies in Foreign exchange market

The foreign exchange market is a decentralized and over-the-counter market where all currency exchange trades occur. It is the largest (in terms of trading volume) and the most liquid market in the world. On average, the daily volume of transactions on the forex market totals $5.1 trillion, according to the Bank of International Settlements' Triennial Central Bank Survey 2016.

The forex market major trading canters are in major financial hubs around the world, including New York, London, Frankfurt, Tokyo, Hong Kong, and Sydney. Due to this reason, foreign exchange transactions are executed 24 hours, five days a week except weekends. Despite the decentralized nature of forex markets, the exchange rates offered in the market are the same among its participants, as arbitrage opportunities can arise otherwise.

The foreign exchange market is probably one of the most accessible financial markets. Market participants range from tourists and amateur traders to large financial institutions (including central banks) and multinational corporations.

Also, the forex market does not only involve a simple conversion of one currency into another. Many large transactions in the market involve the application of a wide variety of financial instruments, including forwards, swaps, options, etc.

Assume that the EUR/JPY forex pair is quoted at 122.500 by the Bank of London and 122.540 by the Bank of Tokyo. A trader with both offers will be able to buy the London price and sell the Tokyo price. When the price later converges to say 122.550, traders will close both trades. Tokyo positions will fall by 1 pip and London positions will increase by 5 pips, thus reducing the trader's transaction costs by 4 pips.

3 Arbitrage Strategies and Their Identification

In the broad sense of arbitrage, the business of any financial institution can be regarded as arbitrage in a certain sense or degree. For example, a bank's deposit and loan business can be regarded as a combination of risk arbitrage and term arbitrage. Banks pool a large amount of risk by holding many loan positions of different enterprises. Compared with arbitragers lending to enterprises themselves, according to the law of large numbers, the overall risk will be reduced after the accumulation of not completely related risks, so it can earn profit from risk arbitrage. In addition, banks use short-term deposits of arbitragers for long-term loans to earn profits from term arbitrage. Since China is currently in a period of transition from a planned economy to a market economy, the market economy system has not been fully established. As a difficulty in economic system reform, the financial system is still in the stage of underdevelopment and imperfection. The definition of arbitrage is to use the imperfection of the price system in the market to obtain profits through buying and selling. Arbitrage is essentially a means of market governance. The difference between arbitrage and investment lies in their different purposes. The purpose of investment is to buy and invest money to gain value, while the purpose of arbitrage is to buy and sell, and to use the imperfect market to earn the difference. This thesis will cover 8 arbitrage strategies that will work. This thesis will focus on statistical arbitrage. And in chapter 4, this thesis will describe how to use statistical arbitrage for arbitrage.

3.1 Spatial or geographic arbitrage

Spatial arbitrage refers to buying a commodity at a low price in one market and selling the same commodity at a high price in another market to earn the difference between the two prices. Spatial arbitrage is a relatively simple arbitrage method. To make spatial arbitrage profitable, the price difference between the two markets must be sufficient to cover the transaction and transportation costs incurred, and the effect of arbitrage will bring the two markets back to a new equilibrium. In this state, arbitrage activities cannot obtain excess profits. The ideal simplified situation is the law of one price, that is the prices of the same commodity in different places should tend to be the same. With the development of information, the opportunities for spatial or geographic arbitrage become less and less. And if they appear, arbitrage opportunities are fleeting because of a large number of arbitrage activities. Now, geographic arbitrage is more of a mindset. Therefore, this thesis sees that more and more venture capitalists are focusing on emerging markets, applying business models that have been successful in other countries to replicate overseas. For example, the success of Uber, a shared car has gradually evolved into China's Didi Taxi. There is also geographic arbitrage in education in China because there is a saying in China that the housing price near the school will be much higher.

In fact, everyone has a way of geographic arbitrage. For example, individuals can choose to work remotely. Just like Chinese programmers, benefiting from the dividends of technological development and globalization, remote work can benefit a lot through geographic arbitrage. It is also possible to diversify the currency in China and make global investments. Take bank deposits as an example. In China, the deposit interest rate is only about 3%, and the RMB may depreciate at any time. However, if arbitragers change the country and change the currency to deposit, the annual deposit interest rate in some places can even reach 8%. It can also be said to be a good geographical arbitrage.

Let's take the real estate investment that everyone likes to do, the most critical factor to consider is the real estate rental rate and future real estate appreciation. In some new first-tier cities in China, the housing prices in these cities are far less high than those in Beijing and Shanghai, but the rents in these new first-tier cities are not much lower than those in Beijing and Shanghai. In terms of rental returns, they are even higher than those in Beijing and Shanghai. Much higher, so there is also geographic arbitrage in real estate.

For example, in China, Hong Kong can be used for geographic arbitrage. Most people know that Hong Kong is very cheap to buy things, such as milk powder, cosmetics, famous brand bags, etc. In fact, this is also geographic arbitrage, but there is more in-depth geographic arbitrage.

Arbitragers can register a Hong Kong company, because Hong Kong's policies are very favourable, and the taxation of mainland China and Hong Kong is very different. And arbitragers can use Hong Kong companies to link the mainland and even the international market. Opening a company in Hong Kong has many advantages, such as high international reputation, convenient international trade, simple registration process, low tax rate, less tax, convenient foreign exchange settlement, no restrictions on business scope and regional scope, no restrictions on arbitragers, shareholders, directors, etc. If the business is not in Hong Kong, you can directly do 0 tax declaration. Anyway, registering a Hong Kong company is more cost-effective than registering a company in mainland China.

At the same time, arbitragers can also use Hong Kong insurance for geographical arbitrage. Unlike the closed-door countries in other places, in Hong Kong there is more complete free competition, so the products can only be continuously optimized and upgraded, otherwise arbitragers will eventually be eliminated by the market. Therefore, Hong Kong insurance has many advantages. The underwriting is strict, but the entry is strict, and the exit is strict. The underwriting of Hong Kong insurance is strict, and the principle of highest integrity is adopted, there is no past disease, surgical records and chronic medical history, or the insurance amount is lower than the exemption limit (different insurance companies). The amount of exemption from physical examination is different. Generally, physical examination is not required, but there is a possibility of being randomly checked; however, if the insured has a history of disease or other health conditions, arbitragers should take the initiative to declare. And it is cost-effective, for example, the determination of critical illness insurance premiums is based on the average life expectancy, probability of illness and age at the time of insurance. As Hong Kong, which has the highest average life expectancy in the world (currently, the average life expectancy of Hong Kong people is 81.3 years for men and 87.3 years for women) corresponding to the same age. The mortality rate in Hong Kong is also lower than that in the mainland, so Hong Kong's critical illness insurance premiums are about one-third cheaper. To diversify currency risk, Hong Kong's policy payment currency can choose Hong Kong dollar and US dollar, which is a good diversification method for most of us who own RMB assets. To resist medical inflation, simply take serious illness as an example, and there are dividends, which can resist medical inflation and so on.

3.2 Time Arbitrage or Carrying Cost Arbitrage

Time arbitrage refers to buying a commodity at a low price at one moment and selling it at a higher price at another moment in the future. The pricing formula is as follows:

$$F = S \times (1 + RT) \tag{3.1}$$

Among them, F is forward price at time T, S is spot price at time T, R is risk free rate. The formula is about forward price in financial engineering is the application of this arbitrage. Buying the spot now and selling it for delivery in the future requires costs, that is, holding a position requires funds, and funds have time value (more strictly speaking, time cost here), commodities and storage costs. On the other hand, there are certain benefits to be gained from holding certain types of commodities. The difference between the cost and the benefit is the net holding cost of holding the commodity. The no-arbitrage pricing theory makes the spot and forward prices of the commodity satisfy the formula mentioned above. If it is not satisfied, such as $FS(1 + RT)$, you can do this and buy the commodity at the price S in the current period, hold the commodity and sell it at the pre-determined forward price F at the end of the expiration, $F - S(1 + RT)$. That is arbitrage profit. The launch of China's stock index futures has led to an operation called futures and spot arbitrage in the market, that is using the price difference between the index futures price and the underlying CSI 300, using the forward pricing formula, or buying futures and selling the corresponding index at the same time stock, or selling the futures and buying the stock corresponding to the index to earn the difference. Due to the imperfect market price in China, this operation has achieved a lot of excess profits after the launch of stock index futures. However, with the popularization of such arbitrage operations, it is expected that such arbitrage will be difficult to maintain lasting excess profits.

There are other methods of time arbitrage, where arbitragers can use options to buy a stock when it falls or to profit when it doesn't. The arbitragers identify the stocks arbitragers intend to hold for the long term. Then arbitragers sold a put option. If the stock doesn't fall, meaning its value continues to rise or stay above the strike price, arbitragers can keep the sell premium and end up not holding the stock. If the stock falls to the strike price, the arbitragers buy the stock at the lower effective price because the option premium charged to date offsets some of the purchase cost. The risk is that the stock is well below the strike price, which means that the arbitragers will end up buying shares in the company arbitragers wants to own at a premium to the market price.

For example, the stock of company A is a dazzling arbitrager with ever-increasing profits thanks to a new revolutionary product. The stock is currently trading at 270 yuan, and the price-earnings ratio is very reasonable, the valuation is for the rapid development of the company. If arbitragers are optimistic about their prospects, arbitragers can buy 100 shares for 27,000 yuan, plus commissions and fees. Alternatively, arbitragers can sell a 250 yuan put option that expires in January for 30 yuan and expire in two years. This means that the option will expire on the third Friday of January in two years, with an exercise price of 250 yuan. An options contract covers 100 shares and allows arbitragers to receive an option premium of 3,000 yuan over time. By selling this option, arbitragers agree to buy 100 shares of company A at a price of 250 yuan within one month after two years. Obviously, since the stock of company A is priced at 270 yuan today, a put buyer would not ask arbitragers to buy the stock at 250 yuan. So, arbitragers can collect the premium while arbitragers wait. If the stock falls to 250 yuan before expiry in January in two years, arbitragers will be required to buy the 100 shares at that price. But arbitragers will keep the premium of 30 yuan per share, so net cost of arbitragers will be 220 yuan per share. If the stock never drops to 250 yuan, the option will expire worthless, and arbitragers will keep the full 3000 yuan premium. In summary, as an alternative to buying 100 shares for 27,000 yuan, arbitragers can sell the put option and reduce the net cost to 220 yuan /share (or 22,000 yuan /share if the price drops to 250 yuan /share). If the option expires worthless, arbitragers can keep the premium of 30 yuan per share, which translates to a 12% return on the 250 yuan bid price. Selling put options on securities arbitragers want to own is very attractive. If company A refuses, arbitragers need to pay 25,000 yuan to buy the shares for 250 yuan. Since arbitragers keep 3000 yuan premium, net cost of arbitragers will be 22,000 yuan.

3.3 Tax arbitrage

It is a way to make use of the difference in tax rates of different taxpayers to transfer profits from taxpayers with high tax rates to taxpayers with low tax rates by buying and selling certain types of goods, or transfer profits from areas with high tax rates to those with low tax rates. The way is the region that obtains benefits. John Marshall mentioned the emergence of high-tax companies in the United States holding preferred shares issued by low-tax companies as an example of tax arbitrage. In China, there is a lot of tax arbitrage, that is the transfer of profits to taxpayers with lower tax rates through affiliated transactions between parent-subsidiary or sibling companies at non-market prices. Many multinational companies' subsidiaries in China use this method to sell certain types of technology, trademarks or core components and other assets to their domestic subsidiaries through foreign parent companies at non-market prices to transfer profits, thereby avoiding tax obligations in China. Other examples include the adoption of a trust plan or partnership rather than a limited liability company, and the transfer of tradable shares after the IPO to tax-advantaged provinces or territories, and so on. Since taxation is an unavoidable factor in any market economic activity, it is crucial for the practice of financial engineering to consider the taxation impact of financial activities.

3.4 Risk arbitrage

Risk arbitrage refers to an arbitrage method that reduces the overall risk by pooling different risks and earns a risk premium. According to the principle of large numbers, when multiple risks that are not related to each other (or related but not completely related) are aggregated, the overall risk will be greatly reduced. Since economic entities are generally risk-averse, under the condition that other conditions remain unchanged, the increased value of risk reduction, the economic entity is willing to pay for the increased value, and this cost is the source of profit for risk arbitrageurs. Insurance is a typical application of this arbitrage. Funds and other diversified investment financial instruments can also be regarded as a certain degree of application of risk arbitrage.

3.5 Term arbitrage

Term arbitrage utilizes the inconsistent yields of products with the same other conditions but different terms in the financial market and obtains profits by compounding or splitting products and converting products with different terms. In financial theory, the relationship between maturity and yield is called the term structure of interest rates, and the term structure of financial products with different terms under the same other conditions, represented by a chart, is called the yield curve. Under normal circumstances, the term structure of interest rates is characterized by an upward-sloping yield curve.

A common spread arbitrage in China's bond market is essentially a form of term arbitrage. That is by purchasing treasury bonds or credit bonds with a longer term, assuming the purchase of AA credit bonds with a maturity of 5 years, the yield to maturity is 7%. The interest rate is 3%. After the repurchase, transaction expires, the second repurchase transaction is carried out at the repurchase rate at the expiry time. Repeatedly, if the yield curve does not change, this arbitrage operation can be carried out. Earn 4% per annum with no capital or a small amount of your own capital. Through term arbitrage, arbitragers essentially play the function of providing liquidity to the financial market, which is one of the core functions of financial enterprises.

3.6 Liquidity arbitrage

Liquidity arbitrage refers to arbitrage by using the price difference of commodity prices when other conditions are the same, but the market liquidity is different by providing liquidity to the market. The price decision of financial products is determined at the balance point of supply and demand, so at this price point, if there is a change in supply or demand, it will cause supply and demand to move to a new balance point for arbitragers if arbitragers want. If arbitragers need to buy or sell a financial product at the current price, the act of buying or selling will lead to an unfavourable price change, that is if arbitragers need to buy, the price will be at the current price due to the increase in market demand. The base rises, resulting in it being unable to buy enough of the product at the desired price. If it needs to be sold, due to the increase in market supply, the price will fall on the basis of the current price, resulting in the inability to sell a sufficient amount of the product at the desired price. In financial theory, the degree of influence of a certain amount of a product bought and sold on its current price or the difference between a product's bid and ask prices is often used to measure the liquidity of a product. For some financial products, there are many of them. Therefore, the liquidity is good, and buying or selling a certain amount has less impact on the price, while for some products, there are fewer demand and supply sides, so the liquidity is very poor, buying or selling a certain amount has a great impact on the price. For such commodities, liquidity arbitrage is very promising.

The success of Nasdaq in the United States is closely related to its implementation of the market maker system, which provides liquidity to the market through market makers and acts as a counterparty for arbitragers to buy or sell at a certain price, which greatly reduces the arbitragers ' liquidity risk, thus attracting many arbitragers to participate. Many other countries and regions such as Hong Kong launched exchanges similar to Nasdaq, which have not developed due to insufficient liquidity. The current reduction of large-scale transactions in China's financial market can also be regarded as an application of liquidity arbitrage, that is stockholders who need short-term realization, because they are worried that a large reduction in their holdings in the short term will cause a major downward impact on current prices. However, the stocks they hold are transferred to a special investment institution through bulk transactions at a certain discount, and the investment institution will slowly clear it out in instalments in the next period, so that it will not have a big impact on the price. The arbitrage interest of the investment institution is the difference between the selling and buying prices.

In the early stage of the development of asset-backed securities, according to classical financial theory, when new financial products are not easily priced because they are not familiar to most arbitragers when they are first launched, they will face the problem of insufficient liquidity. Acting as a market maker for liquidity arbitrage is very critical. It is not only a prerequisite for the effective development of the market, but also brings a lot of profits to the market maker.

3.7 Product switching arbitrage

Financial products can be regarded as a series of specific cash flows. Product conversion refers to dividing or combining the cash flows of specific financial products to construct a new series of cash flows, that is new financial products. Arbitrage the difference between the price and the original cash flow price.

Financial products with the same cash flow have the same value to arbitragers for their own use. However, after considering the exchange value, it cannot necessarily come to the conclusion that the price of the product is the same, that is the pricing of financial products does not necessarily satisfy the linear pricing principle, which is the theoretical basis of product switching arbitrage. There are many assumptions in theory whether financial products meet the linear law, but it is easy to find in daily life that the price of beef noodles made from a piece of beef and a bowl of noodles is higher than the price of the beef and noodles used. This should generalize to the pricing of financial products. Obviously, the price of financial products conforms to the linear law, which should be the characteristic of the complete efficiency of the financial market, and this perfection is gradually obtained through arbitrage.

The structural design of financial products is a form of product conversion arbitrage. One of the practical reasons for the structured design may be that some financial institutions are restricted by investment. For example, insurance companies can only invest in credit bond products above AA level, even if the insurance company is considering the risk of default. After the factors and risk premium, they were more willing to buy low-risk credit bond products. The existence of investment restrictions will make high-credit bonds above AA priced high, that is investing in high-credit bonds, the income obtained does not match the risks and funds invested, which is not worth the loss, only due to policy restricted as a last resort. In this case, a structured product is designed to change the cash flow distribution method of the low credit level product, so that the insurance company will be paid first, and other arbitragers will receive cash flow payment after the insurance company is paid. The redistribution of cash flow makes the risk transfer between the priority products and the secondary products. Through the structural design, the priority products are sold to the investment-restricted insurance institutions at high prices, which originally could not be invested by the insurance institutions. is profitable.

Restrictions on investment varieties can be regarded as a form of market segmentation. Through structural design, financial products can be converted so that products can be traded in markets that could not be traded before. Arbitragers who buy can also be regarded as a certain degree of geographic arbitrage, that is buying at a low price in one market and selling at a high price in another market. Product switching arbitrage opportunities can also arise when there is a strong preference in the financial market for a particular grade of debentures.

3.8 Statistical arbitrage

In China, the main arbitrage is the arbitrage of stock index futures. Based on the CSI 300 ETF, this thesis conducted an empirical study on the statistical arbitrage of stock index futures. The research of this thesis on the statistical arbitrage of stock index futures has three steps: the first step is to construct a spot position, the second step is to determine the transaction threshold to identify the start and end signals of the arbitrage, and the third step is to select the statistical arbitrage trading model. For the establishment of spot positions, this thesis first selects two mature CSI 300 ETF funds, Huatai-Pinebridge CSI 300ETF and Harvest CSI 300ETF. For the setting of the arbitrage trading threshold in the arbitrage trading strategy, the trading threshold when the arbitrage income reaches the maximum value is calculated by using the arbitrage expected return function.

3.8.1 Cointegration and Error Correction Models

In the process of statistical arbitrage, the basic idea of statistical arbitrage is mean reversion, and its actual concrete manifestation is the idea of cointegration. If there is a long-term equilibrium relationship between the two economic variables, then when the two prices deviate, this thesis think this is only a temporary phenomenon, and the price difference between the two will always return to a reasonable range. Assets that will rise, while selling assets whose prices are overvalued will inevitably fall, when the price difference between the two returns to the equilibrium value, close the position to make a profit. Otherwise, do the opposite. If there is no cointegration relationship between the two economic variables, arbitrage trading may make mistakes even if the spread series deviates greatly. Therefore, before conducting statistical arbitrage trading, it is necessary to first study the cointegration relationship between the two.

3.8.2 Unit root test

When testing the cointegration relationship between variables, the first step is to carry out unit root testing, that is to test whether the two economic variables have the same number of unit roots, that is the so-called single-integration relationship of the same order. Currently, DF and ADF tests are widely used. In the 1970s and 1980s, Dickey-Fuller established a test method, named after him as the DF test. Since the DF test is only suitable for testing the first-order autoregressive process and cannot test the p-order autoregressive process, Dickey-Fuller On this basis, the DF test is modified and expanded, and the ADF test is defined to test the unity of the time series. First set the regression equation, introduce the lag difference term Δy_{t-i} of the dependent variable y_t, on the right side of the equation, and set the time series to be a p-order autoregressive process, namely AR (p). The regression equation of the ADF test is as follows:

$$\Delta y_t = \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \qquad (3.2)$$

Among them: y_t is the time series data, t is the time trend term, ε_t is the error term, β_i is coefficient and p is the lag term. Hypothesis: null hypothesis $H_0 : \gamma = 0$, alternative hypothesis $H_1 : \gamma < 0$. If the null hypothesis is rejected, it means that there is no unit root, and the time series is stationary. If the null hypothesis cannot be rejected, only the null hypothesis can be accepted, indicating that the time series has a unit root and the time series is not stationary. Then, the original time series is differentiated (this can increase the constraints), and the unit root test is continued on the differentiated sequence data until the result is that the null hypothesis is rejected. If the null hypothesis cannot be rejected after many differences, the original sequence is a unit root sequence. In formula (3.2), in order to ensure that the error term ε_t is white noise, p must be large enough to eliminate the autocorrelation of ε_t, and p must be small enough to ensure that the test formula has more degrees of freedom.

3.8.3 Cointegration Test

Defined by cointegration, it can be determined whether there is a cointegration relationship among N time series data by performing a unit root test on the unbalanced error series. The null hypothesis H_0: the unbalanced error sequence has a unit root, and the alternative hypothesis H_1: the unbalanced error sequence does not have a unit root. The corresponding test is: Null hypothesis H_0: There is no cointegration relationship among N time series, and the alternative hypothesis is H_1 : The sequence has a cointegration relationship. Therefore, the equilibrium relationship between the time series can be tested by the ADF statistic. The steps are as follows:

If the k sequences y_{1t}, y_{2t},..., y_{kt} are all first-order single integral sequences, establish the regression equation:

$$y_{1t} = \beta_1 + \beta_2 y_{2t} + \cdots + \beta_k y_{kt} + \mu_t \tag{3.3}$$

Among them, β_1, β_2, ..., β_k are the least squares estimators. The model estimated residuals are:

$$\mu_t = y_{1t} - \beta_1 - \beta_2 y_{2t} - \cdots - \beta_k y_{kt} \tag{3.4}$$

The residual sequence should be. The unit root test is performed to determine whether the time series has a cointegration relationship. If the residual series is stationary, there is a cointegration relationship between the variables.

3.8.4 Error correction model

The Error Correction Model was first proposed by Sargon (1964) and further improved by Hen-Anderson and Davidson (1977) and others. There are two types of error correction models: single equation and multi-equation. This thesis only introduces the single-equation model. The model expression is as follows:

$$\Delta y_t = \beta_0 \Delta x_t + \beta_1 ECM_{t-1} + v_t \tag{3.5}$$

Among them, $\beta_1 ECM_{t-1}$ represents the error correction term, and $ECM_t = y_t - \alpha_0 - \alpha_1 x_1$, which is the unbalanced error, β_1 is the correction coefficient, which represents the correction speed of the error correction term to Δy_t, v_t is the random error term, and $y_t = \alpha_0 + \alpha_1 x_1$ represents the long-term equilibrium relationship between y_t and x_t.

Advantages of error correction models:

In the above formula, the least squares estimator of the regression parameters has excellent characteristics, there is no spurious regression problem, and the ECM_t has stationarity if and only if there is a cointegration relationship between y_t and x_t.

The error correction model has parameters describing both the short-term model and the long-term model, which not only studies the long-term economic problems, but also shows the short-term economic characteristics. The static equilibrium relationship under the time series is realized by continuous adjustment in the dynamic process.

If the cointegration relationship between two time series is discussed, β_i must be negative, because the error correction mechanism should be a feedback process. If the cointegration relationship between multiple time series is discussed, β_i is not necessarily negative.

3.8.5 GARCH model

Most of the economic time series data do not have a fixed variance but show a relatively stationary phase after a certain high volatility. The main purpose of introducing the residual series fluctuation model is as follows. First, the so-called program is related to the study of the characteristics of economic time series data. For example, random inspection of GDP, fiscal data, interest rates, exchange rates do not have a fixed mean and variance, many data seem to have a decisive trend or exhibit high or low volatility. The variance of a random sequence is fixed is called homoscedasticity, otherwise it is heteroscedasticity. For the volatility exhibited by time series data, although the variance of some data is usually large, the variance without setting conditions is generally constant. Second, mining the heteroscedasticity of time series data. Many arbitragers are interested in the volatility of returns over an asset's holding period, not the volatility over historical periods. Therefore, the introduction of residual series fluctuation model is helpful to predict conditional heteroskedasticity.

Suppose this thesis predict model $y_t = a_0 + a_1 y_{t-1} + \varepsilon_t$, the conditional mean of y_{t+1} is $E(y_{t+1}) = a_0 + a_1 y_t$, and the conditional variance is $Var(y_{t+1}|y_t) = E(\varepsilon_{t+1})^2$, then:

$$\varepsilon_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \varepsilon_{t-2}^2 + \cdots + \alpha_q \varepsilon_{t-q}^2 + v_t \quad (3.6)$$

v is a white noise sequence.

$$E(\varepsilon_{t+1)}^2) = \alpha_0 + \alpha_1 \varepsilon_t^2 + \alpha_2 \varepsilon_{t-1}^2 + \alpha_q \varepsilon_{t+1-q}^2 \quad (3.7)$$

Equation (3.6) is the ARCH model, which is called obeying the ARCH(q) process and denoted as $\varepsilon_t \sim ARCH(q)$. The basic idea of the ARCH model is to introduce the variation of variance with time into the model to analyse the variation of the variance of the current period depending on the disturbance term of the previous period.

The LaGrange multiplier (LM) test can be used to test whether the time series has an ARCH effect, which consists of the following two steps: use the least squares to estimate the regression equation or the ARCH model and make ε_t^2 equal to the square of the fitted variance. Regress these residual squares $\varepsilon_{t-1}^2, \varepsilon_{t-2}^2, \dots, \varepsilon_{t-q}^2$ and fix the lag order R^2 to check whether the coefficients in equation (3.6) are all 0 at the same time. Usually, the coefficient of determination R^2 in the regression equation is small and has little explanatory effect. Using the number of samples and the number of observations n, the test statistic $LM = nR^2$, where n represents the number of observations, R^2 is the coefficient of determination, and $LM \sim \chi^2(q)$. If the probability of the coefficients being 0 at the same time is very small, or if one coefficient is significantly different from 0, the sequence data is considered to have an ARCH effect; if all the coefficients are 0 at the same time, it is considered that there is no ARCH effect. The null and alternative hypotheses are: $H_0: \alpha_1 = \alpha_2 = \cdots = \alpha_q = 0, H_1: \exists \alpha\_i \neq 0$， $(1 \leq i \leq q)$

Given a significant level α and degrees of freedom q, if $LM > \chi^2(q)$, reject the null hypothesis, accept the alternative hypothesis, and consider that the sequence has an ARCH effect, if $LM < \chi^2(q)$, accept the null hypothesis and think that the sequence does not have an ARCH effect.

In practice, the ARCH model will encounter the problem of infinite expansion of the lag order q. Usually, the regression coefficient obtained may be negative, which violates the original assumption that the coefficient is non-negative. Only if the coefficient is non-negative can the variance ε_t^2 be constant and positive. Therefore, we introduce a generalized autoregressive conditional difference variance model, that is the GARCH model, which is like the ARCH model. It also models the random disturbance term of the regression model. The form is as follows:

$\varepsilon_t = v_t\sqrt{h_t}$, where $\sigma_v^2 = 1$, and

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-1}^2 + \sum_{j=1}^{p} \beta_j h_{t-j}^2 \tag{3.8}$$

This sequence is called a generalized $ARCH\ (p, q)$ model or $GARCH(p, q)$ model, which allows autoregressive and moving autoregressive heteroscedasticity. If we set $p = 0, q = 1$, then the GARCH model is a first-order ARCH model. Therefore, if $b = 0$, then the GARCH model is equivalent to the ARCH model. The benefits of the GARCH model are obvious, the GARCH model is better for prediction and calculation, while the higher-order ARCH model is much worse. In Equation (3.8), all coefficients are positive, and to ensure a suitable variance, all eigenvalues fall within the unit circle. Obviously, the worse the performance, the smaller the bounds on the coefficients.

3.8.6 Select the transaction object

A complete statistical arbitrage model should include selecting appropriate trading objects, constructing investment portfolios, and establishing arbitrage entry points, exit points and stop loss points. The key lies in the setting of the entry point, exit point, and stop loss point of the arbitrage interval. The selection of the transaction threshold is directly related to the profit margin of the arbitrage and the success of the arbitrage.

When selecting trading objects for statistical arbitrage, there is often a strong correlation between trading objects. This thesis selects the CSI 300 ETF with small tracking error and high correlation with the CSI 300 index to study the futures and spot arbitrage of stock index futures. At the same time, the CSI 300 stock index futures also directly track the CSI 300 index, which is basically the same as the CSI 300 index, which greatly improves the efficiency of arbitrage, that is the possibility of successful arbitrage. At the same time, in terms of the frequency of data selection, the selection of high-frequency trading data is also of great help to the realization of arbitrage. High-frequency trading data refers to sample data drawn at time intervals such as seconds, minutes, and hours. Compared with high-frequency data, daily, weekly, and monthly data are low-frequency data. At the same time, ultra-high-frequency data cannot be ignored. Trading data, UHF data reflects the dynamic process of continuous changes in price. In the selection of sample data, if low-frequency data is selected, the arbitrage result will be unsatisfactory, and the market will lose more. Therefore, more and more arbitragers in the financial sector are using high-frequency data. In the early days, it was difficult to obtain high-frequency data. With the development of modern information technology, the acquisition of high-frequency data is convenient, so its application research has become more and more extensive. At the same time, due to the high sampling frequency of high-frequency data, the price contains a lot of rich information, so it has a strong market representation. Using high-frequency financial data allows us to explore the financial market price formation mechanism in more detail, understand the market organization structure, and master the market transaction mechanism.

This thesis selects Huatai-Pinebridge CSI 300ETF and stock index futures contract IF2101, selects 240 1-minute high-frequency trading data in the data area of 2020.12.25, and selects 240 data in the out-of-sample data range from 2020.12.18, 2020.12.26, 2021.1.6 and 2021.1.12 1-minute high-frequency trading data, excluding the data of stock index futures and ETF transactions that are not synchronized, select a total of 1200 1-minute high-frequency trading data from 9:31 to 11:30, and 13:01 to 15:00. The five days using transaction data are randomly selected. Based on this, this thesis can find arbitrage opportunities for stock index futures and ETF futures.

3.8.7 Portfolio building

The key to building an investment portfolio is to select an asset portfolio that is highly correlated, long-term balanced, and has high market liquidity. High market liquidity can ensure that arbitragers can obtain expected returns regardless of market conditions. This thesis takes the CSI 300 ETF as a spot position and studies the futures arbitrage situation of the CSI 300 stock index futures based on the CSI 300 ETF. The spot and futures track the CSI 300 index at the same time, and the CSI 300 ETF is used to simulate the stock index futures. The spot portfolio has a strong market. representative.

Assuming that the HS300 stock index futures price sequence is $Price\ (IF_t)$ and the spot position CSI 300 ETF price sequence is $Price\ (I_t)$, observing the correlation between the two-time series, only the two-time series with higher correlations have the possibility of successful arbitrage. The specific operation steps of statistical arbitrage based on cointegration are as follows: To examine the stationarity of two time series, if two non-stationary time series data are used to establish a regression model type, which will lead to incorrect results, they usually introduce the concept of cointegration to describe the long-term equilibrium relationship between the two series. First, perform the unit root (ADF) test on the two time series data to observe the stationarity of the two-time series, and then pass the cointegration test to see whether there is a cointegration relationship between the two, that is, a long-term stable relationship. This stable relationship will not change with time. It changes over time, that is, when the price difference between the two-time series deviates from the equilibrium value, it will always return to the mean value after a period. The basic idea of cointegration test is to test the stationarity of two-variable regression residuals. By establishing the regression variance of two time series variables, observe the degree of explanation of the dependent variable by the independent variable. The residual indicates that the dependent variable cannot be explained by the independent variable, so the residual series is tested for the cointegration relationship between unit roots. If there is a cointegration relationship, it means that there is an arbitrage opportunity between the two, and it is feasible to select it as the arbitrage transaction object.

Assuming that there is long-term stability between the two-time series, the regression analysis results of the two are as follows:

$$Price(IF_t) = \beta_0 + \beta_1 Price(I_t) + \varepsilon_t \quad (3.9)$$

$Price\ (IF_t)$ represents the closing price of the CSI 300 stock index futures contract at time t, $Price\ (I_t)$ represents the closing price of the CSI 300 ETF at time t, and et is the residual sequence. The residual sequence is the price difference between the two, so it is considered that the residual sequence is the price difference sequence existing between the two. Therefore, the price difference sequence equation of the two is established according to the cointegration relationship:

$$spread_t = Price(IF_t) - \beta_0 - \beta_1 Price(I_t) \quad (3.10)$$

The spread series shows the price difference between $Price\ (IF_t)$ and $Price\ (I_t)$. The equilibrium spread level is obtained through statistical analysis of the $spread_t$ series, and the reasonable arbitrage range and trading position are deduced accordingly. The series is centered according to the mean of the spread series, where:

$$mspread_t = spread_t - mean(spread_t) \quad (3.11)$$

By finding the standard deviation σ of mspread, find the trading threshold k, and when the logarithmic spread deviates to a certain extent, a trading signal is obtained. In the establishment of the investment portfolio, the most important thing is the size β_1 of the pairing relationship coefficient obtained by the cointegration analysis. This thesis tries to open a position through the pairing coefficient to determine the arbitrage trading position, that is when the arbitrage is positive, this thesis short one lot of stock index futures contracts, and at the same time, this thesis sell β_1 lots of ETFs. When the $spread_t$ narrows, close the position to buy stock index futures contracts and sell ETF contracts at the same time. In reverse arbitrage, buying one lot of stock index futures contracts and shorting β_1 lots of ETF contracts. Doing so ensures that the trading portfolio meets market-neutral standards.

3.8.8 Establishment of signalling mechanism

The establishment of the signal mechanism is the most important part of statistical arbitrage, involving the selection of entry and exit signals and stop-loss signals. Arbitrators generally operate by examining the degree of deviation between the entry and exit signals and the equilibrium value. When the deviation occurs, that is when the spread sequence fluctuates up and down When an arbitrage opportunity occurs, the price difference will always return to the equilibrium level in the future. At this moment, it is the signal to close the position, take profit, and wait for the emergence of the next arbitrage opportunity.

The details of setting entry and exit points and stop loss points are as follows:

When the spread series crosses the standard deviation of k times, that is $mspread_t > -k\sigma_t$ (k^4 is the arbitrage trading threshold, σ_t is the standard deviation of the spread series), it indicates that the price of stock index futures is overvalued and the price of ETF is undervalued, so a positive forward direction can be implemented. Arbitrage strategy, that is selling stock index futures and buying ETFs. When the price difference between the two returns to the equilibrium level, that is close to 0, set $mspread_t \approx 0$ to immediately reverse the take profit, and complete a complete arbitrage transaction by closing the position.

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The larger the k, the greater the arbitrage space, but the arbitrage opportunity will be reduced accordingly. Conversely, the smaller the k, the smaller the arbitrage space and the greater the arbitrage opportunity. Therefore, it is very important to find the optimal threshold, that is the threshold when the expected profit of arbitrage hits the maximum value.

According to the model experience, when $k \in (1.1,1.3)$, the arbitrage effect is the most ideal. This thesis is trying to determine the threshold k at which the expected return of arbitrage reaches its maximum value through the statistical arbitrage expected return function.

Find the moment when statistical arbitrage is triggered in the residual sequence and find out the corresponding stock index futures closing price $Price(IF)$ and ETF closing price $Price(ETF)$, the price of each lot of IF2101 stock index futures = IF2101 closing price × 300, the price of each lot of ETF = The price of each ETF×100, and the number of ETF lots to be traded is determined according to the coefficient β_1 of the cointegration equation. One lot of CSI 300 stock index futures corresponds to β_1 lot of CSI 300 ETF.

3.8.9 Statistical Arbitrage Trading Model Based on Spread Volatility

This thesis thinks the residual sequence is the price difference sequence of time series data, and the price difference sequence represents the degree of deviation between the two. In this part, this thesis first needs to conduct a specific research and analysis on the volatility characteristics of the price difference (residual) sequence. Volatility characteristics are properly modelled to spot arbitrage opportunities.

In this part, two methods of measuring spread fluctuations will be used to reasonably analyse and model the spread series. One is to use the ordinary least squares to analyse the constant fluctuation of residuals and build a model accordingly. The other is to use the GARCH model to measure the fluctuations of residuals over time and build the corresponding model.

3.8.10 Residual Constant Volatility Trading Model

The first model is expressed as follows:

$$Price(IF_t) = \beta_0 + \beta_1 Price(I_t) + \varepsilon_t \tag{3.12}$$

This thesis makes the following assumptions about the random error term, the residual sequence ε_t: The residual sequence ε_t is T random variables, that is obeys the probability distribution.

$E(\varepsilon_t) = 0$ means that the expectation of the residual is 0. In the model, if the factors affecting the dependent variable can be guaranteed to be negligible, it is reasonable to assume that the expectation is 0.

$Var(\varepsilon_t) = E(\varepsilon_t - E(\varepsilon_t))^2 = \sigma^2$, ε_t is homoscedastic and the variance is always σ^2.

$\varepsilon_t \sim N(0, \sigma^2)$, which means ε_t obeys a normal distribution, and if ε_t is guaranteed to be composed of many factors, these components will not have any effect on the total change.

$cov(\varepsilon_i, \varepsilon_j) = 0$, which means that the random variables are independent of each other and are not autocorrelated.

Use ordinary least squares to perform regression analysis to obtain the residual sequence ε_t, and calculate the mean and variance of the residual sequence. The residual fluctuation properties obtained by this method are constant in the residual series, that is the residuals have homoscedasticity. Therefore, using the model assumption of ordinary least squares to model the time series data of two assets by least squares regression (OLS), the residual sequence is:

$$\varepsilon_t = Price(IF_t) - \beta_0 - \beta_1 Price(I_t) \tag{3.13}$$

Using the zero mean and homoscedasticity assumptions of least squares regression to model to obtain the spread sequence is the most simple and effective method to construct the statistical arbitrage of stock index futures based on ETF. The trading rules are designed as follows:

Therefore, when $\varepsilon_t > k\sigma$, forward arbitrage means that the price of stock index futures is overvalued, and the price of ETF is undervalued. Sell one lot of stock index futures contracts at the price $Price\ (IF_t)$ currently, and at the same time use the price $Price\ (I_t)$ Buy ETFs of equal value. When $\varepsilon_t \approx 0$, it means that the stock index futures and ETFs return to the equilibrium level, and the positions are closed at the current price to take profit.

Therefore, when $\varepsilon_t < k\sigma$, reverse arbitrage means that the price of stock index futures is undervalued, and the price of ETF is overvalued. Buy one lot of stock index futures contracts at the price $Price\ (IF_t)$ at this time, and at the same time use the price $Price\ (I_t)$. Selling ETFs of equal value when $\varepsilon_t \approx 0$, means that the stock index futures and ETFs return to the equilibrium level, and the positions are closed at the current price to take profits.

3.8.11 GARCH Residual time-varying volatility trading model

The above arbitrage research is mainly based on the simple multiple of the standard deviation of the spread series to construct the arbitrage and stop loss boundary. It is assumed that the standard deviation of the spread series does not change with time and has time-varying characteristics, to improve the arbitrage characteristics.

First, analyse the autocorrelation function and partial autocorrelation function of the residual sequence, and try to establish an AR model. By establishing the AR model of $Mspread_t$, the ARCH-LM heteroscedasticity test is performed to determine whether the error term of the regression model has autoregressive conditional heteroscedasticity, and the mean variance and the ARCH effect equation are determined accordingly. The following equation is obtained:

$$\epsilon_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 \tag{3.14}$$

Therefore, when $\varepsilon_t > k\sigma$, forward arbitrage means that the price of stock index futures is overvalued, and the price of ETF is undervalued. Sell one lot of stock index futures contracts at the price $Price\ (IF_t)$ currently, and at the same time use the price $Price\ (I_t)$ to buy ETFs of equal value. When $\varepsilon_t \approx 0$, it means that the stock index futures and ETFs return to the equilibrium level, and the positions are closed at the current price to take profit.

Therefore, when $\varepsilon_t < k\sigma$, reverse arbitrage means that the price of stock index futures is undervalued, and the price of ETF is overvalued. Buy one lot of stock index futures contracts at the price $Price\ (IF_t)$ at this time, and at the same time use the price $Price\ (I_t)$ to sell ETFs of equal value when $\varepsilon_t \approx 0$, means that the stock index futures and ETFs return to the equilibrium level, and the positions are closed at the current price to take profits.

Comparing the least squares constant volatility model and the GARCH time-varying volatility model, theoretically the GARCH time-varying volatility model has better arbitrage effect, GARCH model can more truly describe the time-varying characteristics of variance, and GARCH model can better explore arbitrage opportunities and improve arbitrage efficiency.

3.8.12 Error Measurement Theory

Before doing the test, this thesis first analyses the return and risk characteristics of the ETF and the underlying index, and only compare the performance of the ETF and its underlying index. The returns for each ETF and underlying index are calculated as follows:

$$NR_{i,t} = \frac{NAV_{i,t} - NAV_{i,t-1}}{NAV_{i.t-1}} \tag{3.15}$$

$$IR_{i,t} = \frac{Index_{i,t} - Index_{i,t-1}}{Index_{i.t-1}} \tag{3.16}$$

Among them, $NR_{i,t}$ represents the rate of return of the i-th ETF in the t period, $IR_{i,t}$ represents the rate of return of the underlying index i in the t period, $NAV_{i,t}$ represents the asset value of the i-th ETF in the t period, and $Index_{i,t}$ represents the i-th ETF in the t period. The closing price of the underlying index in period t.

The standard deviation of the risk utilization return of the ETF and the underlying index is defined as follows:

$$\sigma_{NAV_i} = \sqrt{\frac{\sum_{t=1}^{n}(NR_{i,t} - \overline{NR_i})^2}{n-1}} \quad (3.17)$$

$$\sigma_{Index_i} = \sqrt{\frac{\sum_{t=1}^{n}\left(IR_{i,t} - \overline{IR_i}\right)^2}{n-1}} \quad (3.18)$$

Among them, $\overline{NR_i}$ represents the average return on the net asset value (NAV) of the i-th ETF; $\overline{IR_i}$ represents the average return of the i-th underlying index.

Tracking error is defined as the deviation of an ETF's performance from the underlying index, and this approach may underestimate the error as the differences cancel each other out. In this thesis, I have used mean absolute difference, standard error of regression analysis, and standard deviation of return difference.

First, tracking error can only be estimated by the mean absolute difference between the returns of the ETF and the underlying index. Therefore, the equation for calculating the daily tracking error is as follows:

$$TE_1 = \frac{\sum_{t=1}^{n}\left|NR_{i,t} - IR_{i,t}\right|}{n} \quad (3.19)$$

Among them, TE_1 represents the average daily tracking error of the i-th ETF's net asset value (NAV) and the benchmark index based on the absolute value difference.

The second method uses the standard error of the regression analysis of the daily returns of each ETF and its benchmark index to estimate the tracking error. The model is as follows:

$$NR_{i,t} = \alpha_i + \beta_i \times IR_{i,t} + \varepsilon_{i.t} \quad (3.20)$$

α_i represents the excess return obtained by the i-th ETF beyond the underlying index. Due to the various associated fees associated with ETFs, the coefficient αi is expected to be 0 or negative, but not positive. The coefficient β_i represents the systematic risk and the replication strategy of the ETF, so the coefficient should be close to 1 if the ETF replicates well. However, the coefficients α and β should not be part of the regression model. In this model, the tracking error is replaced by the standard deviation of the regression model. If the ETF replicates the underlying index well, then the standard deviation of the residuals in the regression must be close to 0.

A third way to estimate tracking error is to measure the standard deviation of the difference between the ETF's return and the underlying index's return, calculated as follows:

$$TE_3 = \sqrt{\frac{\sum_{t=1}^{n}\left(ND_{i,t} - \overline{ND_i}\right)^2}{n-1}} \tag{3.21}$$

Among them, $ND_{i,t}$ represents the difference between the net asset value (NAV) return of the ETF and the return of the underlying index. If the ETF is replicating the underlying index well, the average tracking error should be close to zero.

3.8.13 Mean reversion half cycle

The mean-reverting half-period formula defined by Madhavan and Simit:

$$T/_2 = \left|\frac{\ln(2)}{\ln(1+\gamma)}\right| \tag{3.22}$$

The half-period expectation of the non-equilibrium deviation from the mean recovery can be obtained by the coefficient γ of ECM, and the obtained value is t time intervals, and the specific time is multiplied by the time represented by each t interval.

3.8.14 Sharp ratio

The study of Sharpe ratio in modern investment theory shows that the size of risk plays a fundamental role in determining the performance of a portfolio. The risk-adjusted rate of return is a comprehensive indicator that can consider both benefits and risks and can rule out the adverse effects of risk factors on performance evaluation in the long run. The Sharpe ratio is one of the three classic indicators that can simultaneously consider both return and risk. There is a conventional feature in investment, that is the higher the expected return of the investment target, the higher the volatility risk that arbitragers can tolerate; conversely, the lower the expected return, the lower the volatility risk. Therefore, the main purpose of rational arbitragers in choosing investment targets and investment portfolios is to pursue the maximum return under a fixed risk that they can bear or to pursue the lowest risk under a fixed expected return.

The Sharpe ratio is calculated as follows:

$$SR = \frac{E(R) - R_f}{\sigma(R)} \tag{3.23}$$

Among them, $E(R)$ is the average rate of return in the trading cycle, $\sigma(R)$ is the standard deviation of the rate of return, and R_f is the risk-free rate.

Annualized Sharpe ratio is as follows:

$$SR^A = \sqrt{N} \times SR_T \tag{3.24}$$

Among them, SR_T represents the initial Sharpe ratio of one day, and N is the number of trading cycles in a year.

3.8.15 Arbitrage Cost

The cost of completing an arbitrage transaction is divided into two parts, fixed transaction cost and variable transaction cost. Fixed transaction costs include commissions, stamp duties, handling fees, transfer fees, securities management fees and securities settlement fees. Variable transaction costs are dominated by shock costs simultaneously. It should be noted that the arbitrage costs required by different arbitragers are different. For securities companies, institutional arbitragers and individual arbitragers, the required arbitrage costs increase in turn. This thesis roughly estimates the minimum required arbitrage costs.

Fixed transaction costs include ETF transaction costs and stock index futures transaction costs.

ETF transaction costs, according to the Notice on the Reduction and Exemption of Transaction Fees Related to Exchanged Open-end Index Funds issued by the Shanghai Stock Exchange in September 2010, in order to promote the development of exchanged open-end index funds, it is convenient for securities companies to participate in the purchase and redemption agency. For ETF transactions, especially those related to ETF arbitrage, the Shanghai Stock Exchange temporarily waived handling fees for ETF subscription and redemption transactions and reduced or exempted transaction unit traffic fees to a certain extent. Therefore, the required ETFs after commissions are deducted

The transaction cost is roughly around 2bp ($1bp = 1/10{,}000$). The level of the ETF commission rate depends on the negotiating ability of arbitragers and brokers, and we assume 2bp here. Then the fixed transaction cost related to the ETF transaction is about 4bp in total. According to the two-way calculation, it takes 8bp to complete one arbitrage.

The transaction cost of stock index futures, according to the regulations of China Financial Futures Exchange, the minimum futures transaction fee is 0.5bp, and the comprehensive settlement member is generally 1bp to 1.5bp, and it is charged bilaterally. Then we take the unilateral transaction cost of stock index futures as 0.5bp, and complete one transaction. The two-way transaction fee required for carry trade is 1bp. To sum up, the fixed cost required to complete an arbitrage transaction is about $8bp \times ETF\ transaction\ amount + 1bp \times stock\ index\ futures\ transaction\ amount.$

Another cost is variable transaction costs. The variable costs involved in high-frequency trading mainly include shock costs and waiting costs. The shock cost is the liquidity cost in the usual sense. The better the market liquidity, the smaller the shock cost. The shock cost itself is when a certain asset is bought or sold on a large scale in a transaction, and it is not in accordance with the implementation agreement. When the price is traded, the cost of paying more than the agreed price is the impact cost. Waiting cost refers to choosing to wait in order to avoid the huge impact of instant transactions on the market. The cost incurred is the waiting cost. The waiting cost is generally small and can be ignored. The main contract IF2101 of stock index futures selected in this thesis has strong liquidity, so the impact cost must be greatly reduced. Let the unilateral impact cost of stock index futures be l bp, and the bilateral transaction cost can be set to 2bp. For the large scale of CSI 300 ETF circulation, the impact cost can also be controlled, generally within the range of a few thousandths. This thesis assumes that the impact cost of Huatai-Pinebridge CSI 300ETF is 2bp, and the impact cost of bilateral transactions is 4bp. Combining the above description of fixed transaction costs and variable transaction costs, the bilateral arbitrage cost of stock index futures is less than 3bp, and the bilateral arbitrage cost of Huatai-Pinebridge CSI 300ETF CSI 300 ETF is 12bp.

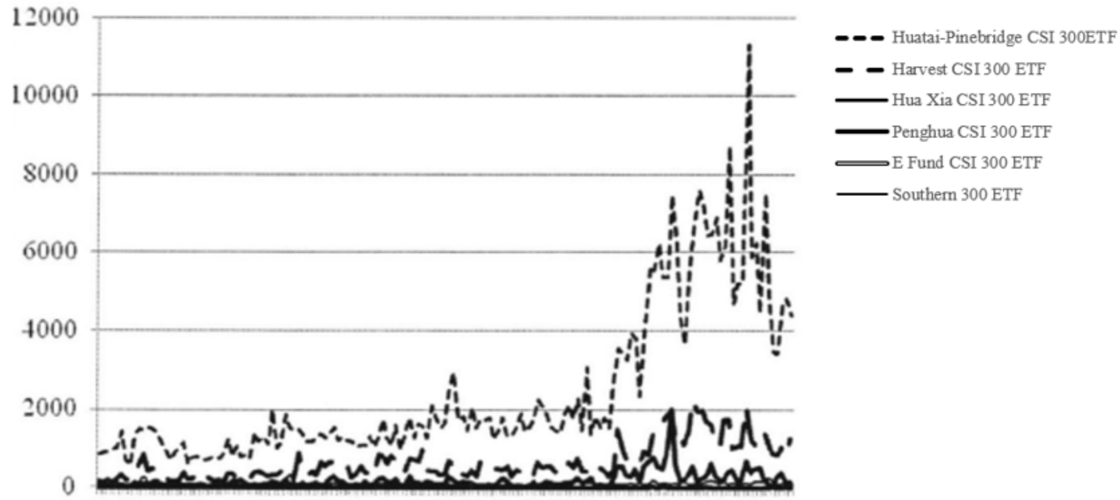
4 Analysis of Arbitrage Opportunities at Chinese Financial Market

This chapter is based on the empirical research of CSI 300 stock index futures and ETF statistical arbitrage. This chapter first selects data, and then uses the model established in the previous chapter to study and analyses the statistical arbitrage of CSI 300 stock index futures and ETFs.

4.1 Arbitrage Sample Selection

At present, the CSI 300 ETF products that have been issued and traded in China include: Huatai-Pinebridge CSI 300ETF, Harvest CSI 300 ETF, Hua Xia CSI 300 ETF, Southern Kaiyuan CSI 300 ETF, E Fund CSI 300 ETF and Penghua Shanghai 300 ETF. This section selects the daily transaction data of 157 trading days from June 3, 2020, to January 19, 2021, as the research sample, and compares and analyses the daily trading volume of the six listed ETF funds to compare their liquidity.

Figure 4.1 ETF daily trading volume from 2020.6.3 to 2021.1.19



Source: Own calculation

As can be seen from the Figure 4.1, the daily trading volume of Huatai-Pinebridge CSI 300ETF is significantly higher than the other five ETFs, followed by Harvest CSI 300 ETF and Hua Xia CSI 300 ETF, Penghua CSI 300 ETF, E Fund CSI 300 ETF and Southern 300 ETF The amount pales in comparison to the top three ETFs. Therefore, observing the changes in the daily turnover of Huatai-Pinebridge CSI 300ETF, Harvest

CSI 300ETF and Hua Xia 300ETF within half a year, this thesis can see that the turnover has increased significantly since December 2020, and the turnover of Huatai-Pinebridge CSI 300ETF has continued to rise, until 2021.1.5 the transaction amount reached the maximum, Harvest CSI 300ETF and Huatai-Pinebridge CSI 300ETF have similar trends, but the daily transaction amount is less volatile than Huatai-Pinebridge CSI 300ETF. The Hua Xia CSI 300 ETF reached its maximum value in 2020.12.10, and then the trading volume continued to decline. To sum up, Huatai-Pinebridge CSI 300 ETF has the best liquidity, followed by Harvest CSI 300 ETF. Therefore, it is believed that Huatai-Pinebridge CSI 300 ETF and Harvest CSI 300 ETF can be selected as the spot varieties of stock index futures arbitrage, then it is necessary to calculate the true tracking error of the two ETFs for the CSI 300 index through quantitative research to see if they reach the fund level. According to the basic requirements in the prospectus, the selected CSI 300 ETF is a good substitute for the CSI 300 Index.

First, calculating the daily tracking error of the entire sample range of Huatai-Pinebridge CSI 300ETF and Harvest CSI 300 ETF. This thesis can calculate the result using the formula from the theory in chapter 3, the results are as follows.

Table 4.1 The constant of ETF daily Tracking error

ETF	TE1	TE2	TE3
Huatai Pineapple CSI 300 ETF	0.1624%	0.2858%	0.4630%
Harvest CSI 300 ETF	0.3335%	0.3148%	0.4455%

Source: Own calculation

From Table 4.1, the tracking objectives of Huatai-Pinebridge CSI 300ETF and Harvest CSI 300 ETF are: the daily tracking deviation does not exceed 0. 2%. During the sample period, the tracking errors of Huatai-Pinebridge CSI 300 ETF are calculated by three methods， method one is less than 0.2%, which can be considered to meet the tracking requirements in the fund prospectus, while the tracking errors of Harvest CSI 300 ETF are greater than 0.2%, believing that the basic goals in the fund prospectus have not been achieved.

Based on the research on liquidity and tracking error, it is found that Huatai-Pinebridge CSI 300 ETF can be used as a good spot variety for stock index futures arbitrage. The correlation between the CSI 300 ETF and the CSI 300 stock index futures is shown in the following figure.

Figure 4.2 The correlation analysis of CSI 300 ETF and Index Futures

Source: Own calculation

4.2 Research method

The empirical research of CSI 300 stock index futures and ETF carry trade is divided into two stages. First, in the first stage of this thesis, 240 one-minute high-frequency historical transaction data of 2020.12.25 are used to conduct paired transactions to construct the optimal arbitrage combination. The second stage uses a total of 960 1-minute high-frequency trading data from 2020.12.18, 2020.12.26, 2021.1.6 and 2021.1.12 and conducts simulated trading according to the pairing and arbitrage strategies formed in the first stage, and analyses the benefits and risks of simulated trading, so as to marinate the feasibility of arbitrage.

Select CSI 300 stock index futures contract IF2101, CSI 300 ETF is Huatai-Pinebridge CSI 300 ETF, and exclude the selected two-stage time data transactions that are not synchronized, the time period is 9:31-11:30, 13:01-15: 00.

4.3 Cointegration Test and Error Correction Model

In this part, this thesis will first perform a unit root test on the variables to determine whether each variable has the same single-order integer, then test the cointegration relationship between the two-time series, and finally establish an error correction model to analyse the adjustment mechanism.

4.3.1 Unit root test

Before the cointegration test, the same single integer order of each variable must be determined. Therefore, the unit root test of the variables must be performed first. The price of each stock index futures lot and the price of each lot of ETFs are used as the research objects. The results of the ADF test are as follows.

Table 4.2 The ADF test of IF_t and I_t

Variable	ADF	The critical value at the significance level of 1%	The critical value at the significance level of 5%	The critical value at the significance level of 10%	Prob.*
IF_t	-0.460791	-3.457630	-2.873440	-2.573187	0.8950
I_t	-0.605462	-3.457630	-2.873440	-2.573187	0.8657

Source: Own calculation

It can be seen from the Table 4.2 that the stock index futures IF2101 and Huatai-Pinebridge CSI 300ETF price series IF_t and I_t are both non-stationaries, and neither passed the ADF test. Therefore, the ADF test was performed on the first-order difference series ΔIF_t and ΔI_t of IF_t and I_t , the result is as follows.

Table 4.3 The ADF test of ΔIF_t and ΔI_t

Variable	ADF	The critical value at the significance level of 1%	The critical value at the significance level of 5%	The critical value at the significance level of 10%	Prob.*
ΔIF_t	-15.5131	-3.457747	-2.873492	-2.573215	0.0000
ΔI_t	-15.8460	-3.457747	-2.873492	-2.573215	0.0000

Source: Own calculation

It can be seen from the Table 4.3 that the stock index futures IF2101 and Huatai-Pinebridge CSI 300ETF price series ΔIF_t and ΔI_t have passed the ADF test, and both are first-order single integral sequence, and there may be a cointegration relationship. The CSI 300ETF price series IF_t and I_t are tested for cointegration.

4.3.2 Cointegration test

After the unit root test is performed on the stock index futures and ETF time series data, if each series is a non-stationary series and the series is stationary after differencing, that is the time series is a first-order single integral series, then when modelling the two non-stationary time series, it is necessary to test the stationarity of the residual series to identify the correctness of the model, then there is no cointegration relationship, indicating that the regression obtained by modelling is a false regression.

Cointegration test methods include Engel-Granger's EG two-step method, Johansen test, etc. This thesis used the EG two-step method to test the cointegration relationship between two time series. Proceed is as follows.

A regression model with constants is established for the stock index futures and ETF time series, and the regression coefficient is obtained. Test the stationarity of the residual series ε_t of the regression model. The unit root test can be performed on ε_t. If the residual sequence is stationary, the two time series data are co-integrated. Otherwise, the cointegration does not hold. Using the EG two-step method, the least squares method is used to establish a univariate regression equation with constants about the price series IF_t and I_t of the stock index futures IF2101 and Huatai-Pinebridge CSI 300 ETF. The results are as follows:

$IF_t = 2992.947I_t + e_t$;

$$R^2 = 0.976674, DW = 0.767104, T = 240$$

The unit root test was performed on the residuals, and the results were as follows:

Table 4.4 Cointegration

Variable	ADF	The critical value at the significance level of 1%	The critical value at the significance level of 5%	The critical value at the significance level of 10%	Prob.*
ε_t	-3.38127	-3.457984	-2.873596	-2.57327	0.0126

Source: Own calculation

It can be seen from the Table 4.4 that the residual sequence is stationary, there is a long-term equilibrium relationship between the two time series data of stock index futures IF2101 and Huatai-Pinebridge CSI 300 ETF, which has a cointegration relationship.

4.3.3 Error correction model

The cointegration test done above shows that there is a long-term equilibrium relationship between stock index futures IF2101 and Huatai-Pinebridge CSI 300 ETF, so the short-term deviation from the equilibrium value can be realized in the long-term through short-term continuous fluctuations, which can establish error modified model (ECM) analyses this regulatory mechanism. The error modified model is estimated as follows.

From the previous section, we can see that the long-term equilibrium error is: $e_t = IF_t - 2992.94I_t$, let $ecm_{t-1} = e_{t-1}$

And error modified model:

$$\Delta IF_t = \beta_0 + \beta_1 \Delta I_t + \gamma ecm_{t-1} + \varepsilon_t$$

Estimated by Ordinary least squares (OLS):

$$\Delta IF_t = 2280.985\Delta I_t - 0.282769ecm_{t-1} + \varepsilon_t$$

Among them, the error correction term is:

$$ecm_{t-1} = IF_{t-1} - 2992.947I_{t-1}$$

Since the size of the coefficient λ of the error correction term ecm_{t-1} reflects the adjustment strength of the short-term deviation from the long-term equilibrium recovery, the estimated coefficient of the calculated error correction term is -0.288, which means that the speed of the previous non-equilibrium error of 28.3% affects the IF_t of the current period. Correction in the opposite direction brings its spread back towards the mean. According to the defined mean value recovery half cycle formula in chapter 3. The expected value of the half cycle of the equilibrium value recovery is 2.0835 minutes, and the recovery speed is relatively fast.

4.4 An Empirical Study of Statistical Arbitrage

In this part, this thesis first calculated the spread series, obtained the spread between the IF2101 and CSI 300ETF series, then determined the threshold during the arbitrage period, and finally brought the data into the statistical arbitrage trading model for research.

4.4.1 Spread series calculation

By estimating the cointegration equation, the cointegration coefficient of statistical arbitrage between IF2101 and Huatai-Pinebridge CSI 300 ETF is 2993.

From the perspective of long-term equilibrium, the spread between the IF2101 and the CSI 300 ETF sequence is:

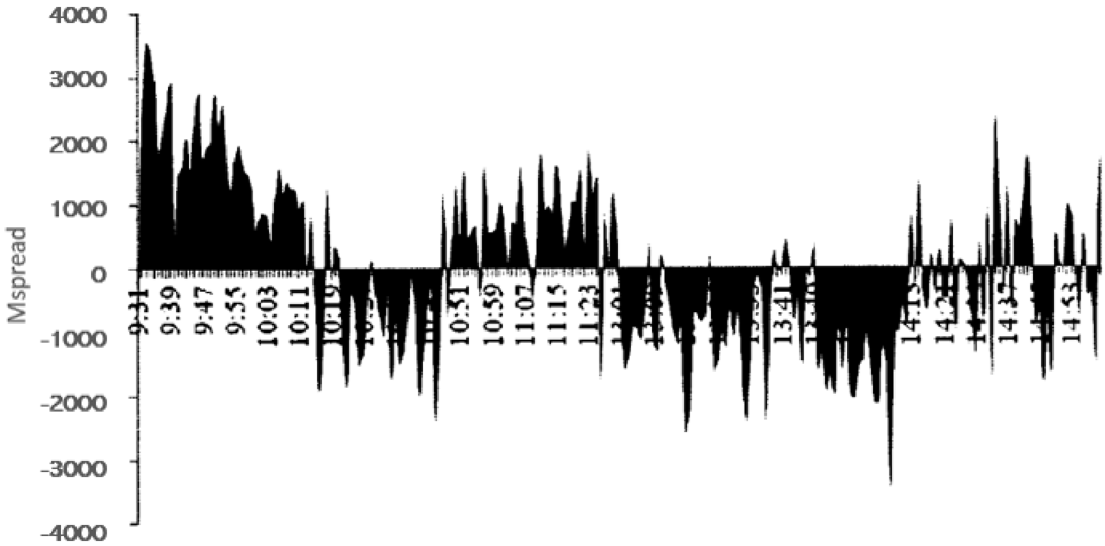
$$Spread_t = IF_t - 2993I_t$$

Decentralized to get the $Mspread_t$ sequence:

$$Mspread_t = Spread_t - mean(Spread_t)$$

The sample decentralized spread sequence $Mspread_t$ is shown in the following Figure 4.3.

Figure 4.3 The spread sequence of removed center sample



Source: Own calculation

From Figure 4.3, by obtaining the $Mspread_t$ sequence, a suitable arbitrage strategy for stock index futures and CSI 300 ETF can be constructed. When determining the arbitrage trading strategy, when $Mspread_t$ is greater than the specified arbitrage trading threshold, it means that the stock index futures are overvalued, and the ETF is relatively undervalued. Abitragers should sell one lot of CSI 300 stock index futures, buy 2993 lots of CSI ETF, and make a profit when $Mspread_t$ returns to the equilibrium value. Similarly, when $Mspread_t$ is less than the specified arbitrage trading threshold, it means that stock index futures are undervalued, and ETFs are relatively overvalued. Currently, buying one lot of CSI 300 stock index futures and selling 2993 lots of CSI 300 ETFs. When $Mspread_t$ returns to equilibrium Close the position to take profit when it is worth it. Therefore, the choice of the threshold has a significant impact on the statistical arbitrage returns of stock index futures and ETFs. If the value of k is too large, the arbitrage space will increase, resulting in a substantial reduction of arbitrage opportunities, while if the value of K is too small, although the arbitrage opportunities will increase. However, due to frequent transactions, the arbitrage cost is also very large, and the profit is small, and the desired arbitrage effect is still not achieved. Therefore, the selection and determination of the threshold will be discussed next.

4.4.2 Determination of Threshold

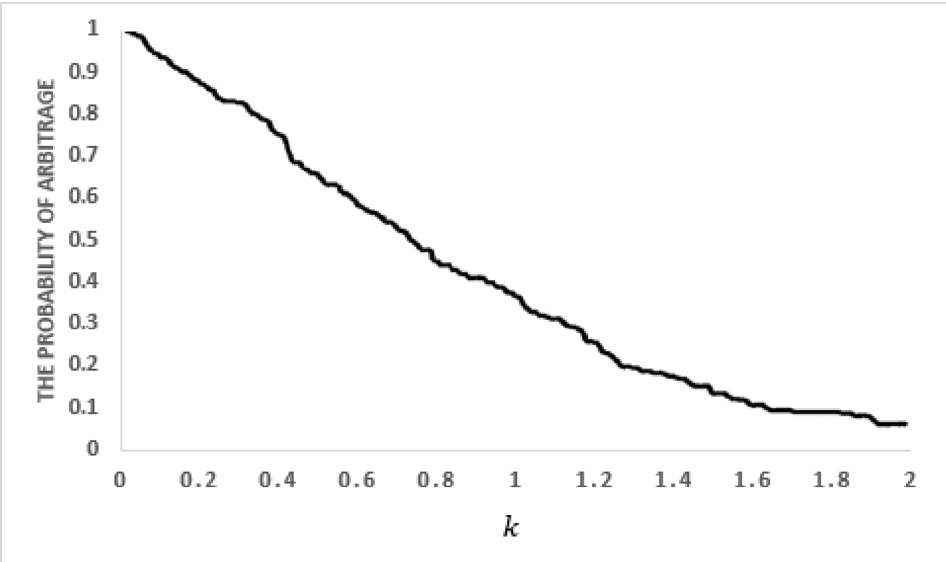
This thesis has already studied the long-term equilibrium relationship between stock index futures IF2101 and Huatai-Pinebridge CSI 300 ETF above, so the key to arbitrage is when it will succeed, that is the discovery of arbitrage opportunities. This thesis first sets it to $k\sigma$ by setting the trading threshold (k is a certain parameter and σ is the standard deviation of $Mspread_t$). When $Mspread_t > k\sigma$, sell IF2101 and buy CSI 300 ETF. When $Mspread_t$ returns to near the mean value, that is close to 0, perform the reverse operation and close the position to take profit. When $Mspread_t < k\sigma$, buy IF2101 and sell CSI 300 ETF. When $Mspread_t$ returns to near the mean value, perform the reverse operation and close the position to take profit.

Let the arbitrage return expectation function be: $E(k\sigma) = \lambda \times R(k\sigma) \times \varphi^{-1}(k\sigma)$

Among them, λ is a constant, $R(k\sigma) = k\sigma$ is the arbitrage space when the threshold value is $k\sigma$, because $\varphi(x) = \{k\sigma|P(|Mspread_t| \geq k\sigma) = x\}$, $\varphi^{-1}(k\sigma)$ represents the probability of $|Mspread_t| > k\sigma$, and the optimal value of k is $k = \{\gamma|E(k\sigma) \leq E(\gamma\sigma), k \in (0,2)\}$.

Calculate the function $\varphi^{-1}(k\sigma)$, take k from 0 to 2 and take 200 values with a step size of 0.01, calculate the number of points where $|Mspread_t| \geq k\sigma$ and set it as n, then $P(|Mspread_t| \geq k\sigma) = n/N$, where N is the number of samples.

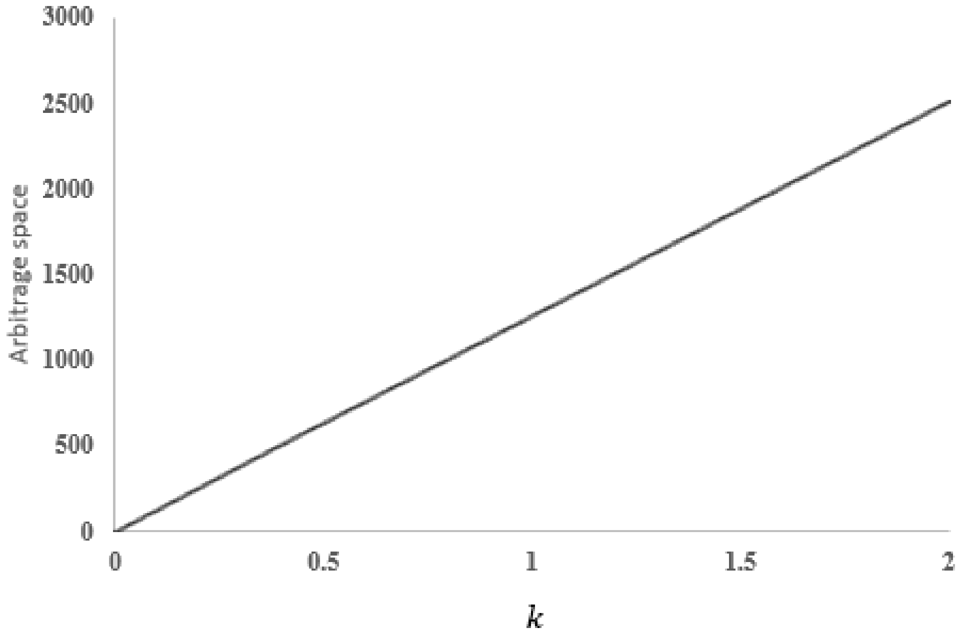
Figure 4.4 The Probability of spread sequence more than $k\sigma$



Source: Own calculation

From Figure 4.4, this figure represents the probability that the spread sequence $Mspread_t$ exceeds the threshold $k\sigma$.

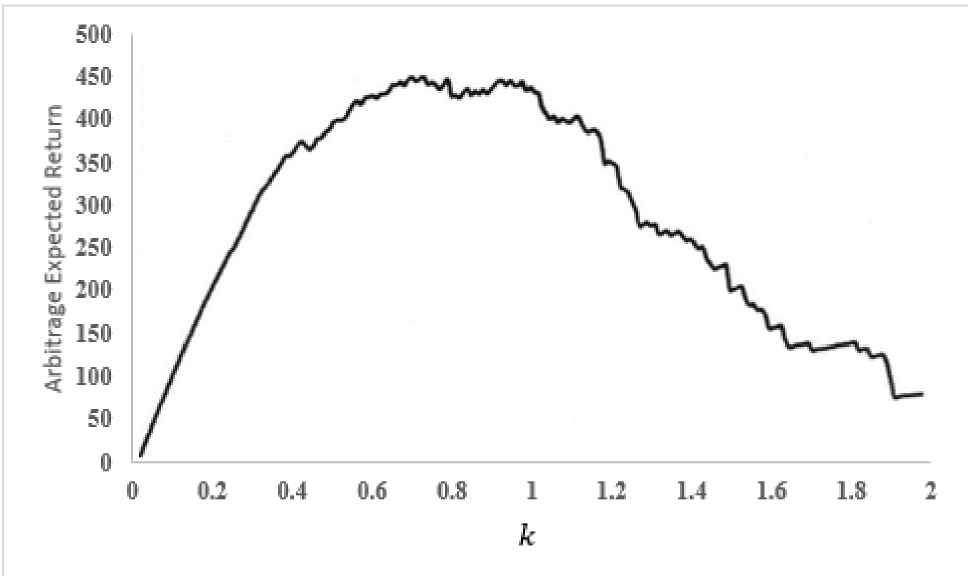
Figure 4.5 The Function of $R(k\sigma)$



Source: Own calculation

From Figure 4.5, this figure shows the arbitrage space when the threshold value is $k\sigma$.

Figure 4.6 The Function of $R(k\sigma) \times \varphi^{-1}(k\sigma)$



Source: Own calculation

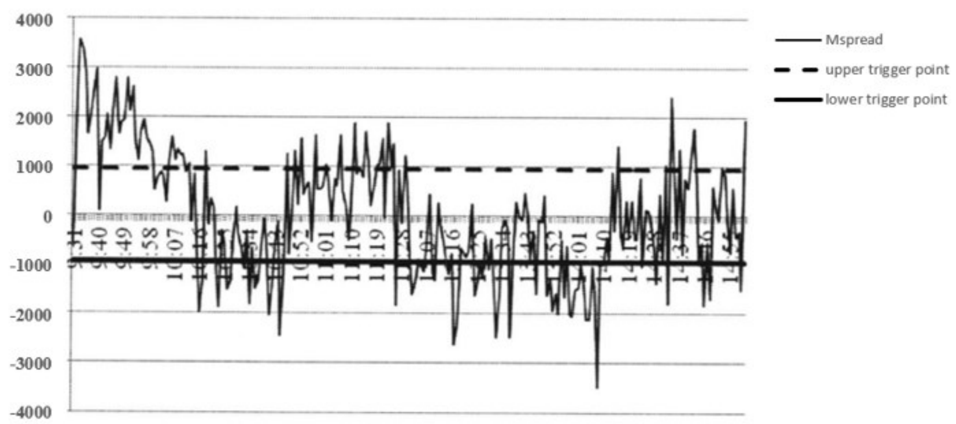
From Figure 4.6, this figure shows the expected return of arbitrage when the threshold value is $k\sigma$.

As can be seen from the figure, when k is 0.73, the expected arbitrage profit is the largest, so this thesis selects the trigger point of the in-sample and out-of-sample arbitrage periods as 0.73σ.

4.5 Statistical arbitrage within the sample

This thesis first analyses the returns of the OLS constant volatility trading model during the sample period. It can be seen from the above analysis that when k is 0.73, the arbitrage profit will reach the maximum value. Therefore, this thesis sets the upper trigger point of forward arbitrage as 0.73σ. When the spread sequence $Mspread_t$ crosses 0.73σ, sell one lot of stock index futures and buy 2993 lots Huatai-Pinebridge CSI 300 ETF will close the position and take profit when the spread sequence returns to near the mean value of 0. Since the expected value of the half-period recovery to the equilibrium value after the non-equilibrium deviation of the spread sequence is 2.0835 minutes through calculation, the recovery speed is fast, so the calculation of arbitrage in this thesis does not involve stop loss. The arbitrage chart is as follows.

Figure 4.7 The Arbitrage within the sample based on OLS (2020.12.25)



Source: Own calculation

From Figure 4.7, the calculation of the rate of return obtained during the arbitrage period shows that the China Financial Futures Exchange stipulates that the minimum trading margin for stock index futures is 12% of the transaction value, that is the minimum margin amount for one lot of stock index futures is as follows. $Margin = stock\ index\ futures\ closing\ price \times 300 \times 12\%$. According to the trading rules of Shanghai and Shenzhen Stock Exchanges, the margin ratio of Huatai-Pinebridge CSI 300 ETF shall not be less than 50%, and it has a securities lending policy. This thesis assumes that Huatai-Pinebridge CSI 300 ETF used for ETF arbitrage is fully traded. Therefore, the margin amount of the first-hand Huatai-Pinebridge CSI 300ETF is: $contract\ quotation \times 100$.

As can be seen from the Figure 4.7, during the sample period, the number of forward arbitrages was 13 times, including 4 times of profit and 9 times of loss. The reason why the model's trading results showed a loss is that the profit from the arbitrage was not enough to make up for the procedures of high-value transactions. The result is that frequent arbitrage transactions have negative returns. Taking the first arbitrage transaction as an example to illustrate, at 9:34 on December 25, 2020, the residual sequence $Mspread_t = 3565.512$, $Price\ IF = 3277.6$, $Price\ ETF = 3.274$, at this time, the spread sequence crossed $0.73\sigma = 943.1129$, and the stock index futures price being overvalued, the price of Huatai-Pinebridge CSI 300 ETF is undervalued, so one lot of IF2101 is sold and 2,993 lots of CSI 300 ETF are bought. When the spread returns to the average value, the position is closed when it is close to 0. When the position is closed, $Mspread_t = 87.61$, $Price\ IF = 3265.6$, $Price\ ETF = 3.273$, sell 1 lot of IF2101, buy 2993 lots of CSI 300ETF, without considering transaction costs such as handling fees. Use the formula in Chapter 3, to gain income: $Profit = (3.273 - 3.274) \times 100 \times 2993 + (3277.6 - 3265.6) \times 300 = 3300.7\ yuan$, stock index futures handling fee is: $\frac{(3277.6+3265.6)\times300\times0.5}{10000} = 98.148\ yuan$, Huatai-Pinebridge CSI 300ETF handling fee is $\frac{(3.273+3.274)\times100\times2993\times4}{10000} = 783.8\ yuan$, the impact cost of stock index futures is: $(3277.6 + 3265.6) \times 300 \times 1 \div 10000 = 196.296\ yuan$, the impact cost of Huatai-Pinebridge CSI 300ETF is $\frac{(3.273+3.274)\times100\times2993\times2}{10000} = 391.9\ yuan$, deducting the net income from fixed costs and variable costs is $3300.7 - 98.148 - 783.8 - 196.296 - 391.9 = 1830.556\ yuan$, the margin required for stock index futures during the arbitrage period is: $3277.6 \times 300 \times 12\% = 117993.6\ yuan$, and the margin required for CSI 300ETF is : $3.273 \times 100 \times 2993 = 979608.09\ yuan$, a total deposit of $117993.6 + 979608.09 = 1097601.6\ yuan$ is required.

After that, we analyse the returns of the GARCH time-varying volatility trading model during the sample period. The above arbitrage research is mainly based on the arbitrage and stop-loss boundaries constructed by a simple multiple of the standard deviation of the spread series. It is assumed that the standard deviation of the spread series does not change with time, but in practice the standard deviation of the spread series of financial time series is a change with time. Fluctuations and changes have time-varying characteristics, so it is necessary to consider the situation when the variance of the model changes. Therefore, the GARCH model can be used to simulate the time-varying characteristics of variance and improve the arbitrage characteristics.

First, analyse the autocorrelation function and partial autocorrelation function of the $Mspread_t$ sequence. The analysis shows that the first-order coefficient of the partial autocorrelation diagram obviously exceeds the standard deviation range of twice, and the coefficient of PAC is much smaller than the coefficient of AC, so you can try build an AR model. By establishing the AR model of the spread, it can be obtained that the eigenvalues in the Inverted AR Roots are less than 1, which means that the eigenvalues of the regression equation are all greater than 1, outside the unit circle, which ensures that the AR model of the spread stability.

The ARCH-LM heteroscedasticity test was performed on whether the error term of the regression model had autoregressive conditional heteroscedasticity, and the lag order of the ARCH test was 1, indicating that the $Mspread_t$ sequence had an ARCH effect.

The mean equation and the ARCH effect equation are estimated, and the specific expressions are:

$$Spread_t = 0.617161Spread_{t-1} + u_t$$

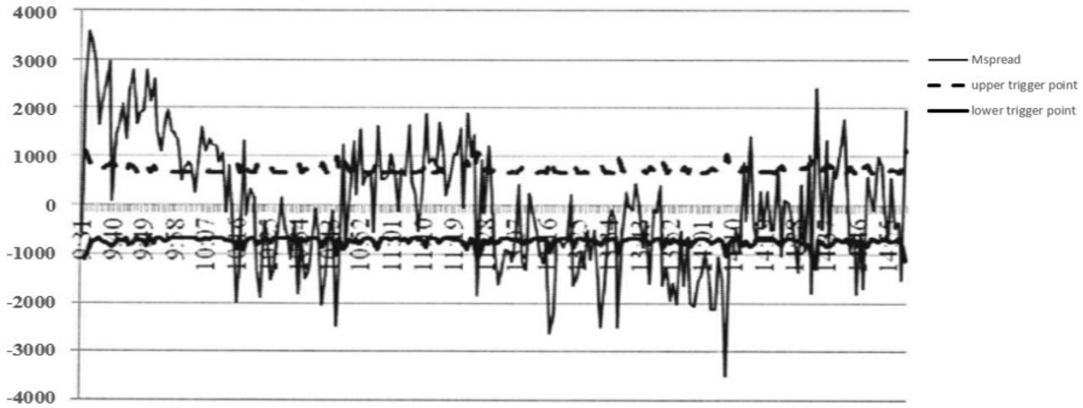
$$R^2 = 0.377554, DW = 2.331, Inverted\ AR\ Roots = 0.86$$

The ARCH (1) equation is:

$$\sigma_t^2 = 826800.2 + 0.180475u_{t-1}^2$$

After applying the GARCH model to obtain the standard deviation with time-varying volatility, the arbitrage threshold is no longer a simple 0.73σ, and σ changes continuously with time. From the above analysis, it can be seen that when k is 0.73, the expected arbitrage return will reach the maximum value, so this thesis sets the upper trigger point of the forward arbitrage as $0.73\sigma_t$. When the spread sequence $Mspread_t$ crosses $0.73\sigma_t$, sell one lot of stock index futures and buy 2993 lots of Huatai-Pinebridge CSI 300 ETF. When the spread sequence returns to the mean value of 0, Close the position to take profit. Since the calculated spread sequence value deviates from the equilibrium value and returns to the equilibrium value, the half-cycle expected value is 2.0835 minutes, and the recovery speed is fast. Therefore, the calculation of arbitrage in this thesis does not involve stop loss. The arbitrage chart is as follows.

Figure 4.8 The Arbitrage within the sample based on GARCH (2020.12.25)



Source: Own calculation

Then we analyse the transaction results in the sample period of the two models. Relevant indicators of the transaction results in the sample of this thesis, all the rates of return in this thesis have been annualized. Use the formula in chapter 3: $actual\ rate\ of\ return = \frac{actual\ net\ arbitrage\ profit}{trading\ margin}$, $annual\ rate\ of\ return = (1 + actual\ rate\ of\ return)^{252} - 1$, assuming there are 252 trading days in a year and arbitrage transactions occur every day, $average\ profit = \frac{total\ profit}{times\ of\ profit}$, $winning\ rate = \frac{times\ of\ profit}{times\ of\ transactions}$, average return is expected value of return per transaction, income rate standard deviation is standard deviation of each rate of return. Judging from the income estimate, the margin required for each arbitrage transaction is about 1.1 million yuan. In order to avoid the situation where the position has to be closed due to the full position operation, it is necessary to reserve a part of the transaction settlement reserve. It can be assumed that the initial investment is 150 yuan. 10,000 yuan, $accumulated\ yield\ at\ the\ end = \frac{the\ accumulated\ net\ income\ at\ the\ end\ of\ the\ period}{initial\ capital}$. The results of forward arbitrage and reverse arbitrage based on OLS and GARCH models calculated according to traditional indicators are shown in the following table.

Table 4.5 The transactions within the sample

Model	OLS Model		GARCH Model	
Indicator	Positive arbitrage	Reverse arbitrage	Positive arbitrage	Reverse arbitrage
Annualized average rate of return	-21%	13%	20%	5%
Standard deviation	0.40	0.50	0.29	0.45
Average time between transactions	5min	7min	5min	4min
Number of transactions	12	12	17	16
Number of profits	3	8	14	9
Number of loss	9	4	3	7
Win rate	12.00%	66.70%	82.35%	56.25%
Average profit	1271.2	1192.6	1066.2	1096.1
Average loss	-2607.6	-2071.6	-1267.1	-1727.6
Cumulative Net Profit	-19454.5	1254.1	11125.2	-2228.7
End-of-period cumulative rate of return	-1.31%	0.08%	0.74%	-0.15%
Cumulative annualized rate of return at the end of the period	-96.40%	23.44%	543.75%	-31.25%
Maximum profit	1921.75	3928.4	2428.2	3928.3
Maximum loss	-4975.7	-4175	-1288.7	-2070.2

Source: Own calculation

The positive arbitrage annualized rate of return of the OLS model and the cumulative rate of return at the end of the period are both negative, and the winning rate is only 30.7%. The reverse arbitrage result is better, the annualized average rate of return is high, and the winning rate of the transaction is increasing, and both the actual cumulative rate of return and the cumulative annualized rate of return at the end of the period performed well.

The annualized average rate of return, actual cumulative rate of return and accumulated annualized rate of return of the forward arbitrage and reverse arbitrage of the GARCH model all performed well, and the number of transactions increased significantly, and the return volatility was not large. The winning rate of forward arbitrage is higher than that of reverse arbitrage.

In general, the time interval for each arbitrage transaction is about 5 minutes. From the perspective of key indicators such as the annualized average rate of return, the cumulative rate of return at the end of the period, and the winning rate, the performance of the GARCH model is better than that of the OLS model, which is consistent with the previous theoretical results. The resulting GARCH model has a better arbitrage effect, which further verifies that the GARCH model can better describe the variance time-varying characteristics of the spread series.

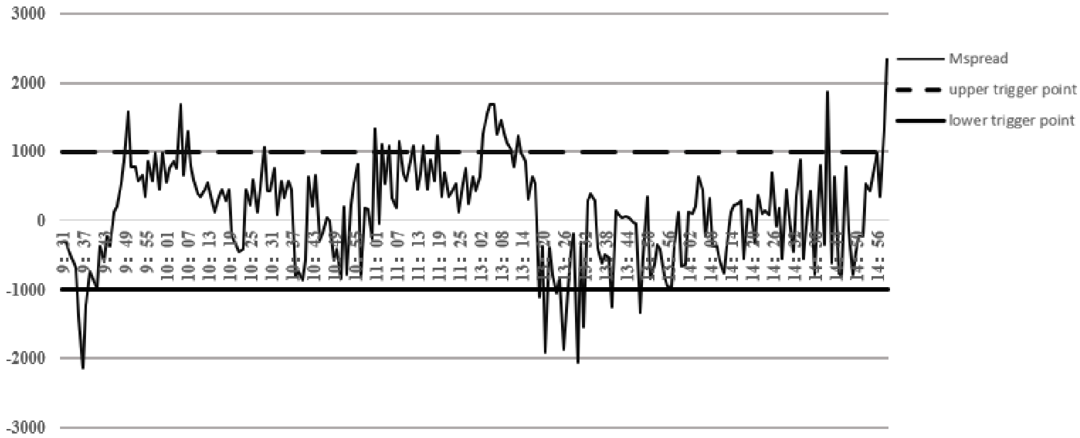
4.6 Statistical arbitrage out the sample

Take a total of 960 1-minute high-frequency trading data on 2020.12.18, 2020.12.26, 2021.1.6 and 2021.1.12, for simulated arbitrage trading, and use the ratio of $stock\ index\ futures: ETF\ =\ 1:2993$ to conduct arbitrage trading, and assume that the mean value of the spread series during the simulation period is -16.5117, so set $Sequence\ value\ of\ decentralized\ spread\ during\ simulated\ arbitrage\ =$ $stock\ index\ futures\ -\ 2993ETF\ +\ 16.5117$, and upper trigger point=0.73σ_t, lower trigger point=-0.73σ_t.

Among them, σ_t is constant in the OLS model, and changes with time in the GARCH model, which reflects the time-varying variance of the GARCH model. Also, because the expected value of the half-cycle of the spread sequence value calculated by using the in-sample data deviates from the equilibrium value and returns to the equilibrium value is 2.0835 minutes, the recovery speed is relatively fast. Therefore, it is considered that the arbitrage transaction situation outside the sample is the same, so the out-of-sample arbitrage transaction is the same. The arbitrage calculation also does not involve stop loss.

Similarly, this thesis first analyses the simulated returns of the OLS constant volatility trading model. Select the one-minute high-frequency data on December 18, 2020, simulate the out-of-sample spread trading according to the pairing trading strategy formed during the sample period, and calculate the spread sequence $Mspread_t$ in the simulation range. Also select the standard deviation of the in-sample data period σ=1291.9355, When $Mspread_t$ is greater than 0.73σ, sell IF2101 and buy 2993 lots of Huatai-Pinebridge CSI 300 ETF, close the position and make a profit when the spread sequence returns to the average value, when $Mspread_t$ is less than 0.73σ, buy IF2101 and sell 2993 lots of Huatai-Pinebridge CSI 300ETF, close the position and make a profit when the spread sequence returns to the average value. The arbitrage opportunity simulated by out-of-sample data based on the OLS model is shown in the following figure.

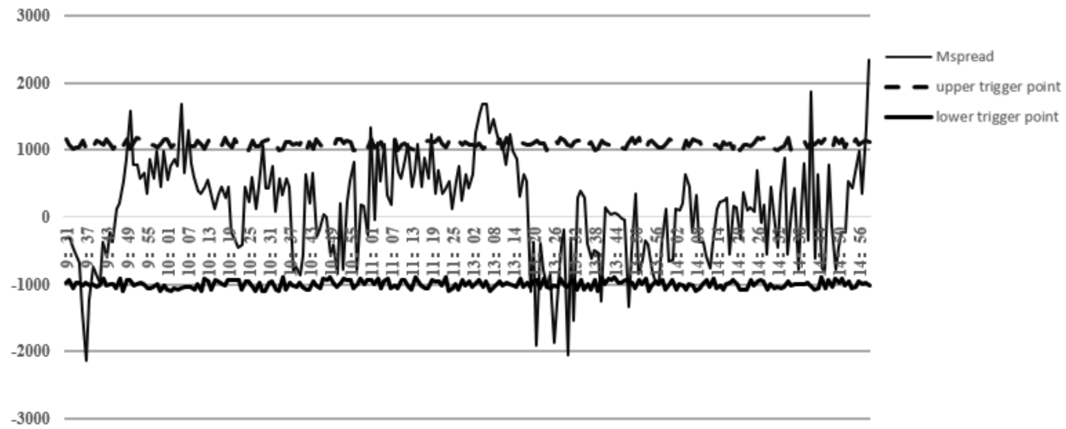
Figure 4.9 The Arbitrage out the sample based on OLS (2020.12.18)



Source: Own calculation

This thesis then analyses the simulated returns of the GARCH time-varying volatility trading model. According to the arbitrage trading strategy formed during the sample period, the out-of-sample returns are simulated. When the standard deviation is the standard deviation σ of 240 changes calculated using the GARCH model on the previous trading day, when $Mspread_t$ is greater than 0.73 σ, sell IF2101 and buy 2993 Huatai-Pinebridge CSI 300ETF, close the position and make a profit when the spread sequence returns to the average value. When $Mspread_t$ is less than 0.73σ, buy IF2101 and sell 2993 lots of Huatai-Pinebridge CSI 300ETF, and close the position to make a profit when the spread sequence returns to the average value. The arbitrage opportunity simulated by out-of-sample data based on the GARCH model is shown in the following figure.

Figure 4.10 The Arbitrage out the sample based on GARCH (2020.12.18)



Source: Own calculation

This thesis then analyses the trading results simulated by the two models. For the test results of out-of-sample simulated arbitrage transactions, this thesis calculates and analyses forward arbitrage and reverse arbitrage based on OLS and GARCH models according to the traditional indicators mentioned above. The results are as follows.

Table 4.6 The transactions out of the sample (2020.12.18)

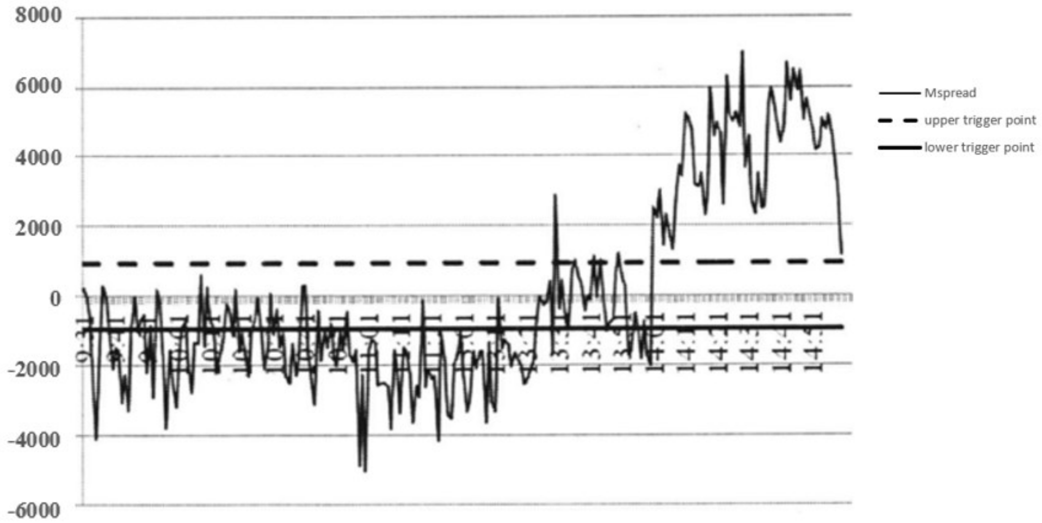
Model	OLS Model		GARCH Model	
Indicator	Positive arbitrage	Reverse arbitrage	Positive arbitrage	Reverse arbitrage
Annualized average rate of return	-1.32%	7.23%	11.22%	4.73%
Standard deviation	0.04%	0.08%	0.11%	0.12%
Average time between transactions	4.23min	6.63min	3.49min	4.42min
Number of transactions	12	12	18	19
Number of profits	4	7	11	9
Number of loss	8	5	7	10
Win rate	33.33%	58.33%	61.11%	47.37%
Average profit	423.6	578.4	636.1	724.6
Average loss	-301.8	-274.6	-418.2	-424.6
Cumulative Net Profit	-724.4	3168.5	5137.5	2703.5
End-of-period cumulative rate of return	-0.11%	0.33%	0.61%	0.29%
Cumulative annualized rate of return at the end of the period	-22.41%	126.23%	310.21%	105.63%
Maximum profit	512.4	1749.3	2016.2	2524.3
Maximum loss	-689.4	-523.6	-1011.3	-1173.9

Source: Own calculation

According to the paired trading strategy formed in the sample, the simulation results of one-minute out-of-sample high-frequency data show that the time interval of each arbitrage is about 5 minutes. Based on the out-of-sample test results of the OLS and GARCH models, the winning rate is not much different, but the reverse arbitrage rate of the two models is higher than that of the forward arbitrage, and observing the ratio of profit and loss, it is found that the GARCH model positive arbitrage > OLS reverse arbitrage > GARCH reverse arbitrage > OLS positive arbitrage, because the profit-loss ratio measures profit. It can be shown that the statistical arbitrage strategy based on the two models is more suitable for reverse arbitrage.

Select the one-minute high-frequency data on December 26, 2020, simulate the out-of-sample spread trading according to the pairing trading strategy formed during the sample period, and calculate the spread sequence $Mspread_t$ in the simulation range. Also select the standard deviation of the in-sample data period σ=1291.9355, When $Mspread_t$ is greater than 0.73σ, sell IF2101 and buy 2993 lots of Huatai-Pinebridge CSI 300 ETF, close the position and make a profit when the spread sequence returns to the average value, when $Mspread_t$ is less than 0.73σ, buy IF2101 and sell 2993 lots of Huatai-Pinebridge CSI 300ETF, close the position and make a profit when the spread sequence returns to the average value. The arbitrage opportunity simulated by out-of-sample data based on the OLS model is shown in the following figure.

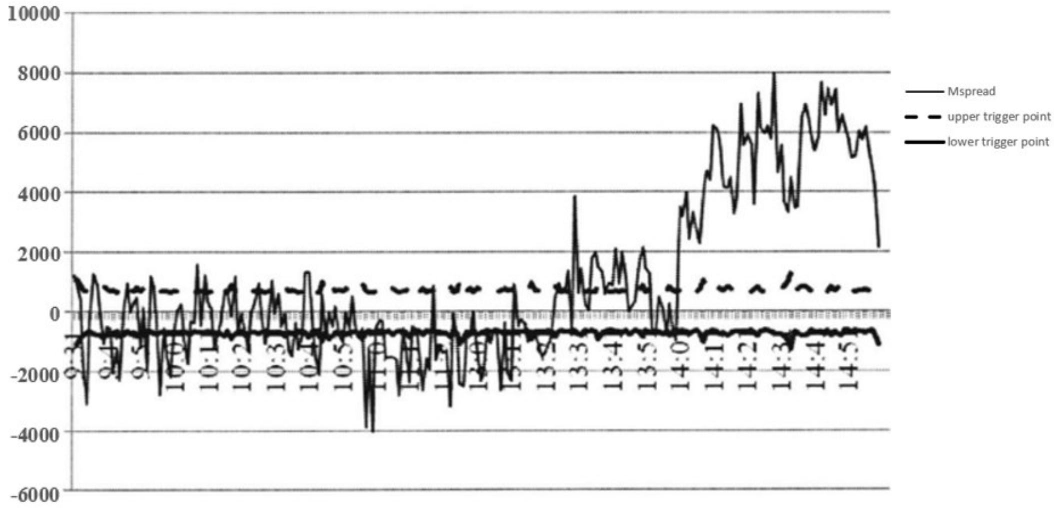
Figure 4.11 The Arbitrage out the sample based on OLS (2020.12.26)



Source: Own calculation

According to the arbitrage trading strategy formed during the sample period, the out-of-sample returns are simulated. When the standard deviation is the standard deviation σ of 240 changes calculated using the GARCH model on the previous trading day, when $Mspread_t$ is greater than 0.73 σ, sell IF2101 and buy 2993 Huatai-Pinebridge CSI 300ETF, close the position and make a profit when the spread sequence returns to the average value. When $Mspread_t$ is less than 0.73σ, buy IF2101 and sell 2993 lots of Huatai-Pinebridge CSI 300ETF, and close the position to make a profit when the spread sequence returns to the average value. The arbitrage opportunity simulated by out-of-sample data based on the GARCH model is shown in the following figure.

Figure 4.12 The Arbitrage out the sample based on GARCH (2020.12.26)



Source: Own calculation

For the test results of out-of-sample simulated arbitrage transactions, this thesis calculates and analyses forward arbitrage and reverse arbitrage based on OLS and GARCH models according to the traditional indicators mentioned above. The results are as follows.

Table 4.7 The transactions within the sample (2020.12.26)

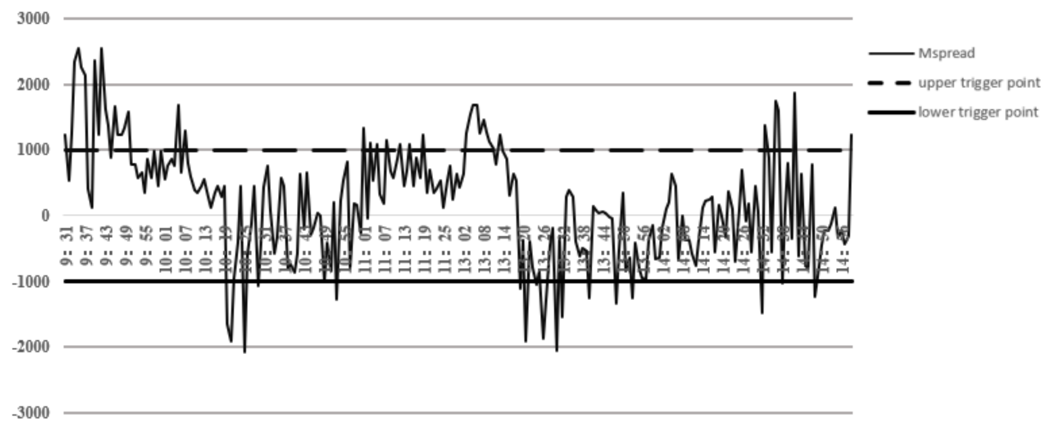
Model	OLS Model		GARCH Model	
Indicator	Positive arbitrage	Reverse arbitrage	Positive arbitrage	Reverse arbitrage
Annualized average rate of return	-6.00%	13.00%	2.00%	17.00%
Standard deviation	0.22	0.24	0.19	0.44
Average time between transactions	3min	5min	3min	5min
Number of transactions	7	17	12	20
Number of profits	3	12	7	12
Number of loss	4	5	5	8
Win rate	42.86%	70.59%	53.33%	60.00%
Average profit	651.3	961.2	639.1	1488.5
Average loss	-1168.6	-849.5	-888.8	-1207
Cumulative Net Profit	-2720.3	7287	30.1	8207
End-of-period cumulative rate of return	-0.18%	0.49%	0.00%	0.55%
Cumulative annualized rate of return at the end of the period	-36.71%	239.14%	0.51%	295.51%
Maximum profit	1079.9	1530.6	1080	3481
Maximum loss	-1769.2	-1288.7	-1470.2	-1771.4

Source: Own calculation

According to the paired trading strategy formed in the sample, the simulation results of one-minute out-of-sample high-frequency data show that the time interval of each arbitrage is about 4 minutes. Based on the out-of-sample test results of the OLS and GARCH models, the winning rate is not much different, but the reverse arbitrage rate of the two models is higher than that of the forward arbitrage, and observing the ratio of profit and loss, it is found that the GARCH model reverse arbitrage > OLS reverse arbitrage > GARCH positive arbitrage > OLS positive arbitrage, because the profit-loss ratio measures profit. It can be shown that the statistical arbitrage strategy based on the two models is more suitable for reverse arbitrage.

Similarly, this thesis first analyses the simulated returns of the OLS constant volatility trading model. Select the one-minute high-frequency data on January 6, 2021, simulate the out-of-sample spread trading according to the pairing trading strategy formed during the sample period, and calculate the spread sequence $Mspread_t$ in the simulation range. Also select the standard deviation of the in-sample data period σ=1291.9355, When $Mspread_t$ is greater than 0.73σ, sell IF2101 and buy 2993 lots of Huatai-Pinebridge CSI 300 ETF, close the position and make a profit when the spread sequence returns to the average value, when $Mspread_t$ is less than 0.73σ, buy IF2101 and sell 2993 lots of Huatai-Pinebridge CSI 300ETF, close the position and make a profit when the spread sequence returns to the average value. The arbitrage opportunity simulated by out-of-sample data based on the OLS model is shown in the following Figure 4.13.

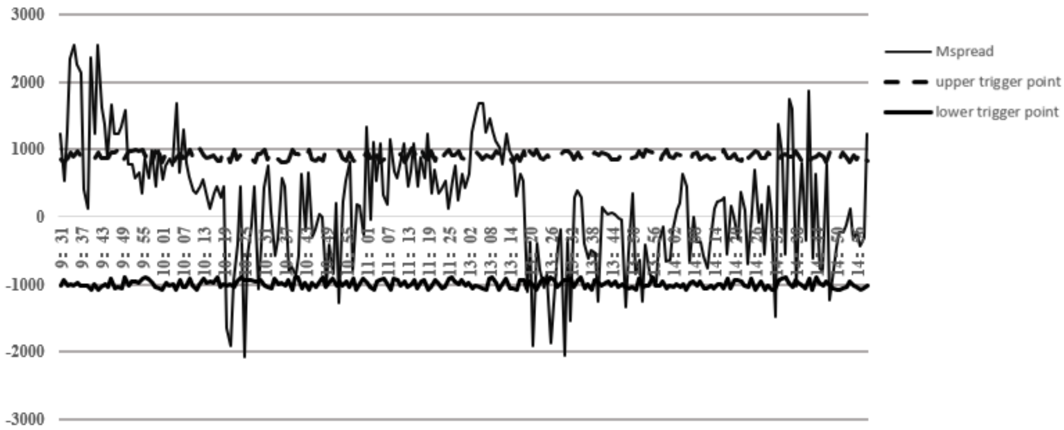
Figure 4.13 The Arbitrage out the sample based on OLS (2021.1.6)



Source: Own calculation

This thesis then analyses the simulated returns of the GARCH time-varying volatility trading model. According to the arbitrage trading strategy formed during the sample period, the out-of-sample returns are simulated. When the standard deviation is the standard deviation σ of 240 changes calculated using the GARCH model on the previous trading day, when $Mspread_t$ is greater than 0.73 σ, sell IF2101 and buy 2993 Huatai-Pinebridge CSI 300ETF, close the position and make a profit when the spread sequence returns to the average value. When $Mspread_t$ is less than 0.73σ, buy IF2101 and sell 2993 lots of Huatai-Pinebridge CSI 300ETF, and close the position to make a profit when the spread sequence returns to the average value. The arbitrage opportunity simulated by out-of-sample data based on the GARCH model is shown in the following Figure 4.14.

Figure 4.14 The Arbitrage out the sample based on GARCH (2021.1.6)



Source: Own calculation

This thesis then analyses the trading results simulated by the two models. For the test results of out-of-sample simulated arbitrage transactions, this thesis calculates and analyses forward arbitrage and reverse arbitrage based on OLS and GARCH models according to the traditional indicators mentioned above. The results are as follows.

Table 4.8 The transactions out of the sample (2021.1.6)

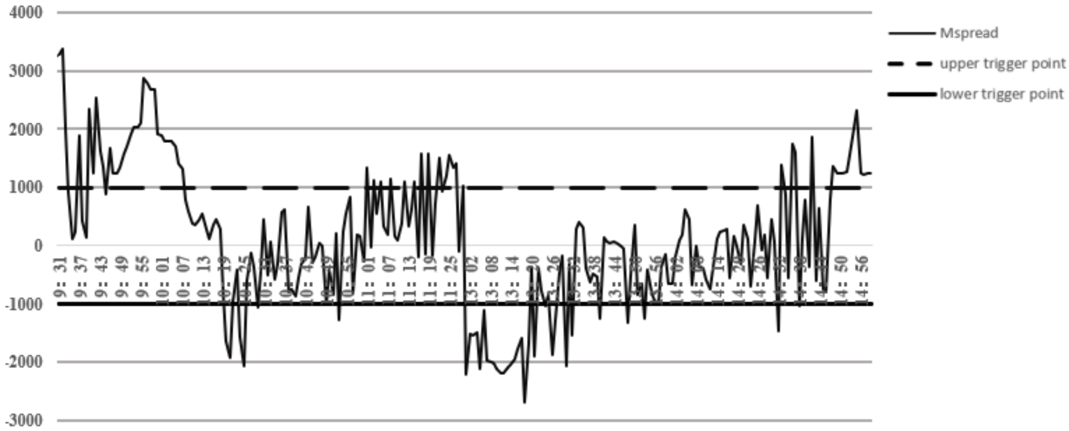
Model	OLS Model		GARCH Model	
Indicator	Positive arbitrage	Reverse arbitrage	Positive arbitrage	Reverse arbitrage
Annualized average rate of return	3.54%	14.68%	20.54%	8.89%
Standard deviation	0.10%	0.12%	0.15%	0.18%
Average time between transactions	5.23min	8.13min	5.65min	5.89min
Number of transactions	14	13	19	20
Number of profits	5	9	13	11
Number of loss	9	4	6	9
Win rate	35.71%	69.23%	68.42%	55.00%
Average profit	513.4	703.1	789.4	843.2
Average loss	-421.1	-423.4	-527.3	-512.4
Cumulative Net Profit	-1324	3893.3	7031.4	3317.4
End-of-period cumulative rate of return	-0.18%	0.48%	0.69%	0.46%
Cumulative annualized rate of return at the end of the period	-30.10%	186.20%	481.30%	153.60%
Maximum profit	912.6	2314.6	2705.2	2903.5
Maximum loss	-889.2	-845.2	-1405.2	-1387.4

Source: Own calculation

According to the paired trading strategy formed in the sample, the simulation results of one-minute out-of-sample high-frequency data show that the time interval of each arbitrage is about 6 minutes. Based on the out-of-sample test results of the OLS and GARCH models, the winning rate is not much different, but the reverse arbitrage rate of the two models is higher than that of the forward arbitrage, and observing the ratio of profit and loss, it is found that the GARCH model positive arbitrage > OLS reverse arbitrage > GARCH reverse arbitrage > OLS positive arbitrage, because the profit-loss ratio measures profit. It can be shown that the statistical arbitrage strategy based on the two models is more suitable for reverse arbitrage.

Similarly, this thesis first analyses the simulated returns of the OLS constant volatility trading model. Select the one-minute high-frequency data on January 12, 2021, simulate the out-of-sample spread trading according to the pairing trading strategy formed during the sample period, and calculate the spread sequence $Mspread_t$ in the simulation range. Also select the standard deviation of the in-sample data period σ=1291.9355, When $Mspread_t$ is greater than 0.73σ, sell IF2101 and buy 2993 lots of Huatai-Pinebridge CSI 300 ETF, close the position and make a profit when the spread sequence returns to the average value, when $Mspread_t$ is less than 0.73σ, buy IF2101 and sell 2993 lots of Huatai-Pinebridge CSI 300ETF, close the position and make a profit when the spread sequence returns to the average value. The arbitrage opportunity simulated by out-of-sample data based on the OLS model is shown in the following Figure 4.15.

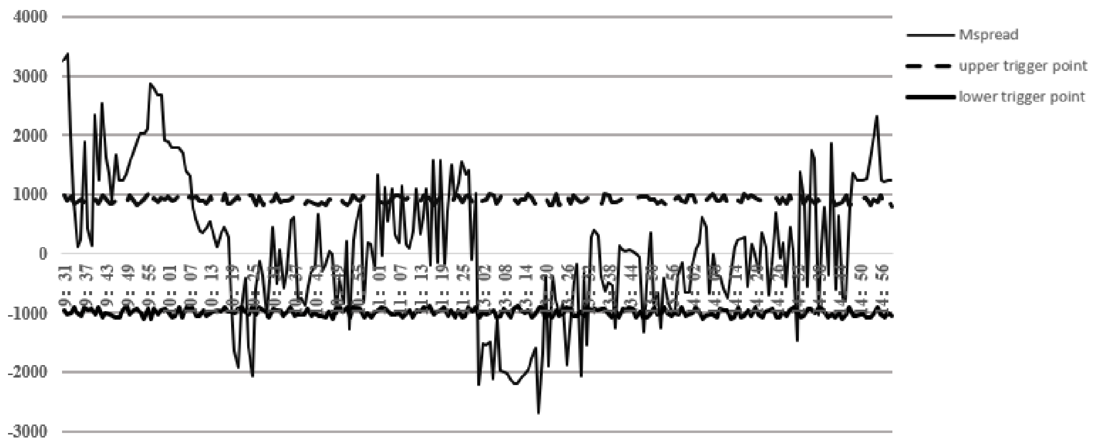
Figure 4.15 The Arbitrage out the sample based on OLS (2021.1.12)



Source: Own calculation

This thesis then analyses the simulated returns of the GARCH time-varying volatility trading model. According to the arbitrage trading strategy formed during the sample period, the out-of-sample returns are simulated. When the standard deviation is the standard deviation σ of 240 changes calculated using the GARCH model on the previous trading day, when $Mspread_t$ is greater than 0.73 σ, sell IF2101 and buy 2993 Huatai-Pinebridge CSI 300ETF, close the position and make a profit when the spread sequence returns to the average value. When $Mspread_t$ is less than 0.73σ, buy IF2101 and sell 2993 lots of Huatai-Pinebridge CSI 300ETF, and close the position to make a profit when the spread sequence returns to the average value. The arbitrage opportunity simulated by out-of-sample data based on the GARCH model is shown in the following Figure 4.16.

Figure 4.16 The Arbitrage out the sample based on GARCH (2021.1.12)



Source: Own calculation

This thesis then analyses the trading results simulated by the two models. For the test results of out-of-sample simulated arbitrage transactions, this thesis calculates and analyses forward arbitrage and reverse arbitrage based on OLS and GARCH models according to the traditional indicators mentioned above. The results are as follows.

Table 4.9 The transactions out of the sample (2021.1.12)

Model	OLS Model		GARCH Model	
Indicator	Positive arbitrage	Reverse arbitrage	Positive arbitrage	Reverse arbitrage
Annualized average rate of return	3.54%	14.68%	20.54%	8.89%
Standard deviation	0.10%	0.12%	0.15%	0.18%
Average time between transactions	5.23min	8.13min	5.65min	5.89min
Number of transactions	14	13	19	20
Number of profits	5	9	13	11
Number of loss	9	4	6	9
Win rate	35.71%	69.23%	68.42%	55.00%
Average profit	513.4	703.1	789.4	843.2
Average loss	-421.1	-423.4	-527.3	-512.4
Cumulative Net Profit	-1324	3893.3	7031.4	3317.4
End-of-period cumulative rate of return	-0.18%	0.48%	0.69%	0.46%
Cumulative annualized rate of return at the end of the period	-30.10%	186.20%	481.30%	153.60%
Maximum profit	912.6	2314.6	2705.2	2903.5
Maximum loss	-889.2	-845.2	-1405.2	-1387.4

Source: Own calculation

According to the paired trading strategy formed in the sample, the simulation results of one-minute out-of-sample high-frequency data show that the time interval of each arbitrage is about 5 minutes. Based on the out-of-sample test results of the OLS and GARCH models, the winning rate is not much different, but the reverse arbitrage rate of the two models is higher than that of the forward arbitrage, and observing the ratio of profit and loss, it is found that the GARCH model positive arbitrage > OLS reverse arbitrage > GARCH reverse arbitrage > OLS positive arbitrage, because the profit-loss ratio measures profit. It can be shown that the statistical arbitrage strategy based on the two models is more suitable for reverse arbitrage.

4.7 Statistical arbitrage trading model performance evaluation

The above-mentioned indicators such as the annualized average rate of return, the cumulative rate of return at the end of the period, the accumulated annualized rate of return at the end of the period, the winning rate and the profit-loss ratio only describe the statistical arbitrage situation of the OLS model and the GARCH model in the most basic traditional sense. These indicators only consider the income situation does not consider the risks brought by the income, and the inspection method is relatively rough. Although the standard deviation of the rate of return is calculated in the thesis, this standard deviation only measures the overall fluctuation of the rate of return and does not consider the individual extreme cases risk, so only using these indicators to evaluate the quality of a model is one-sided. Therefore, this thesis uses the Sharpe ratio to evaluate the performance of an investment. At present, the Sharpe ratio has become a standard tool for investment performance and is a risk-adjusted performance evaluation method. The Sharpe ratio is calculated as follows in chapter 3. It should be noted that, for intraday trading strategies, there is no financing cost due to the fact that the position is not held overnight, so the calculation of the Sharpe ratio ignores the risk-free interest rate. The research on in-sample and out-of-sample arbitrage of the statistical arbitrage model in the previous section shows that the out-of-sample data of statistical arbitrage performs better, and arbitragers pay more attention to the performance of out-of-sample data, so this thesis uses out-of-sample data to calculate the Sharpe ratio. Its annualized, annualized Sharpe ratio is as follows in chapter 3. The Sharpe ratio based on out-of-sample one-minute high-frequency trading data is shown in the following table.

Table 4.10 Performance evaluation of statistical arbitrage trading models

	OLS Positive arbitrage	OLS Reverse arbitrage	GARCH Positive arbitrage	GARCH Reverse arbitrage
Cumulative annualized rate of return	156.60%	930.01%	616.20%	118.70%
SR	9.2	28.3	28.86	11.35

Source: Own calculation

According to model experience, the larger the Sharpe ratio, the better the performance of the trading model. According to the above calculation of the Sharpe ratio, the reverse arbitrage of the OLS model and the positive arbitrage of the GARCH model are the best. The cumulative annualized rate of return and the Sharpe ratio are both on the premise of lower annualized rate of return, the Sharpe ratio of OLS model positive arbitrage and GARCH model reverse arbitrage performance is poor, which is consistent with the arbitrage effect evaluated by traditional indicators.

Therefore, it is recommended that arbitragers prefer the positive arbitrage operation of the GARCH model when using high-frequency data for statistical arbitrage trading strategies, followed by the reverse arbitrage of the OLS model, and finally the GARCH model reverse arbitrage.

5 Conclusion

As China is currently in the transition period from a planned economy to a market economy, the market economy system is being established and the system is not perfect. The financial system, as a place where reform of the economic system is more difficult, is more underdeveloped and imperfect. In actual trading activities, arbitrage activities with pure zero risk are rare. Therefore, actual traders often do not require zero risk when arbitraging, and a considerable part of arbitrage activities are risky arbitrage. For the arbitrage behavior of arbitrageurs, the biggest limitation of China's financial system comes from the acquisition of low-cost funds and the construction of positions. When commercial banks monopolize funds, the investment judgment of commercial banks actually dominates the pricing of fixed-income products in the capital market, which often leads to the convergence of investment in the fixed-income product market, and other arbitragers are forced to follow suit.

The purpose of this thesis is to study arbitrage opportunities in Chinese financial markets. And this thesis focuses on statistical arbitrage opportunities in China's financial market.

This thesis comprehensively studies the statistical arbitrage of CSI 300 stock index futures and Huatai-Pinebridge CSI 300ETF based on 1-minute high-frequency data. Firstly, Huatai-Pinebridge CSI 300 ETF and Harvest CSI 300 ETF are selected as the substitutes of spot index, and three methods are used to calculate the tracking error of two CSI 300 ETFs for CSI 300 index. The research shows that Huatai-Pinebridge CSI 300 ETF is better Tracking the CSI 300 index, the tracking error calculated by the three methods is less than 0.2%, while the daily tracking error of the Harvest CSI 300 ETF is greater than 0.2%. Therefore, the Harvest CSI 300 ETF is excluded from the selection of the CSI 300 ETF varieties, only the Huatai-Pinebridge CSI 300 ETF, which has been established for a long time, is relatively mature in operation, has good liquidity and has good tracking performance for the CSI 300 Index is selected. Secondly, the correlation between Huatai-Pinebridge CSI 300 ETF and CSI 300 stock index futures IF2101 is studied. The correlation between the two is very high. Only when the correlation is high, the results obtained by using the statistical arbitrage model will be more reliable, because the essence of statistical arbitrage is the mean value. Reply, that is, when the prices of the two assets maintain the same price trend for a long period of time as a whole, once the price difference between the two assets changes due to market fluctuations, after a short period of correction, the price difference will always be consistent again and develop toward equilibrium. The statistical arbitrage in this thesis hopes to capture the arbitrage opportunity through the established model and obtain the income from the change of the price difference. This thesis uses two statistical arbitrage models, namely the least squares OLS constant volatility model and GARCH time-varying volatility model, select the 1-minute high-frequency trading data closing prices of stock index futures IF2101 and Huatai-Pinebridge CSI 300 ETF, first perform unit root ADF test on the two time series to test their stationarity, and then test the 1 Minute high-frequency data establishes a regression equation, and finally determines the transaction threshold of $0.73\sigma_t$ when the arbitrage profit is the largest. The first stage uses the in-sample historical transaction data to conduct pairing transactions, determines the pairing transaction strategy, determines the pairing transaction coefficients according to the cointegration test, and constructs the optimal arbitrage combination. The empirical results show that: using in-sample data, from the perspective of traditional indicators such as annualized average return, cumulative return at the end of the period, winning rate and other key indicators, the performance of the GARCH model is better than that of the OLS model. The simulated transaction results of out of sample data show that the reverse arbitrage yield of the OLS model is higher than that of the forward arbitrage, indicating that the statistical arbitrage strategy based on the OLS model is more suitable for reverse arbitrage. The statistical arbitrage strategy of the GARCH model is more suitable for positive arbitrage most of the time.

Judging from the combination of traditional data and Sharpe ratio, using the GARCH model for forward arbitrage results is the best. Therefore, it is recommended that arbitragers prefer the GARCH model for the positive arbitrage operation, followed by the OLS model for the reverse arbitrage operation when conducting statistical arbitrage in China.

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List of Annexes

Annex

Annex1: NAV and Cumulative net worth in futures contracts

Huatai				
	NAV	Cumulative net worth	daily growth rate	NR
2020.12.18	3.3811	1.2843	-0.36%	
2020.12.19	3.4197	1.2986	1.14%	1.14%
2020.12.22	3.4316	1.303	0.35%	0.35%
2020.12.23	3.3591	1.2761	-2.11%	-2.11%
2020.12.24	3.2636	1.2407	-2.84%	-2.84%
2020.12.25	3.37	1.2801	3.26%	3.26%
2020.12.26	3.4801	1.321	3.27%	3.27%
2020.12.29	3.4907	1.3249	0.30%	0.30%
2020.12.30	3.4933	1.3259	0.07%	0.07%
2020.12.31	3.5693	1.3541	2.18%	2.18%
2021.01.05	3.6782	1.3945	3.05%	3.05%
2021.01.06	3.6757	1.3935	-0.07%	-0.07%
2021.01.07	3.6741	1.393	-0.04%	-0.04%
2021.01.08	3.5884	1.3612	-2.33%	-2.33%
2021.01.09	3.5749	1.3562	-0.38%	-0.38%
2021.01.12	3.5417	1.3438	-0.93%	-0.93%

Havarst						index	
	NAV	Cumulative net worth	daily growth rate	NR			
2020.12.18	3.4882	1.3333	-0.44%			2020.12.18	3057.52
2020.12.19	3.527	1.3481	1.11%	1.11%		2020.12.19	3108.6
2020.12.22	3.5384	1.3524	0.32%	0.32%		2020.12.22	3127.45
2020.12.23	3.4657	1.3247	-2.05%	-2.05%		2020.12.23	3032.61
2020.12.24	3.3667	1.2868	-2.86%	-2.86%		2020.12.24	2972.53
2020.12.25	3.4762	1.3287	3.25%	3.25%		2020.12.25	3072.54
2020.12.26	3.5914	1.3727	3.31%	3.31%		2020.12.26	3157.6
2020.12.29	3.601	1.3764	0.27%	0.27%		2020.12.29	3168.02
2020.12.30	3.6028	1.3771	0.05%	0.05%		2020.12.30	3165.81
2020.12.31	3.6819	1.4073	2.20%	2.20%		2020.12.31	3234.68
2021.01.05	3.794	1.4501	3.04%	3.04%		2021.01.05	3350.52
2021.01.06	3.793	1.4498	-0.03%	-0.03%		2021.01.06	3351.45
2021.01.07	3.7953	1.4506	0.06%	0.06%		2021.01.07	3373.95
2021.01.08	3.7064	1.4167	-2.34%	-2.34%		2021.01.08	3296.46
2021.01.09	3.6936	1.4118	-0.35%	-0.35%		2021.01.09	3282.41
2021.01.12	3.6587	1.3984	-0.94%	-0.94%		2021.01.12	3255.32

Annex 2: The correlation analysis of CSI 300 ETF and Index Futures

	沪深300	华泰柏瑞沪深300ETF
2020/6/3	2149	2.1491
2020/6/4	2128	2.1277
2020/6/5	2150	2.1504
2020/6/6	2134	2.1364
2020/6/9	2134	2.1356
2020/6/10	2161	2.1625
2020/6/11	2160	2.162
2020/6/12	2153	2.1552
2020/6/13	2176	2.1786
2020/6/16	2185	2.1946
2020/6/17	2169	2.1744
2020/6/18	2161	2.1661
2020/6/19	2124	2.1334
2020/6/20	2137	2.1453
2020/6/23	2131	2.1437
2020/6/24	2141	2.1576
2020/6/25	2135	2.148
2020/6/26	2146	2.1643
2020/6/27	2152	2.167
2020/6/30	2169	2.1821
2020/7/1	2164	2.1822
2020/7/2	2169	2.1889
2020/7/3	2180	2.2002
2020/7/4	2178	2.1993
2020/7/7	2174	2.1971
2020/7/8	2178	2.2012
2020/7/9	2146	2.1701
2020/7/10	2136	2.1666
2020/7/11	2149	2.1786
2020/7/14	2170	2.2038
2020/7/15	2172	2.2073
2020/7/16	2166	2.2039
2020/7/17	2147	2.1922
2020/7/18	2164	2.2029
2020/7/21	2162	2.2051
2020/7/22	2191	2.2319
2020/7/23	2199	2.2372
2020/7/24	2243	2.2768
2020/7/25	2272	2.3012

2020/7/28	2286	2.365
2020/7/29	2326	2.3728
2020/7/30	2324	2.3647
2020/7/31	2321	2.3933
2020/8/1	2341	2.3723
2020/8/4	2336	2.4186
2020/8/5	2376	2.4122
2020/8/6	2358	2.4059
2020/8/7	2363	2.3698
2020/8/8	2329	2.3742
2020/8/11	2338	2.4085
2020/8/12	2361	2.4001
2020/8/13	2358	2.402
2020/8/14	2357	2.3789
2020/8/15	2337	2.4042
2020/8/18	2366	2.418
2020/8/19	2378	2.4183
2020/8/20	2371	2.4096
2020/8/21	2365	2.3975
2020/8/22	2352	2.4085
2020/8/25	2367	2.3857
2020/8/26	2339	2.3666
2020/8/27	2323	2.3703
2020/8/28	2328	2.3538
2020/8/29	2317	2.3813
2020/9/1	2340	2.3984
2020/9/2	2359	2.4297
2020/9/3	2389	2.4522
2020/9/4	2411	2.4697
2020/9/5	2433	2.4929
2020/9/9	2452	2.4884
2020/9/10	2435	2.4756
2020/9/11	2430	2.4665
2020/9/12	2418	2.4821
2020/9/15	2433	2.4809
2020/9/16	2440	2.4319

2020/9/17	2395	2.4445
2020/9/18	2396	2.4519
2020/9/19	2409	2.4686
2020/9/22	2378	2.4216
2020/9/23	2399	2.4423
2020/9/24	2441	2.4851
2020/9/25	2436	2.4797
2020/9/26	2437	2.48
2020/9/29	2447	2.4903
2020/9/30	2450	2.4931
2020/10/8	2478	2.5204
2020/10/9	2481	2.5237
2020/10/10	2466	2.508
2020/10/13	2454	2.4958
2020/10/14	2446	2.4869
2020/10/15	2463	2.504
2020/10/16	2444	2.4845
2020/10/17	2441	2.4818
2020/10/20	2454	2.4949
2020/10/21	2433	2.4731
2020/10/22	2418	2.4583
2020/10/23	2395	2.4354
2020/10/24	2390	2.4299
2020/10/27	2368	2.4079
2020/10/28	2416	2.456
2020/10/29	2451	2.4907
2020/10/30	2468	2.5078
2020/10/31	2508	2.5467
2020/11/3	2512	2.5508
2020/11/4	2513	2.5512
2020/11/5	2503	2.5412
2020/11/6	2506	2.5437
2020/11/7	2502	2.5395
2020/11/10	2565	2.6026
2020/11/11	2558	2.5954
2020/11/12	2594	2.6311

2020/11/13	2579	2.6161
2020/11/14	2581	2.6174
2020/11/17	2567	2.603
2020/11/18	2541	2.577
2020/11/19	2537	2.5727
2020/11/20	2537	2.5726
2020/11/21	2583	2.6201
2020/11/24	2649	2.6865
2020/11/25	2685	2.7227
2020/11/26	2723	2.7589
2020/11/27	2754	2.7892
2020/11/28	2808	2.8414
2020/12/1	2819	2.8504
2020/12/2	2923	2.9538
2020/12/3	2967	2.9977
2020/12/4	3104	3.1337
2020/12/5	3124	3.1522
2020/12/8	3124	3.2795
2020/12/9	3252	3.1336
2020/12/10	3106	3.2512
2020/12/11	3221	3.2158
2020/12/12	3183	3.2274
2020/12/15	3193	3.2492
2020/12/16	3217	3.3345
2020/12/17	3303	3.3932
2020/12/18	3360	3.3811
2020/12/19	3345	3.4197
2020/12/22	3383	3.4316
2020/12/23	3324	3.3591
2020/12/24	3445	3.2636
2020/12/25	3455	3.37
2020/12/26	3457	3.4801
2020/12/29	3533	3.4907
2020/12/30	3641	3.4933
2020/12/31	3641	3.5693
2021/1/5	3643	3.6782
2021/1/6	3559	3.6757
2021/1/7	3546	3.6741
2021/1/8	3513	3.5884
2021/1/9	3514	3.5749
2021/1/12	3502	3.5417
2021/1/13	3604	3.5418
2021/1/14	3635	3.5292
2021/1/15	3355	3.6299
2021/1/16	3414	3.6601
2021/1/19	3616	3.3787

Annex 3: Spread series

9： 31	-312	1087	-915
9： 32	-312	1025	-1029
9： 33	-423	1009	-981
9： 34	-532	1088	-901
9： 35	-672	1079	-967
9： 36	-1378	1033	-992
9： 37	-2135	1099	-990
9： 38	-1234	1020	-1030
9： 39	-738	1174	-1043
9： 40	-834	1173	-1060
9： 41	-984	1035	-1096
9： 42	-367	1077	-1075
9： 43	-589	1117	-1098
9： 44	-236	1023	-909
9： 45	-367	1180	-1058
9： 46	123	1148	-957
9： 47	213	1102	-979
9： 48	536	1141	-1072
9： 49	874	991	-1016
9： 50	1578	1016	-1027
9： 51	789	1087	-1032
9： 52	789	997	-1007
9： 53	567	1026	-988
9： 54	657	995	-1012
9： 55	345	1165	-917
9： 56	867	1071	-947
9： 57	567	1071	-959
9： 58	978	1042	-1052
9： 59	456	1166	-944
10： 00	987	1135	-945
10： 01	546	1165	-1008
10： 02	756	1129	-1047
10： 03	867	1063	-1031
10： 04	756	1179	-958
10： 05	1692	1129	-964
10： 06	657	1139	-930
10： 07	1304	1069	-1008
10： 08	798	1167	-909
10： 09	589	1055	-932

10：10	389	1133	-1081
10：11	352	1174	-1012
10：12	456	1001	-933
10：13	548	1171	-1010
10：14	289	1182	-928
10：15	123	1143	-1091
10：16	345	1116	-1029
10：17	456	1146	-1089
10：18	290	1061	-920
10：19	456	1016	-958
10：20	-234	1181	-1008
10：21	-345	1001	-1072
10：22	-456	1043	-1028
10：23	-413	1102	-1005
10：24	456	1049	-926
10：25	235	1163	-1100
10：26	604	1009	-990
10：27	123	1150	-1051
10：28	456	1069	-1054
10：29	1062	1015	-964
10：30	438	1139	-946
10：31	442	1106	-1099
10：32	756	1087	-1081
10：33	79	1095	-1028
10：34	580	1169	-1006
10：35	326	1177	-926
10：36	580	1157	-993
10：37	456	1062	-928
10：38	-807	1120	-925
10：39	-750	1155	-935
10：40	-873	1114	-1017
10：41	-567	1103	-1069
10：42	645	1070	-973
10：43	206	1100	-903
10：44	663	1085	-1029
10：45	-294	1017	-1089

10： 46	-190	1026	-1063
10： 47	43	1169	-913
10： 48	6	1003	-978
10： 49	-567	1137	-946
10： 50	-420	1122	-912
10： 51	-848	1113	-1047
10： 52	215	1063	-1094
10： 53	-789	1033	-992
10： 54	233	1173	-932
10： 55	541	1033	-1058
10： 56	825	1115	-1059
10： 57	-812	1035	-1066
10： 58	176	1047	-1004
10： 59	161	1074	-1009
11： 00	-276	1022	-1085
11： 01	1343	1151	-1046
11： 02	-35	991	-991
11： 03	1118	1135	-959
11： 04	543	1092	-993
11： 05	1095	1053	-1044
11： 06	329	1102	-927
11： 07	176	1054	-950
11： 08	1154	1138	-940
11： 09	678	1105	-1019
11： 10	567	1055	-996
11： 11	868	1110	-1076
11： 12	1099	1136	-978
11： 13	456	1174	-931
11： 14	678	1061	-969
11： 15	1093	1002	-926
11： 16	456	995	-953
11： 17	886	1133	-1026
11： 18	567	1006	-979
11： 19	1234	1163	-1062
11： 20	345	1090	-930
11： 21	707	1129	-1034

11：22	345	1000	-985
11：23	413	1164	-1066
11：24	534	1103	-1078
11：25	123	1009	-1057
11：26	534	1091	-952
11：27	756	1180	-1055
11：28	254	1076	-990
11：29	645	1084	-1071
13：01	423	990	-1077
13：02	645	1008	-976
13：03	1253	1150	-955
13：04	1542	1007	-908
13：05	1687	1117	-992
13：06	1679	1054	-1098
13：07	1246	996	-1077
13：08	1466	1136	-932
13：09	1267	1155	-929
13：10	1134	991	-920
13：11	1032	1140	-1012
13：12	782	1062	-941
13：13	1234	1087	-924
13：14	978	1017	-1026
13：15	874	1146	-1032
13：16	312	1157	-993
13：17	632	1008	-969
13：18	543	1104	-948
13：19	-1102	1163	-914
13：20	-373	1010	-945
13：21	-1905	1027	-1097
13：22	-387	1086	-1052
13：23	-775	1179	-1005
13：24	-1046	1131	-949
13：25	-838	1146	-1086
13：26	-1871	1002	-956
13：27	-1304	1178	-1010
13：28	-462	1056	-1100

13： 29	-175	1007	-1086
13： 30	-2057	1023	-973
13： 31	-315	1113	-1074
13： 32	-1536	1022	-964
13： 33	294	1174	-919
13： 34	400	1040	-1049
13： 35	297	1161	-1007
13： 36	-397	1082	-975
13： 37	-617	1028	-1058
13： 38	-490	1069	-985
13： 39	-544	1144	-987
13： 40	-1257	1049	-1066
13： 41	134	1021	-976
13： 42	78	1186	-962
13： 43	45	1086	-1070
13： 44	56	1136	-944
13： 45	34	1062	-1089
13： 46	-12	1070	-1083
13： 47	-45	1171	-969
13： 48	-1331	1118	-983
13： 49	-540	1057	-952
13： 50	357	1042	-986
13： 51	-844	1076	-1074
13： 52	-642	1184	-1009
13： 53	-345	1016	-1016
13： 54	-402	1147	-1076
13： 55	-794	1142	-1022
13： 56	-941	1097	-960
13： 57	-977	1131	-978
13： 58	-369	1111	-1012
13： 59	123	1135	-1035
14： 00	-664	1111	-916
14： 01	-641	1169	-1033
14： 02	123	1162	-972
14： 03	100	1164	-1032
14： 04	198	1054	-1005

14：05	629	993	-994
14：06	448	1021	-907
14：07	-234	1101	-961
14：08	321	1145	-1003
14：09	-367	1015	-983
14：10	-378	1150	-1016
14：11	-578	1115	-923
14：12	-758	1187	-1030
14：13	-378	1079	-931
14：14	123	1181	-1090
14：15	234	1183	-985
14：16	256	1135	-1090
14：17	278	992	-943
14：18	-546	1037	-1099
14：19	174	1132	-1000
14：20	134	998	-957
14：21	-322	1142	-1029
14：22	361	1112	-942
14：23	107	1087	-1049
14：24	142	1142	-978
14：25	72	1042	-1068
14：26	697	1068	-1013
14：27	-88	1127	-1018
14：28	182	1169	-1042
14：29	-561	1146	-961
14：30	449	998	-967
14：31	70	1178	-917
14：32	-456	1086	-1033
14：33	345	1087	-972
14：34	892	1127	-975
14：35	-546	1052	-908
14：36	123	1014	-945
14：37	423	1145	-976
14：38	-789	1102	-973
14：39	112	1111	-963
14：40	798	1100	-1043
14：41	-353	1094	-1091
14：42	1875	1097	-970
14：43	-615	1107	-938
14：44	642	990	-959
14：45	-755	1155	-1023
14：46	-799	1107	-1034
14：47	789	1081	-963
14：48	-123	1112	-975
14：49	-789	1079	-917
14：50	-456	1034	-1068
14：51	-234	1017	-1037
14：52	-234	1029	-959
14：53	534	1064	-914
14：54	423	1111	-993
14：55	653	1132	-920
14：56	987	1093	-976
14：57	345	1024	-911
14：58	1324	1026	-1014
14：59	2345	1134	-995

Annex 4: OLS positive arbitrage

ols positive arbitrage	1	2	3	4	5	6	7	8	9	10	11	12
Mspread	3566	2878	1972	1602	1623	1613	1623	1368	1100	2488	1254	1869
price if	3278	3265	3252	3275	3263	3264	3253	3253	3265	3270	3255	3271
price ETF	3.274	3.272	3.273	3.274	3.272	3.274	3.272	3.271	3.275	3.274	3.272	3.275
close the position												
Mspread	87.61	98.2	97.02	0	-78.3	-65.2	-10.3	-83.4	-53.4	-83.4	-98.4	-40.2
PriceIF	3265.6	3262.4	3251.5	3261.3	3265.6	3265.2	3261.3	3265.6	3261.6	3265.1	3261.2	3264.2
PriceETF	3.273	3.271	3.272	3.272	3.271	3.273	3.269	3.27	3.273	3.272	3.27	3.273
Buy 2993 lots of CSI 300ETF												
profit	3301	571	-29	3391	-1199	-779	-3508	-4169	511	961	-2609	1531
stock index fee	98.148	97.9155	97.5585	98.0385	97.923	97.932	97.7085	97.7745	97.9035	98.031	97.7355	98.0325
300ETF fee	783.80684	783.32796	783.5674	783.68712	783.32796	783.80684	783.08852	783.08852	783.92656	783.68712	783.2082	783.9266
stock index shock costs	196.296	195.831	195.117	196.077	195.846	195.864	195.417	195.549	195.807	196.062	195.471	196.065
300ETFcosts	391.90342	391.66398	391.7837	391.84356	391.66398	391.90342	391.54426	391.54426	391.96328	391.84356	391.6041	391.9633
net profit	1830.54574	-898.03844	-1497.3266	1921.75382	-2668.06094	-2248.80626	-4975.65828	-5637.25628	-958.20034	-508.22368	-4076.619	61.41266
stock index margin	117993.6	117550.8	117086.4	117885.6	117453.6	117489.6	117093.6	117097.2	117550.8	117730.8	117162	117766.8
300ETFmargin	979608.9	979010.3	979309.6	979309.6	979010.3	979608.9	978411.7	978711	979608.9	979309.6	978711	979608.9
total margin	1097602.5	1096561.1	1096396	1097195.2	1096463.9	1097098.5	1095505.3	1095808.2	1097159.7	1097040.4	1095873	1097376
real rate of return	0.167%	-0.082%	-0.137%	0.175%	-0.243%	-0.205%	-0.454%	-0.514%	-0.087%	-0.046%	-0.372%	0.006%
annual rate of return	52.19%	-18.65%	-29.13%	55.43%	-45.88%	-40.37%	-68.25%	-72.74%	-19.76%	-11.02%	-60.91%	1.42%
	0.542563016	0.000794949	0.005868685	0.591348392	0.059561228	0.035720751	0.218767152	0.262817095	0.000292842	0.010925919	0.155484	0.052414

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Annex 5: OLS reverse arbitrage

ols reverse arbitrage	1	2	3	4	5	6	7	8	9	10	11	12
Mspread	-2000	-1983	-1532	-1823	-2003	-2450	-1891	-1702	-2689	-2558	-1499	-3562
price if	3268	3256	3267	3276	3263	3256	3276	3258	3260	3266	3264	3274
price ETF	3.271	3.27	3.271	3.272	3.271	3.268	3.275	3.269	3.268	3.271	3.272	3.272
close the position												
Mspread	-87.3	-98	34	-21	-35	85	-12	67	65	-13	-9	-56
PriceIF	3275	3258	3273	3274	3255	3255	3257	3267	3268	3270	3278	3276
PriceETF	3.27	3.266	3.268	3.269	3.264	3.266	3.265	3.268	3.27	3.269	3.268	3.266
Buy 2993 lots of CSI 300ETF												
profit	2399.3	1797.2	2697.9	297.9	-304.9	298.6	-2707	2999.3	1801.4	1798.6	5397.2	2395.8
stock index fee	98.145	97.71	98.1	98.25	97.77	97.665	97.995	97.875	97.92	98.04	98.13	98.25
300ETF fee	783.08852	782.48992	782.84908	783.08852	782.3702	782.25048	782.9688	782.60964	782.72936	782.9688	782.9688	782.7294
stock index shock costs	196.29	195.42	196.2	196.5	195.54	195.33	195.99	195.75	195.84	196.08	196.26	196.5
300ETFcosts	391.54426	391.24496	391.42454	391.54426	391.1851	391.12524	391.4844	391.30482	391.36468	391.4844	391.4844	391.3647
net profit	930.23222	330.33512	1229.32638	-1171.48278	-1771.7653	-1167.77072	-4175.4382	1531.76054	333.54596	330.0268	3928.357	926.956
stock index margin	117648	117216	117612	117936	117468	117216	117936	117288	117360	117576	117504	117864
300ETFmargin	978711	977513.8	978112.4	978411.7	976915.2	977513.8	977214.5	978112.4	978711	978411.7	978112.4	977513.8
total margin	1096359	1094729.8	1095724.4	1096347.7	1094383.2	1094729.8	1095150.5	1095400.4	1096071	1095987.7	1095616	1095378
real rate of return	0.085%	0.030%	0.112%	-0.107%	-0.162%	-0.107%	-0.381%	0.140%	0.030%	0.030%	0.359%	0.085%
annual rate of return	23.83%	7.90%	32.65%	-23.62%	-33.52%	-23.58%	-61.81%	42.21%	7.97%	7.88%	146.44%	23.76%
	0.012812966	0.00212456	0.040579856	0.1305092	0.211889114	0.13025704	0.552344936	0.088220741	0.00206087	0.002140315	1.793674	0.012656

Annex 6: GARCH positive arbitrage

garch positive arbitrage	1	2	3	4	5	6	7	8	9	10	11	12	13
Mspread	3566	2878	1972	1602	1623	1613	1623	1368	1100	2488	1254	1869	985
price if	3278	3265	3259	3275	3263	3264	3268	3270	3265	3275	3267	3271	3273
price ETF	3.274	3.272	3.273	3.274	3.272	3.274	3.272	3.271	3.275	3.274	3.273	3.275	3.274
close the position													
Mspread	85	94	96	0	-76	-65	-10	-79	-53.4	-80	-96	-40	12
PriceIF	3265.6	3258	3251.5	3261.3	3261	3262	3259	3261	3261.6	3265	3260	3262	3261
PriceETF	3.273	3.271	3.272	3.272	3.271	3.273	3.269	3.27	3.273	3.272	3.27	3.273	3.271
Buy 2993 lots of CSI 300ETF													
profit	3301	1891	1951	3391	181	181	1802	2401	511	2401	1202	2191	2702
stock index fee	98.148	97.8495	97.6575	98.0385	97.854	97.884	97.905	97.965	97.9035	98.1	97.905	97.9995	98.01
300ETF fee	783.80684	783.32796	783.5674	783.68712	783.32796	783.80684	783.08852	783.08852	783.92656	783.68712	783.328	783.9266	783.567
stock index shock costs	196.296	195.699	195.315	196.077	195.708	195.768	195.81	195.93	195.807	196.2	195.81	195.999	196.02
300ETFcosts	391.90342	391.66398	391.7837	391.84356	391.66398	391.90342	391.54426	391.54426	391.96328	391.84356	391.664	391.9633	391.784
net profit	1830.54574	422.15956	482.3764	1921.75382	-1287.85394	-1288.66226	333.75222	932.17222	-958.20034	931.56932	-266.6069	721.5117	1232.72
stock index margin	117993.6	117550.8	117324	117885.6	117453.6	117489.6	117648	117720	117550.8	117900	117612	117766.8	117828
300ETFmargin	979608.9	979010.3	979309.6	979309.6	979010.3	979608.9	978411.7	978711	979608.9	979309.6	978711	979608.9	979010
total margin	1097602.5	1096561.1	1096633.6	1097195.2	1096463.9	1097098.5	1096059.7	1096431	1097159.7	1097209.6	1096323	1097376	1096838
real rate of return	0.167%	0.038%	0.044%	0.175%	-0.117%	-0.117%	0.030%	0.085%	-0.087%	0.085%	-0.024%	0.066%	0.112%
annual rate of return	52.19%	10.19%	11.72%	55.43%	-25.63%	-25.63%	7.97%	23.88%	-19.76%	23.85%	-5.94%	18.01%	32.72%
	0.104733104	0.009286857	0.006565694	0.12675592	0.206623327	0.206633114	0.014038291	0.001647568	0.156698166	0.001618511	0.066396	0.000327	0.01663

Annex 7: GARCH reverse arbitrage

garch reverse arbitrage	1	2	3	4	5	6	7	8	9	10	11	12	13
Mspread	-2000	-1983	-1532	-1823	-2003	-2450	-1891	-1702	-2689	-2558	-1499	-3562	-991
price if	3268	3256	3267	3276	3263	3256	3272	3258	3260	3266	3264	3274	3276
price ETF	3.271	3.27	3.271	3.272	3.271	3.268	3.275	3.269	3.268	3.271	3.272	3.272	3.271
close the position													
Mspread	-87.3	-98	34	-21	-35	85	-12	67	65	-13	-9	-56	-11
PriceIF	3275	3258	3273	3274	3255	3255	3268	3267	3268	3270	3278	3276	3269
PriceETF	3.27	3.266	3.268	3.269	3.264	3.266	3.265	3.268	3.27	3.269	3.268	3.266	3.267
Buy 2993 lots of CSI 300ETF													
profit	2399.3	1797.2	2697.9	297.9	-304.9	298.6	1793	2999.3	1801.4	1798.6	5397.2	2395.8	-902.8
stock index fee	98.145	97.71	98.1	98.25	97.77	97.665	98.1	97.875	97.92	98.04	98.13	98.25	98.175
300ETF fee	783.08852	782.48992	782.84908	783.08852	782.3702	782.25048	782.9688	782.60964	782.72936	782.9688	782.9688	782.7294	782.729
stock index shock costs	196.29	195.42	196.2	196.5	195.54	195.33	196.2	195.75	195.84	196.08	196.26	196.5	196.35
300ETFcosts	391.54426	391.24496	391.42454	391.54426	391.1851	391.12524	391.4844	391.30482	391.36468	391.4844	391.4844	391.3647	391.365
net profit	930.23222	330.33512	1229.32638	-1171.48278	-1771.7653	-1167.77072	324.2468	1531.76054	333.54596	330.0268	3928.357	926.956	-2371.4
stock index margin	117648	117216	117612	117936	117468	117216	117792	117288	117360	117576	117504	117864	117936
300ETFmargin	978711	977513.8	978112.4	978411.7	976915.2	977513.8	977214.5	978112.4	978711	978411.7	978112.4	977513.8	977813
total margin	1096359	1094729.8	1095724.4	1096347.7	1094383.2	1094729.8	1095006.5	1095400.4	1096071	1095987.7	1095616	1095378	1095749
real rate of return	0.085%	0.030%	0.112%	-0.107%	-0.162%	-0.107%	0.030%	0.140%	0.030%	0.030%	0.359%	0.085%	-0.216%
annual rate of return	23.83%	7.90%	32.65%	-23.62%	-33.52%	-23.58%	7.75%	42.21%	7.97%	7.88%	146.44%	23.76%	-42.07%
	0.037091349	0.001109145	0.078871779	0.0794472	0.145098045	0.079250485	0.001009512	0.141689411	0.001155998	0.001097811	2.012647	0.036824	0.21754