Price Discovery and Volatility Spillover Effect in Treasury Bond Futures and Spot Markets: Evidence from China

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Abstract. There is an increasing attention on dynamic relationship between treasury bond futures and spot markets in China. This study investigates price discovery and volatility spillover effect for treasury bond futures and spot markets in China by using 5 minutes high frequency data after China 5-year treasury bond futures trading. The estimation results suggest that, treasury bond futures plays an important role in price discovery function. Then, the results further confirm that treasury bond futures and spot markets exist volatility cluster. Meanwhile, we also find that the volatility spillover effect of treasury bond futures market to spot market is stronger than spot market to treasury bond futures market.

1. Introduction

Treasury bond futures have undergone major institutional evolution since they were first originated in the United States in the 1970s. Generally, treasury bond futures plays two important roles in financial market: one is hedging function, the other is price discovery function. China treasury bond futures trading was first launched at Shanghai Stock Exchange (SSR) in December 1992. However, as to the influence of incomplete market system, successive violation incidents occurred in February 1995 and May 1995, which were called “327” event and “319” event, and then, China Securities Regulatory Commission (CSRC) decided to suspend treasury bond futures trading in the national scope.

As the development of treasury spot market, the rising of market risk aversion demand and the increasing maturity of commodities futures market, China Financial Futures Exchange (CFFE) launched treasury bond futures emulation trading on February 13, 2012, and restarted treasury bond futures trading ultimately on September 6, 2013. Currently, there are two kinds of treasury bond futures in China: 5-year and 10-year treasury bond futures. Until December 2015, China 5-year treasury bond futures trading volume is 4.7568 million hand, 10-year treasury bond futures trading volume is 1.0535 million hand, which mean 5-year treasury bond futures trading volume occupies the main part of treasury bond futures market.

Many studies have examined the dynamic relationship between futures and spot markets using empirical analysis method, with mixed results. So far, most literatures focus on price discovery of futures. Early studies such as Abhyankar (1995) claimed that information can be transferred through futures and spot markets, and futures price has guidance function on spot market. In recent years, there are studies examine volatility spillover effect of futures and spot markets (Sun et al. 2015; Valseth
Therefore, related literature review on relationship between futures and spot markets is mainly discussed from two aspects.

For a long time, much research has focused on the long-term equilibrium and mutual relationship between futures and spot prices by cointegration test and causality test. If there is cointegration relationship between futures price and spot price, related studies further analyze adjustment speed, response speed and explanation degree when futures and spot prices deviate from equilibrium by using vector autoregressive (VAR) model, VEC model, variance decomposition and impulse response. Garbade and LSilber (1983) tested the relationship between spot and futures prices for seven commodities by a partial equilibrium model. Since then, Baillie et al. (2002) and Hasbrouck (2000) studied IS model and presented quantitative method of price discovery. In addition, many scholars have also done a lot of work on financial futures, which perfected the long-term equilibrium relationship research of financial futures and spot prices (Kayali and Celik, 2010).

In recent years, based on intra-day trading data, Jiang and Lo (2014) studied price discovery ability of treasury spot market. Dolatabadi, Nielsen and Xu (2014) developed a fractionally cointegrated vector autoregressive (FCVAR) model to examine price discovery, with the authors showing how CVAR and FCVAR links price discovery and price predictability. Through Granger causality testing, Frijns et al. (2015) found that low price and high trading activity relatively can increase factor contribution of price discovery using United States and Canada stock data from 1996 to 2011. Based on stock index futures and spot data from June 12, 2000 to September 30, 2013, Paul and Kimatta (2015) used ARCH model and GARCH model to measure the relationship of futures and spot volatility, which found that GARCH model is significant.

According to related research results in the current literature and the development situation of China treasury bond futures, this paper studies the long-term equilibrium relationship between China treasury bond futures and spot markets using VEC model. Then, we employ BEKK-GRACH model to reveal volatility spillover effect between both two markets, which further enrich dynamic relationship research of Chinese treasury futures and spot markets.

2. Data and methodology

2.1. Data sources

Using 5 minutes high frequency data after China 5-year treasury bond futures trading from May 18, 2015 to July 18, 2015, we estimate price discovery and volatility spillover effect between China treasury bond futures and spot markets. Our data are collected from Wind database. China treasury bond futures price uses contract data, including TF1312, TF1403, TF1406, TF1409, TF1412, TF1503, TF1506, TF1509 and TF1412. Spot price data uses 5 minutes closing price of Cathay Pacific ETF, because of Cathay Pacific ETF is not only the earliest and most traded treasury ETF in domestic market, but also a substitute of spot in hedging and arbitrage strategy. As opening time of treasury bond futures is 15 minutes ahead of Cathay Pacific ETF, closing time is 15 minutes behind Cathay Pacific ETF, this paper uses futures and spot transaction data at the same time, namely the time period is from 9:30 am to 11:30 am, 13:00 pm to 15:00 pm.

2.2. Methodology

2.2.1. Vector Error Correction (VEC) model. Feldstein and Stock pointed out that, if there is a cointegration relationship between futures price and spot price, VEC model can be used to study mutual relationship between futures and spot markets. The expression for VEC model is:

$$
\Delta \ln S_t = \beta_{s,0} + \gamma_s e_{t-1} + \sum_{i=1}^{p} \beta_{ss,i} \Delta \ln S_{t-i} + \sum_{i=1}^{p} \beta_{sf,i} \Delta \ln F_{t-i} + \epsilon_{s,t}
$$

(1)
\[ \Delta \ln F_t = \beta_{f,0} + \gamma_f e_{t-1} + \sum_{i=1}^{p} \beta_{f,i} \Delta \ln S_{t-i} + \sum_{i=1}^{p} \beta_{ff,i} \Delta \ln F_{t-i} + \varepsilon_{f,t} \]  \hspace{1cm} (2)

Where \( \Delta \ln F_t \) and \( \Delta \ln S_t \) denote futures price and spot price, respectively; \( \beta_i \) and \( \gamma_f \) are constant; \( e_{t-1} \) is error correction term; \( \beta_{f,s}, \beta_{f,f}, \beta_{s,f}, \text{ and } \beta_{f,f} \) are used to measure short-term causality relationship; \( \gamma_s \) and \( \gamma_f \) are used to measure long-term causality relationship; \( \varepsilon_s \) and \( \varepsilon_f \) are residual term.

2.2.2. Price discovery measurement. VEC model can explain mutual relationship between futures and spot markets, but the main purpose of causality relation is to confirm influence direction. Common factor in PT model refers to linear combination of futures and spot prices, so contribution degree of common factor for each market can be measured by weight. According to PT model, the proportion of price discovery between futures and spot markets are \( \theta_f \) and \( \theta_s \), respectively. The equations of \( \theta_f \) and \( \theta_s \) are given by:

\[ \theta_f = \frac{\gamma_s}{\gamma_s - \gamma_f}, \theta_s = \frac{-\gamma_f}{\gamma_s - \gamma_f} \]  \hspace{1cm} (3)

2.2.3. Volatility spillover effect model. Single-variable GRACH model can reflect temporal characteristics of single market volatility, but it cannot inspect mutual influence between two markets. BEKK-GRACH model can ensure that covariance matrix is positive definite. Therefore, this paper uses BEKK-GRACH model to depict GRACH model. BEKK-GRACH model is as follows:

\[ H_t = C' C + B' H_{t-1} B + A' \varepsilon_{t-1} \varepsilon_{t-1}' A \]  \hspace{1cm} (4)

Where \( H_t \) is conditional variance-covariance matrix; \( C \) is upper triangular matrix. BEKK-GRACH model can ensure that covariance matrix is positive definite if \( C'C \) is positive definite.

3. Empirical results

3.1. Price discovery between treasury bond futures and spot markets

3.1.1. Cointegration test. The results for cointegration testing are shown in Table 1. From Tables 1, the results show clearly that the residual et is stationary and the cointegration relation is valid between treasury bond futures and spot prices. Therefore, it means that we can proceed to VEC model test.

| Contracts | t-statistics | 1% level | 5% level | 10% level | p-Value | Conclusions |
|-----------|--------------|----------|----------|-----------|---------|-------------|
| TF1312    | -59.784840   | -3.961724| -3.411610| -3.127675| 0.000000| stationarity|
| TF1403    | -41.126620   | -3.961461| -3.411481| -3.127599| 0.000000| stationarity|
| TF1406    | -29.038620   | -3.961526| -3.411513| -3.127618| 0.000000| stationarity|
| TF1409    | -42.965370   | -3.961032| -3.411271| -3.127474| 0.000000| stationarity|
| TF1412    | -59.324370   | -3.961727| -3.411611| -3.127676| 0.000000| stationarity|
| TF1503    | -60.258950   | -3.960985| -3.411248| -3.127461| 0.000000| stationarity|
| TF1506    | -66.297970   | -3.960942| -3.411227| -3.127448| 0.000000| stationarity|
| TF1509    | -61.960770   | -3.960942| -3.411227| -3.127448| 0.000000| stationarity|
| TF1512    | -60.258950   | -3.961078| -3.411294| -3.127488| 0.000000| stationarity|

3.1.2. Price discovery estimation. The results are reported in Table 2. For treasury bond futures market, the coefficients on first-order and second-order lagged term of futures market under TF1312 construct are -0.278238 and -0.132644, respectively, which are significant at the 0.05 significance level. Meanwhile, the lagged term coefficients of spot market are significant at the 0.05 significance level,
meaning that no matter what viewing from long-term or from short-term, spot price has an influence on treasury bond futures price, namely spot price is Granger causality of treasury bond futures price. Furthermore, for spot market, the coefficients on first-order and second-order lagged term of futures market are both significant at the 0.05 significance level. Thus, treasury bond futures price is Granger causality of spot price no matter we see from long-term or from short-term. The results also indicate that there is a bidirectional relationship between China treasury bond futures and spot markets, and both markets have price discovery function.

Table 2. Granger causality test of treasury bond futures and spot markets based on VEC model

| Contracts | Variables | $e_{t-1}$ | $\Delta \ln F_{t-1}$ | $\Delta \ln F_{t-2}$ | $\Delta \ln S_{t-1}$ | $\Delta \ln S_{t-2}$ | $c$ |
|-----------|-----------|-----------|----------------|----------------|----------------|----------------|-----|
| TF1312    | $\Delta \ln F_t$ | -0.254495** | -0.419762** | -0.208799** | -0.278238** | -0.132644** | 0.0000003*** |
|           |           | (-7.037590) | (-12.744800) | (-8.535910) | (-7.480510) | (-5.433790) | (0.046050) |
|           | $\Delta \ln S_t$ | 0.741376** | -0.348332** | -0.179013** | -0.181595** | -0.117377** | 0.0000004*** |
|           |           | (22.057800) | (-11.378900) | (-7.873820) | (-5.252900) | (-5.173390) | (0.055250) |
| TF1403    | $\Delta \ln F_t$ | -0.519605** | -0.329430** | -0.136916** | -0.377032** | -0.194348** | 0.0000001*** |
|           |           | (-15.920700) | (-11.378700) | (-6.497400) | (-13.386600) | (-9.746090) | (0.015470) |
|           | $\Delta \ln S_t$ | 0.712980** | -0.406611** | -0.171805** | -0.228181** | -0.162595** | 0.0000002*** |
|           |           | (22.245500) | (-14.284600) | (-8.302700) | (-8.251050) | (-8.302970) | (0.029280) |
| TF1406    | $\Delta \ln F_t$ | -0.401170** | -0.407544** | -0.155458** | -0.267634** | -0.223120** | 0.0000001*** |
|           |           | (-13.281200) | (-14.649500) | (-7.195790) | (-11.623600) | (-7.796920) | (-0.08910) |
|           | $\Delta \ln S_t$ | 0.749734** | -0.549373** | -0.267634** | -0.223120** | -0.091328** | 0.0000000*** |
|           |           | (20.103900) | (-15.993800) | (-10.033200) | (-7.844130) | (-4.321670) | (0.016130) |
| TF1409    | $\Delta \ln F_t$ | -0.290081** | -0.408485** | -0.231978** | -0.278593** | -0.154404** | 0.0000001*** |
|           |           | (-12.772000) | (-19.177000) | (-11.419500) | (-11.677600) | (-9.747520) | (-0.021080) |
|           | $\Delta \ln S_t$ | 0.777538** | -0.449133** | -0.224866** | -0.195157** | -0.097592** | -0.0000003*** |
|           |           | (26.992100) | (-14.703200) | (-9.079460) | (-6.797100) | (-5.053410) | (-0.04901) |
| TF1503    | $\Delta \ln F_t$ | -0.451507** | -0.329495** | -0.198897** | -0.385433** | -0.157205** | 0.0000000*** |
|           |           | (-12.924500) | (-11.498900) | (-9.281180) | (-11.304100) | (-6.702000) | (-0.04600) |
|           | $\Delta \ln S_t$ | 0.661401** | -0.367682** | -0.183008** | -0.239177** | -0.088956** | 0.0000000*** |
|           |           | (21.529700) | (-14.017700) | (-9.711200) | (-7.910510) | (-4.312580) | (-0.00405) |
| TF1506    | $\Delta \ln F_t$ | -0.171376** | -0.610363** | -0.290301** | -0.241113** | -0.145389** | 0.0000002*** |
|           |           | (-9.577630) | (-29.074200) | (-16.581100) | (-7.428940) | (-6.797220) | (0.019530) |
|           | $\Delta \ln S_t$ | 0.457854** | -0.237932** | -0.135660** | -0.064938** | -0.089519** | 0.0000000*** |
|           |           | (30.533100) | (-13.552500) | (-9.179040) | (-2.392510) | (-5.045100) | (0.00290) |
| TF1509    | $\Delta \ln F_t$ | -0.012226** | -0.701812** | -0.329810** | -0.071200** | -0.025234** | 0.0000001*** |
|           |           | (-2.389390) | (-40.812600) | (-19.531800) | (-2.717460) | (-1.559330) | (0.00880) |
|           | $\Delta \ln S_t$ | 0.218870** | -0.118871** | -0.058365** | 0.158893** | 0.064447** | 0.0000000*** |
|           |           | (39.083000) | (-6.316230) | (-3.158170) | (5.541090) | (3.638770) | (0.00305) |
| TF1512    | $\Delta \ln F_t$ | -0.033725** | -0.665078** | -0.343793** | -0.067070** | -0.045004** | 0.0000001*** |
|           |           | (-2.754750) | (-33.999400) | (-19.313400) | (-2.629800) | (-2.528340) | (0.009910) |
In addition, we see that most of the effects of $\Delta \ln F_{t-1}$ and $\Delta \ln F_{t-2}$ on $\Delta \ln S_t$ are larger than the effect of $\Delta \ln S_{t-1}$ and $\Delta \ln S_{t-2}$ on $\Delta \ln F_t$ by the coefficients of $\Delta \ln F_{t-1}$, $\Delta \ln F_{t-2}$, $\Delta \ln S_{t-1}$ and $\Delta \ln S_{t-2}$. Furthermore, we calculate price contribution degree of both markets by using Ganzolo and Granger (1995). Table 3 shows that the contribution degree of China 5-year treasury bond futures market is higher than spot market’s contribution, that is, treasury bond futures plays an important role in price discovery function.

3.2. Volatility spillover effect between treasury bond futures and spot markets

By using BEKK-GRACH model, this paper estimate volatility spillover effect in treasury bond futures and spot markets. Matrix A and B denote the estimation coefficients of ARCH term and GARCH term, respectively. Based on the estimation values of BEKK-GRACH model in Table 4, most diagonal elements of covariance matrix and residual matrix are significant at the 0.01 significance level, meaning that treasury bond futures and spot markets exist volatility cluster. Most estimation values of $a_{12}$ and $b_{12}$ are statistically significant at the 1% level, which indicates that the volatility from treasury bond futures market has a significant impact on spot market. Similarly, Table 4 also the volatility from spot market has a significant impact on treasury bond futures market according to the values of $a_{21}$ and $b_{21}$. However, in most cases, the values of $a_{12}$ and $b_{12}$ are larger than the values of $a_{21}$ and $b_{21}$. 

### Table 3. Contribution degree of price discovery between treasury bond futures and spot markets

| Contracts | $\gamma_f$ | $\gamma_s$ | $\theta_f$ | $\theta_s$ |
|-----------|------------|------------|-----------|-----------|
| TF1312    | -0.254495  | 0.741376   | 74.44%    | 25.56%    |
| TF1403    | -0.519605  | 0.712980   | 57.84%    | 42.16%    |
| TF1406    | -0.401170  | 0.749734   | 65.14%    | 34.86%    |
| TF1409    | -0.495479  | 0.706481   | 58.78%    | 41.22%    |
| TF1412    | -0.290081  | 0.775538   | 72.83%    | 27.17%    |
| TF1503    | -0.451507  | 0.661401   | 59.43%    | 40.57%    |
| TF1506    | -0.171736  | 0.457854   | 72.72%    | 27.28%    |
| TF1509    | -0.012226  | 0.218870   | 94.71%    | 5.29%     |
| TF1512    | -0.033725  | 0.450043   | 93.03%    | 6.97%     |

### Table 4. Estimation results of BEKK-GRACH model

| Contracts | $c_{12}$ | $c_{21}$ | $c_{22}$ | $b_{11}$ | $b_{12}$ | $b_{21}$ | $b_{22}$ | $a_{11}$ | $a_{12}$ | $a_{21}$ | $a_{22}$ |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| TF1312    | 0.000025*** | 0.000011*** | 0.000035*** | 0.633740*** | 0.308937*** | 0.164076*** |
| TF1403    | 0.000065*** | 0.000010*** | 0.000000   | 0.443219*** | 0.226055*** | -0.152407*** |
| TF1406    | 0.000046*** | 0.000016*** | 0.000030*** | 0.526158*** | 0.014999   | -0.096810*** |
| TF1409    | 0.000025*** | 0.000014*** | 0.000021*** | 0.850733*** | -0.078163*** | 0.002348   |
| TF1412    | 0.000023*** | 0.000002*** | 0.000000   | 0.848281*** | -0.088378*** | 0.007647*** |
| TF1503    | 0.000036*** | 0.000012*** | 0.000000   | 0.889874*** | 0.089508*** | 0.077072*** |
| TF1506    | 0.000046*** | 0.000016*** | 0.000000   | 0.851289*** | 0.134191*** | -0.000848   |
| TF1509    | 0.000006*** | 0.000008*** | 0.000030*** | 0.993402*** | 0.029938*** | 0.011110*** |
| TF1512    | 0.000051*** | 0.000011*** | 0.000049*** | 0.596956*  | 0.068487   | 0.071396   |
| TF1312    | 0.518351*** | 0.594400*** | -0.037548*** | -0.006428  | 0.656015*** |
| TF1403    | 0.813700*** | 0.054102*** | -0.077966*** | 0.081332*** | 0.505823*** |
| TF1406    | 0.534409*** | 0.008740   | -0.391117*** | 0.187553*** | 0.824752*** |
| TF1409    | 0.732316*** | 0.216638*** | -0.073864*** | 0.005738   | 0.623460*** |
TF1412  0.798382***  0.456937*** -0.027615***  0.001355  0.898930** *
TF1503  0.808744***  0.184888*** -0.213935***  0.046928***  0.546927***
TF1506  0.707461***  0.118535*** -0.125020***  0.065242***  0.900552***
TF1509  0.744470***  0.101945*** -0.324692*** -0.028255***  0.802580***
TF1512  0.632506***  0.179721***  0.039125*** -0.013801  0.428815** *

4. Conclusions
Based on 5 minutes high frequency data after China 5-year treasury bond futures trading, this study shows clearly that the residual term is stationary, which illustrates the cointegration relation is valid between treasury bond futures and spot prices. Second, there is a bidirectional relationship between China treasury bond futures and spot markets, and both markets have price discovery function. However, treasury bond futures plays an important role in price discovery function. Finally, there exists volatility cluster between treasury bond futures and spot markets, and volatility spillover effect of treasury bond futures market to spot market is stronger than spot market to treasury bond futures market.

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