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How to Improve the Price Discovery Function of China's Stock Index Futures Market

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Abstract

Establishing a stock index futures market is an important part of financial supply-side reform, aimed at improving the effectiveness of financial asset prices, enhancing the efficiency of financial resource allocation, thereby improving the price discovery function of the futures market and promoting financial services to the real economy. The key to improving the price discovery function of the futures market lies in how to effectively measure market information and evaluate the validity of information. Based on the heteroscedasticity effect widely present in financial markets, this paper proposes a uniquely identifiable information share index and a volatility spillover-adjusted information share index. Using these two indices, this paper studies the price discovery capability of China's stock index futures market. The research results show that the information contribution of A-share futures and spot markets is a relatively complex process: more information is initially discovered in the futures market, but the information contains more noise; the spot market reinterprets the information from the futures market, and thus the effective price mainly comes from the spot market's interpretation of information, which includes both information "discovered" by the spot market itself and information that flows in from the futures market through volatility spillovers and is reinterpreted. The conclusions of this paper not only enrich the research on quantitative indicators of price discovery but also provide new ideas for China's further effective management of the futures market.

Keywords: Price discovery, Information share, Volatility spillover

1. Introduction

Price discovery is an important economic function of the futures market and the foundation of the futures market's existence and development. The price discovery process refers to the process by which market supply and demand sides form a consistent transaction price for a certain commodity through information exchange in a limited market. Under the assumption of the law of one price, there is no arbitrage space between the spot and futures markets, and their prices follow exactly the same trend. This common price trend reflects the price of the underlying asset behind it. In reality, the price of the underlying asset is simultaneously influenced by factors from both the spot and futures markets. Affected by market supply and demand, the asset prices of the two markets first receive information originating within their own markets—so-called "structural shocks"—which affect the current price of the asset, then influence the price of the corresponding underlying asset, and finally affect the asset price in the other market through the law of one price. Futures markets generally have better characteristics, including trading continuity, standardized trading contracts and settlement mechanisms, etc. The futures markets of major global commodities and financial assets often have higher quality price information, thereby determining the price trend of the spot market. In April 2022, China's "Futures and Derivatives Law" was officially promulgated and implemented, laying the foundation for the high-quality development of the futures and derivatives market. After its promulgation and implementation, the six major financial industries, including banking, securities, insurance, futures, funds, and trusts, all introduced special laws for regulation. This is also an important step in China's further improvement of the multi-level financial market and full utilization of the role of the futures market as financial infrastructure. The Futures and Derivatives Law clarifies the three major functions of the futures market: price discovery, risk management, and resource allocation, among which price discovery is the core function of the futures market (Fang, 2022). How to improve the price discovery function of the futures market has always been a concern of financial researchers.

As one of the most important futures varieties, the price discovery process of stock index futures has always attracted considerable attention. Since the world's first stock index futures contract was listed on U.S. futures exchanges, scholars at home and abroad have conducted extensive research on the price discovery function of stock index futures. Because stock index futures markets often have more convenient short-selling mechanisms, the latest information is more likely to appear there first. Therefore, a large body of literature has found that stock index futures markets contribute more to price discovery. However, as models become increasingly complex and research deepens, some studies have found that the more complex the information, the greater the noise it contains. Hence, the noise in the stock index futures market is greater than that in the spot market, and the spot market may contribute more to more accurate basic information. On April 16, 2010, the China Financial Futures Exchange (CFFEX) first launched the CSI 300 index futures contract. The original intention of establishing China's stock index futures market was to improve the information quality of the stock market, thereby enhancing the effectiveness of financial asset prices, improving the efficiency of financial resource allocation, and promoting financial services to the real economy. This is also an important part of China's financial supply-side reform. The fundamental point of improving the price discovery function of the stock index futures market lies in how to effectively measure market information and evaluate the validity of information. Information originating within each of the spot and futures markets contributes to the underlying asset price. The purpose of price discovery research is to clarify which market's information contribution is greater and thus occupies a dominant position.

Currently, research on the price discovery process of China's stock index futures has not yet formed a unified understanding. The main reason is that existing research on the price discovery process of futures markets heavily relies on the Information Share (IS) model. This method's identification of contemporaneous relationships mainly depends on Cholesky decomposition, which lacks inherent economic meaning. Because it is overly dependent on the ordering of variables, it cannot produce an accurate identification result; one can only take the average of the upper and lower bounds of the results, making it difficult to reach consistent conclusions.

This paper substantially improves the traditional information share model, overcoming its shortcomings such as inability to achieve unique identification and difficulty in dynamization. By utilizing the conditional heteroscedasticity process prevalent in financial markets, this paper constructs an information share index with economic meaning and unique identifiability. Through the volatility spillover manifested in the GARCH effect, a volatility spillover-adjusted information share index is constructed. The improvements to the traditional model in this paper help overcome the limitation of previous studies that could only study information transmission at the price level, enabling better identification of the price discovery process in the stock index futures market, thereby deepening the understanding of the price discovery process.

This paper finds that the price discovery process may exhibit a very complex pattern: the futures market has a greater advantage in rapidly discovering new information but is also more susceptible to noise contamination; a larger proportion of the underlying asset price comes from the interpretation of the spot market. Dynamic research finds that the constraints on futures market trading that began in 2015 overall reduced the information share of the futures market, especially the contribution proportion of all new information. The contribution of noise in futures market information to the underlying asset price also showed a declining trend. In addition, increased market volatility enhances the price discovery capability of the futures market, and informed investors may be more inclined to use leveraged trading and long-short trading instruments in the futures market to obtain excess returns. These findings are conducive to regulatory authorities further improving China's stock index futures market and enhancing its price discovery function.

The marginal contributions and innovations of this paper may be reflected in the following three aspects: First, it constructs a structural GARCH model and achieves identification of the contemporaneous relationship between futures and spot prices through the heteroscedasticity process widely present in financial markets, thereby constructing an information share index with economic meaning and unique identifiability. Second, based on the conditional heteroscedasticity effect, it considers the impact of volatility spillover on information share and proposes a volatility spillover-adjusted information share index that can observe the more complex information transmission and absorption patterns in the price discovery process. Third, it conducts empirical analysis on China's three major stock index futures, particularly dynamically analyzing the impact of trading restrictions on the price discovery capability of the futures market.

The structure of the remainder of this paper is as follows: Section 2 reviews the existing literature; Section 3 presents the new information share measurement method and proposes the research design of this paper; Section 4 is the applied analysis of A-share spot and futures markets; Section 5 presents the conclusions and implications.

2. Literature Review

Comparing the price discovery capabilities of stock index futures and spot markets is the basis for discussing market pricing efficiency and market regulatory norms. From the perspective of research methods, the most traditional tool is cointegration analysis. Yang et al. (2012) conducted pioneering research on the price discovery process of China's stock index futures market using cointegration analysis. By analyzing 5-minute data from April 16 to July 30, 2010 (the initial stage of the stock index futures market), they found that the spot market plays a dominant role in price discovery: when market prices deviate from long-term equilibrium, futures prices actively converge toward spot prices. Fang and Cai (2012) reached similar conclusions, arguing that the spot stock market plays a greater role in the price discovery process relative to the stock index futures market. The logic behind cointegration analysis is that the price that remains stable in the short term reflects the underlying asset price, while the asset that moves toward the other market's price in the short term is at an information disadvantage. The main drawback of this method is that it can only verify whether one market has a spillover effect on the other but cannot precisely determine the true underlying asset price. If both markets deviate from the underlying asset price, the short-term price spillover effect is bidirectional, and cointegration analysis cannot address the price discovery problem of two markets.

Hasbrouck's (1995) information share model is an effective alternative to cointegration analysis. It measures the underlying asset price or "common factor" of the market through a "common stochastic trend" in a vector error correction model (VECM), and then measures the contribution of each market's new information (innovation) to the underlying asset price, defining this contribution proportion as the information share of a particular market. The characteristics of this method are very prominent: it can estimate the underlying asset price with limited information and can simultaneously address price discovery issues for more than two markets. Based on these advantages, this method has been widely used in price discovery research and has formed the general understanding that futures prices lead spot price fluctuations in the long run, with the futures market dominating the price discovery process (Fleming, 1996; Abhyankar, 1998; Kim et al., 1999; Roope et al., 2002; Covrig et al., 2004). In research on the Chinese market, Liu and Zhang, based on 1-minute high-frequency data of CSI 300 stock index futures and spot, found that China's stock index futures market had a strong price discovery function in the early stages of its opening. Tao et al. (2014) also believed that stock index futures play a dominant role in the price information transmission process, with a role significantly greater than the spot market, and this role shows a trend of increasing over time. Li et al. (2016) extended the research to more markets, conducting empirical research using high-frequency data from three varieties of stock index futures and spot in China, also concluding that the stock index futures market has a larger price discovery proportion. Wang and Zhu (2016) used the information share method to study the RMB exchange rate issue and found that offshore market forward exchange rates dominate the price discovery process. Overall, research based on the information share model generally believes that the futures market has a greater amount of information.

In addition, some studies have pointed out that the price discovery function of the futures market exhibits certain dynamic characteristics during special periods. Yang and Yang (2017) found that during the period of severe stock market volatility in 2015, CSI 300 index futures had a one-way volatility spillover to the spot market, thereby increasing the volatility of the spot market, thus the policy of restricting stock index futures trading was effective. Tian et al. (2019) compared the performance of three types of stock index futures during the 2015 Chinese stock market turmoil and found that CSI 500 index futures had a stronger price-leading role than the other two, but their volatility spillover effect was weaker than the other two. Xu and Liu (2019) discussed the impact of trading restriction policies on futures market price discovery, finding that trading restrictions on the futures market increased transaction costs and reduced the price discovery function of futures. Wang and Liu (2019) found that restrictive measures on stock index futures trading could promote microstructural rebalancing of the market by curbing excessive speculation in the futures market, preventing further expansion of abnormal stock market volatility. Tang and Ju (2020) studied the linkage between CSI 300 index futures and FTSE China A50 index futures, finding that policy changes in the futures market affect the direction and scale of information transmission between markets.

However, research based on the information share model also has methodological defects, thereby weakening the accuracy of empirical conclusions. Specifically, the traditional information share model has at least the following three shortcomings:

First, the traditional information share model generally uses Cholesky decomposition, in which the ordering of variables affects the final identification results and quantitative analysis of price discovery, and may even prevent the research from reaching any clear conclusions (Huang, 2002). In view of this, some scholars have proposed solutions, such as factor decomposition based on the residual correlation matrix (Lien & Shrestha, 2009), also known as the Modified Information Share (MIS) model. However, although the MIS model can achieve unique identification of information shares, it still suffers from the problem of overly strict prerequisites: when the cointegrating relationship vector between markets does not strictly satisfy [1, -1], the MIS model cannot obtain effective estimation results.

Second, the conclusions drawn from variance decomposition based on the vector error correction model lack a dynamic perspective. The classical information share model can only produce a static information share level and cannot capture the dynamic evolution of the price discovery function (Figuerola-Ferretti et al., 2015). When capital markets exhibit dynamic characteristics due to shocks from micro-level, external macroeconomic, or natural disaster factors, existing information share indices cannot accurately describe this dynamic process. Some scholars have proposed solutions to this problem, such as dynamic price discovery measures in time-varying coefficient models (Taylor, 2011), and using high-frequency data to determine daily information shares (Christoph & Menkhoff, 2011). However, these methods have significant drawbacks: they either suffer from conditional correlation of residuals, causing measurement results to be heavily dependent on ordering, or contain large amounts of noise in high-frequency data, leading to large biases in estimation results.

Third, discussions and research on the relationship between volatility spillover and information share mostly analyze asset price volatility separately and treat volatility as a short-term indicator, ignoring its long-term effects. The traditional information share indicator ignores volatility spillover; it essentially only measures the proportion of information explained by each market, without considering the effect of information transmission (Zhong et al., 2004). In real environments, price volatility directly affects the asset price volatility of other markets through spillover effects, thereby having long-term effects on various asset prices. The existing literature does not yet have a method that distinguishes between information interpretation and information transmission, but both mechanisms are key to market price discovery and should be distinguished.

To address the problems in existing research, this paper applies the GARCH effect to the identification of the contemporaneous relationship in the VECM, reducing the arbitrariness of identification in traditional information shares. It also uses the volatility spillover manifested in the GARCH effect to construct a volatility spillover-adjusted information share index, thereby breaking through the limitation of traditional information shares that can only study information transmission at the price level. These methodological improvements help better identify the price discovery process in the stock index futures market, deepen the understanding of the price discovery process, and consequently better improve the price discovery function of the stock index futures market.

3. Information Share Index and Research Design

3.1 Traditional Information Share Index

In the traditional information share model, the dynamic price $P_t = (P_{1t}, ..., P_{nt})$ of n assets with similar characteristics can be represented by a q-order error correction model containing (n - 1) cointegrating relationships:

$$\Delta P_t = \alpha(\beta' P_{t-1} - Z) + \Gamma_1 \Delta P_{t-1} + ... + \Gamma_{t-1} \Delta P_{t-t+1} + B\mu_t \quad (1)$$

where ΔP_t is the vector of first differences of n asset prices; Z is an (n-1)-dimensional vector of constants representing the systematic price deviation of the assets; α is an $n \times (n-1)$ coefficient matrix of rank (n-1), representing the adjustment of asset prices to long-run equilibrium; β is also an $n \times (n-1)$ matrix representing the (n-1) cointegrating relationships among endogenous variables; and Γ_1 to Γ_{t-1} are $n \times n$ coefficient matrices representing short-term price dynamics. Converting Equation (1) to a moving average representation:

$$P_t = P_0 + \Psi(1)\Sigma B\mu_t + \Psi^*(L)B\mu_t \quad (2)$$

where $\Psi(1)$ is an $n \times n$ matrix. The stochastic trend $\Psi(1)\Sigma B\mu_t$ follows a random walk process, representing the cumulative result of all historical structural shocks across all asset prices, indicating the underlying price of the n assets. Since the n assets share the same underlying price, all rows of $\Psi(1)$ are the same, and $\psi' = (\psi_1, ..., \psi_n)$ can be used to represent a certain row of $\Psi(1)$. Both Equations (1) and (2) are structural models, where μ_t represents the structural shocks faced by each market. These structural shocks, after acting through contemporaneous correlations, affect each market. These effects after contemporaneous correlation are generally called "innovations." The innovations of all markets impact the underlying price (common stochastic trend).

3.2 Uniquely Identifiable Information Share Index

In a general reduced-form model, $B\mu_t$ in Equation (1) above is commonly directly denoted as ε_t, representing the residual of the reduced-form VECM model. μ_t is an n-dimensional column vector representing structural shocks to the prices of n assets, with a mean of 0 and no serial correlation. These n structural shocks are not correlated across sequences, nor within the same sequence.

The key to the full identification of Equation (1) lies in correctly identifying matrix B through $\varepsilon_t = B\mu_t$. However, since the number of variables to be estimated exceeds the number of equations, specific identification methods are required. The traditional information share index uses Cholesky decomposition, which assumes that the contemporaneous impact of asset prices is unidirectional—certain assets have contemporaneous effects on other assets but are not contemporaneously affected by shocks to other asset prices. This method effectively reduces the number of variables to be estimated and solves the identification problem, but it lacks special economic meaning, and the ordering of variables significantly affects the final results. In practice, the upper and lower bounds for each market are generally calculated using different orderings, and then the information share index is obtained by taking the average.

To address the shortcomings of the traditional information share model, this paper proposes a method for identifying matrix B based on the GARCH process, utilizing the significant heteroscedasticity and variance clustering characteristics of many financial asset price time series. This model can uniquely determine the contemporaneous relationship among price levels across markets, thereby achieving unique identification of the information share level.

Since changes in the amount of information explained by different markets cause changes in the relative shock variances, if the contemporaneous relationship among asset prices remains stable (B matrix fixed), changes in shocks lead to changes in residual correlations. This effect can be used to achieve unique and accurate identification of matrix B. Sentana and Fiorentini (2001) proved that if matrix B is of full rank and the conditional variances of shocks are linearly independent, the model can be identified by the permutation and sign changes of each column in matrix B. As long as the amount of information explained by different markets varies over time, a certain degree of identification can be achieved (Kalev et al., 2004). To achieve uniqueness of model identification, two simple assumptions are made here: first, the first row of matrix B is set to be positive, which is a commonly used assumption in standardized VAR identification. Second, it is assumed that the structural shock of any asset price has the greatest impact on its own price, and its contemporaneous impact on other asset prices is smaller than its impact on its own price. This requires that the absolute value of the diagonal elements of matrix B be greater than the other elements in their respective columns. Under these assumptions, matrix B can be uniquely identified, and the identification conditions are relatively relaxed, applicable to almost all situations, even under conditions of high asset price correlation.

3.3 Volatility Spillover-Adjusted Information Share Index

The traditional information share index decomposes the information contained in the underlying price, separating the contribution proportions of various assets to the underlying price. However, since various assets not only have price spillovers but also volatility spillover properties, and these volatility spillovers are contained in the off-diagonal elements of matrix A (GARCH coefficients) and have long-term effects, they affect the measurement of information shares.

Through the GARCH model, the volatility spillover-adjusted information share index IS has been obtained. The IS proposed in this paper is fundamentally different from the traditional information share index. The traditional information share index, because it ignores the volatility spillover effects among shocks, can only measure the proportion of basic market information that is first discovered, without considering where this basic information originally comes from. In contrast, IS measures the proportion of the original sources of this basic information. Due to differences in information quality across markets, these two price discovery models may produce significantly different results.

3.4 Regression Analysis

Based on the information share indices constructed above, this paper conducts regression analysis to comparatively study several information share indices. The comparative study mainly examines the impact of market volatility and relative market activity on price discovery capability.

4. Empirical Results and Analysis

4.1 Sample Selection

Currently, there are four stock index futures varieties in the A-share market, corresponding to the CSI 300, CSI 500, SSE 50, and CSI 1000 indices. Among these, the constituent stocks of the CSI 300 and SSE 50 have a complete inclusion relationship—the SSE 50 index consists of the 50 largest and most liquid stocks listed on the Shanghai Stock Exchange, while the CSI 300 consists of the 300 largest and most liquid stocks from both the Shanghai and Shenzhen exchanges. Since the market capitalization and liquidity of stocks on the Shanghai Stock Exchange are generally higher than those on the Shenzhen Stock Exchange, all constituent stocks of the SSE 50 are also included in the CSI 300. The CSI 300 and CSI 500 indices have a complementary relationship. The CSI 500 index consists of the top 500 stocks by market capitalization and activity after excluding the constituent stocks of the CSI 300, comprehensively reflecting medium-capitalization companies. The CSI 1000 index also has a complementary relationship with the CSI 300 and CSI 500 indices, consisting of the 1,000 most liquid stocks beyond the 800 stocks included in the CSI 300 and CSI 500 indices. The China Financial Futures Exchange launched the CSI 300 stock index futures product on April 16, 2010, followed by the SSE 50 and CSI 500 stock index futures on April 16, 2015, and the CSI 1000 stock index futures on July 22, 2022. Since the CSI 1000 index futures have been listed for a relatively short time, this paper only studies the price discovery of the main contracts of the first three stock index futures from their listing dates until October 29, 2021.

In the benchmark analysis, 5-minute data are used for estimation, selecting time periods with overlapping data from the two markets, resulting in 48 observation time points per day. The natural logarithm of market prices is taken as endogenous variables, and log differences are used to represent market returns.

Several important features can be observed. First, the standard deviations of futures are all higher than those of their respective index spot prices. Although the A-share market introduced margin trading and short selling for some stocks starting in 2010, with short selling implying the introduction of a short-selling mechanism, the actual scale of the short-selling market is relatively small, and shorting a particular stock is still very difficult. In contrast, the futures market naturally pairs long and short positions, with short selling being more convenient, leading to greater market volatility. Second, all spot indices exhibit left skewness, while all futures exhibit right skewness, and the absolute values of the left skewness are all higher than the right skewness. Since the means and medians of all varieties are close to 0, this is consistent with the random walk assumption of stock prices. The larger absolute left skewness of spot indicates a greater tail probability of large instantaneous price declines in the spot market, while the probability of instantaneous price declines in the futures market is much smaller. Third, the standard deviations of the SSE 50 and CSI 300 are essentially the same, while the CSI 500 has the largest standard deviation. This reflects the characteristic of greater market volatility for small and mid-cap stocks in the A-share market.

4.2 Testing the Lead-Lag Relationship Between Futures and Spot

According to Equation (1), the cointegrating relationship and vector error correction model are first estimated. The ADF test of the VECM shows that both price series are I(1) processes. The Johansen trace test shows that the spot and futures prices of all three indices have a cointegrating relationship, and the LR test cannot reject the theoretical cointegrating relationship $\beta' = (1, -1)$. In the long run, the adjustment coefficients of futures and spot to the ECM term are all significant at the 1% level, with signs in the expected direction, indicating that the error correction term has explanatory power for both. When the system deviates from the equilibrium state, both futures and spot prices show price adjustments, converging toward the equilibrium state. This conclusion differs slightly from the findings of Yang et al. (2012) and Xu and Liu (2019), where in their studies, futures prices in the error correction model did not adjust to the long-run equilibrium deviation between futures and spot prices. The main reason for the different conclusion is that this paper has a longer sample period, especially including the period when futures market trading volume declined substantially in recent years, and the new information from the futures market in price discovery has decreased, while the spot market's influence on futures has been increasing. The dynamic analysis later in the paper will further validate this view. In the short run, both futures and spot price changes are affected by the lagged price changes of the other market, indicating that both futures and spot price changes are Granger causes of each other's price changes, and both have certain price discovery functions.

4.3 Identification of the Structural Model

The core purpose of this paper is to achieve unique identification of the information share index through the conditional heteroscedasticity process. The most critical condition is that the variance ratio of the spot and futures residuals in the error correction model is constantly changing. The empirical process uses the GARCH(1,1) model to preliminarily estimate the conditional variance process of the residuals and calculates the ratio of the conditional variances of the two series. Significant conditional heteroscedasticity is found, allowing the structural GARCH model to be used for identification of the error correction model.

To further test the robustness of the results, this paper also tests the ARCH effects of the standardized shocks and standardized residuals in the model, and the results all reject the existence of ARCH effects. The diagonal elements of matrix A for all three indices are greater than 0, and the off-diagonal elements are all less than 0, indicating that the contemporaneous influences between spot and futures are positive in direction, consistent with the assumptions. Regarding the estimation results of the GARCH effects, the focus is on the two off-diagonal elements A_{12} and A_{21} of matrix A, which represent the volatility spillover from index spot to futures and from futures to spot, respectively.

4.4 Information Share Index

Based on the above estimation results, the uniquely identified information share index and the volatility spillover-adjusted information share index are calculated for the three stock index futures varieties. For better comparison with the traditional information share index, the lower bound, upper bound, and mean of the information share based on Cholesky decomposition are also calculated for the traditional index.

First, the lower and upper bounds of the information share index based on Cholesky decomposition differ greatly, and the estimation results are affected by the setting of the contemporaneous relationship between futures and spot prices. If it is assumed that futures prices in the contemporaneous period do not affect spot prices, and only the influence of spot on futures prices exists, the information share of futures is very low—only 20.5%, 19.0%, and 21.3% for the three index futures. Under the opposite assumption, where futures prices affect spot prices but spot prices do not affect contemporaneous futures prices, the information shares of the three index futures reach 78.3%, 67.4%, and 80.2%, respectively. The averages of the upper and lower bounds of the traditional futures information share index are 49.4%, 43.2%, and 50.8%, with the CSI 300 and CSI 500 information shares slightly lower and the SSE 50 spot information share slightly lower. All three averages are close to 50%, not revealing much rich information about the price discovery of futures and spot markets.

Second, the uniquely identified information share index based on GARCH proposed in this paper fully considers the contemporaneous price interaction information among markets contained in matrix A where off-diagonal elements are non-zero, thereby having better economic meaning. Table 4 shows that the results for CSI 300 and SSE 50 are relatively close, with the futures market contributing approximately 45% to the underlying price and the spot market contributing the remaining 55%. The information share of CSI 500 futures is lower, at only 38.59%. This suggests that the spot market has a stronger price discovery function, indicating that the spot market has more information and thus demonstrates a more effective market pricing mechanism.

Third, considering that futures price volatility has more volatility spillover to the spot market through the GARCH effect, the results show that the information share of futures is higher.

The volatility spillover-adjusted information shares of the futures market obtained in this paper are all above 50%, with the highest being CSI 500 futures at 68.09% and the lowest being SSE 50 index futures at 61.58%. This result indicates that the futures market has a greater price discovery function, consistent with other global markets. The volatility spillover-adjusted information share of futures being greater than 50% also indicates that the main source of the underlying asset price is the "own" variance of the futures market, i.e., the futures market has more original information.

The above two indices yield diametrically opposite conclusions, suggesting that the true price discovery process may be a very complex pattern. This is mainly manifested in three aspects: First, because the futures market has a short-selling mechanism, more information initially appears and is transmitted here. Second, because futures information is mixed with more noise, the futures information absorbed by the spot market may lack accuracy due to partial noise contamination. Third, to improve information accuracy, the spot market reinterprets information from the futures market rather than simply following its price changes. Accordingly, the effective price is mainly based on the spot market's interpretation of information, which includes both information "discovered" by the spot market itself and information flowing in from futures market volatility spillovers that has been reinterpreted. Therefore, the spot market has a higher information share. Due to the greater noise in the futures market, when price differences exist between the two markets, the futures price with more noise moves toward the spot market price with less noise, which is more "correct." Overall, because the futures market has fewer trading restrictions, it has dual effects. On the one hand, it facilitates information discovery, making the price discovery speed of the futures market faster. On the other hand, it also brings more noise to the futures market, making the information interpretation and prices in the futures market less accurate, thereby reducing the information share of the futures market. Accordingly, when the two market prices show a long-term deviation trend, it is more likely that futures prices adjust to the effective spot prices.

Comparing the three indices, CSI 300 and SSE 50 have more similar characteristics. This is because these two indices have an inclusion relationship, and the constituent stocks of the SSE 50 index have the largest weight in the CSI 300 index, dominating its basic trend. The CSI 500 index, however, differs substantially from the former two, reflecting the stock price performance of medium-capitalization listed companies in China. Compared with the former two, the price discovery function of CSI 500 index futures is weaker, and the spot market contributes a greater proportion to the underlying price. However, the volatility spillover-adjusted information share index of CSI 500 futures is larger than the former two, indicating that CSI 500 index futures have greater volatility, and the volatility contains more information, though a large portion of this information is noise that needs to be reinterpreted by the spot market.

4.5 Dynamic Information Share Index

To make the dynamic characteristics of the three information share indices clearer for attribution analysis of index changes, this paper calculates the dynamic information shares of the three indices on a daily basis: the research sample is changed to 1-minute data, yielding 240 overlapping time points between futures and spot per day, and the information share index for each trading day is calculated using this sample. Figure 1 shows the information shares of the three index futures. Since the daily information share index fluctuates greatly, the 60-day moving average of the futures information share is shown in the figure. During the sample period, China's futures market experienced two major adjustments: the tightening of trading restrictions on July 8, 2015, and the relaxation of trading restrictions on February 17, 2017. These time points are marked with vertical dashed lines in the figure.

For most of the time, the information shares of the futures markets for all three stock indices are less than 50%, while the volatility spillover-adjusted information shares are all greater than 50%. This further validates the earlier conclusion that, overall, the spot market has a stronger price discovery function for stock indices. However, the volatility of the futures market index contains richer original information, though this information contains more noise and needs to be reinterpreted by the spot market. Looking at the CSI 300 index, after the imposition of stricter trading restrictions on the futures market in 2015, the information share of the futures market declined significantly, then gradually increased after a brief market adjustment. Meanwhile, the volatility spillover-adjusted information share initially increased after the stronger trading restrictions before beginning to decline. A possible explanation is that since the trading restrictions on stock index futures in July 2015 occurred precisely during a period of substantial stock market volatility, the unique short-selling mechanism of the futures market provided opportunities for some investors to gain profits through shorting the index, making the volatility information embedded in the futures market stronger, with new information first reflected in the futures market. Since the effects of the trading restrictions on the futures market materialized slowly, the information share of futures continued to rise until the end of 2015 before beginning to decline. Regarding the effects of relaxing trading restrictions on stock index futures in 2017, the three indices performed similarly, with the information share of futures rising after the relaxation, but the volatility-adjusted information share still generally in a declining trend. This paper predicts that as market trading becomes more standardized, overall market volatility will decrease, and the proportion of noise contained in the futures market will also decrease. Therefore, the volatility-adjusted information share index will gradually regress toward the traditional information share index.

5. Conclusions and Implications

The volatility-based information share model constructed in this paper can determine the contemporaneous relationship among price levels across markets through an intuitive and universally applicable identification method, achieving uniqueness in the identification of the information share index, thereby overcoming the limitation of the traditional information share model that cannot achieve unique identification. This paper also proposes a volatility spillover-adjusted information share index to measure the proportion of information in the underlying price that originates in each market. The traditional information share measures how each market's interpretation of information forms the effective price, while the volatility spillover-adjusted information share measures how much of the effective price information is first transmitted in a particular market. This is a supplement to the traditional method, providing another perspective to help deepen the understanding of the price discovery process.

In the empirical analysis section, this paper studies the price discovery of three index futures in the A-share market, with three main conclusions. First, the price discovery process exhibits a relatively complex pattern: the futures market has a greater advantage in rapidly discovering new information but is also more susceptible to noise contamination, while a larger proportion of the information share of the underlying price comes from the spot market's interpretation. When the two prices are in a long-term deviation trend, the futures market price is more likely to adjust toward the spot market price. Second, the constraints on futures market trading that began in 2015 overall reduced the information share of the futures market, especially the contribution proportion of all new information, and the contribution of noise in futures market information to the underlying price correspondingly declined. Although restrictions on stock index futures trading began to be relaxed in 2017, this trend did not change. Third, contrary to the conclusions of most previous literature, this paper finds that increased market volatility enhances the price discovery capability of the futures market. Informed investors may be more inclined to use leveraged trading and long-short trading instruments in the futures market to obtain excess returns. Increased activity in the futures market also contributes to enhancing its price discovery capability.

The research conclusions of this paper have the following implications for China's further effective management of the futures market:

First, as an early-emerging on-exchange financial derivative, the stock index futures market has advantages in rapidly discovering new information. Its existence is a great supplement and enrichment to the stock market function and an important component of financial infrastructure. However, the current trading scale of the stock index futures market is far smaller than that of the spot market, making it unable to fully play its role in market price discovery. Given the key role of the futures market and its value in price discovery in the price market, efforts should be made in the future, on the basis of doing a good job in financial market risk prevention and control, to collaboratively promote the enrichment of stock index futures trading varieties, the improvement of trading rules, the establishment of investor protection systems, and innovation in regulatory measures, so as to promote the development of the stock index futures market.

Second, in the price discovery process, there exists a complex linkage between the futures market and the spot market. Therefore, to fully leverage the role of the futures market in price discovery, the cross-linkage effects among different financial markets need to be considered from a holistic perspective. The development of stock index futures needs to be viewed from an overall perspective, with dynamic adjustments made in a timely manner based on the external environment and market reactions. At the same time, sufficient buffer room should be reserved for financial regulatory authorities, allowing the stock index futures market to achieve long-term healthy development under the premise of overall controllable risk.

Third, from the current perspective, the spot market is more effective in interpreting information. The reason is that the long-term stable funding source and sufficient market trading in the spot market can effectively reduce noise in the spot market. After the 2015 stock market crash, China's futures market increased trading restrictions, substantially raising transaction costs. Due to excessively high transaction costs, long-term stable funds in the stock index futures market declined, and the proportion of professional institutional investors decreased, thereby affecting the price discovery capability of the stock index futures market. In the long run, trading restrictions on China's futures market should be further reduced. By increasing the proportion of professional investors and reducing noise in the futures market, its price discovery capability can be improved, ultimately forming professional strength in price discovery.

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