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Abstract

The first modern futures market is said to date back to the Chicago Board of Trade established in 1848. However, there existed an older precedent; the Dojima Rice Market established in 1730 in Osaka. The past literature on Dojima has made it clear that Dojima had well-established trading systems. However, a important question remains unanswered: whether the first well-established futures market efficient or not? This paper first constructs the daily price index from the original historical document, and applies the test of unbiasedness hypothesis and the classic measure of market efficiency; "weak-form efficiency" to Dojima Rice Market, and shows that there existed these types of efficiency.

JEL Classification: G14, L11, N25
Key Words: Tokugawa Period Japan, Futures Market, Informational Efficiency

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I. Introduction

The first modern futures market is said to date back to the Chicago Board of Trade established in 1848. However, there existed an older precedent; the Dojima Rice Market established in 1730 in Osaka, and closed in 1869 due to the collapse of Tokugawa Shogunate. Many works on the Dojima rice market (henceforth referred to as Dojima) have been published in Japan during the past 70 years. The past literature on Dojima has made it clear that Dojima had well-established trading systems. However, a important question remains unanswered: whether the world first well-established futures market of Dojima efficient or not? Whether the efficient market indeed existed or not is still to be inquired with empirically verifying the efficiency of Dojima.

Actually, Ito (1993) and Wakita (2001) had examined the efficiency of Dojima by applying the test of the unbiasedness hypothesis (UBH) to Dojima. Ito (1993) concluded that, from 1763 to 1780, Dojima failed to satisfy the unbiasedness condition, and that Dojima was not the efficient market. On the other hand, Wakita (2001) applied the same test to each month of the year from 1760 to 1864, and concluded that the UBH cannot be rejected for at least six months of the year, while he rejected the hypothesis for all months when applied to the year from 1830 to 1864. These previous analyses indicate that Dojima should probably be recognized as inefficient or marginally efficient market—the first well-established market in the world might not have offered competitive trade opportunities.

These two pioneering literature shed light on the quantitative aspects of Dojima by econometric instruments. However, we can not necessarily conclude that Dojima was inefficient or marginally efficient. For instance, there was a contemporary witness to Dojima's efficiency;

> Futures trades' virtue lies in the fact that it is, unlike spot trades, robust against temporal economic shocks. Hence, it naturally allows traders to freely pursue their own benefits, and it would be unaffected by hoarding or dumping. Rather, prices are fixed on the basis of the interaction of among all traders' intention. In particular, the price fixed in this system is much less biased than those fixed in the spot market. The price at the futures market is a mirror of the economic conditions of local regions, from which we can know their general economic circumstances[1].

This description was presumably written in late 18th century or later, the period covered by Ito (1993) and Wakita (2001). According to the description quoted above, the futures prices at Dojima were regarded as more informative than the spot prices. In other words, the traders in Dojima at that time considered its unbiasedness and thus its virtue of the futures trades.

The purpose of this paper is to consider the difference of the understandings between Ito (1993) and Wakita (2001), and the contemporary observation. Owing the empirical framework to these two previous works, this paper deal with three points: we should (i) construct the daily price index from the original historical document, and (ii) reexamine the

[1] "Rosei-hiroku", cited by Shimamoto, ed (1970), p10

UBH in Dojima, and (iii) employ the classic measure of market efficiency proposed by Fama (1970) to capture the efficiency of Dojima.

The daily price index is necessary because the existing monthly or yearly price indices are not suitable for the purpose of this paper, especially in terms of the frequency and the length of the period covered. The price index on which Ito (1993) relied covers the period from 1763 to 1780. As Ito himself recognized, the period covered here is only a fraction of the whole history of Dojima. On the other hand, the monthly price index presented by Tsuruoka (1972) (henceforth referred to as Tsuruoka Index), on which Wakita (2001) relied, covers the sufficiently long period. However, this price index contains considerable number of wrong figures, and the prices in the period from 1819 to 1827 are not the prices at Dojima, but at another market.

Hence, the conclusions reached by Ito (1993) and Wakita (2001) could have been affected by the problem with these price indices, and can not be considered to represent the efficiency of Dojima appropriately. Hence, we should construct the sufficiently long, reliable, and high-frequency price index, and reexamine the UBH in Dojima. Based on newly constructed price index, this paper shows that Dojima satisfied the unbiasedness conditions in the period from 1798 to 1835.

Finally examined is the classic measure of market efficiency, which was proposed by Fama (1970). One of these criteria is "weak-form efficiency[2]." This paper applies this criterion both to the spot and the futures market, and shows that both markets had this type of efficiency.

The structure of this paper is as follows. Section II introduces the institutional aspects of Dojima, which serves as background for subsequent discussions. Section III reviews the daily price index which was newly constructed, and reexamines the UBH in Dojima. Section IV lays out the model for capturing the weak-form efficiency, and presents an empirical analysis, followed by the concluding remarks.

II. Institutional Aspects of Dojima

Trades in Dojima

This subsection provides a minimum background that is necessary for subsequent analysis[3].

In the Tokugawa era, feudal lords collected the rice in kind as tax, and shipped it to the market (mainly Osaka) for financing their local government budget. They stored the rice in their warehouses and sold at the auction where officially authorized rice brokers bid. Rice brokers who made a successful bid received the rice bills which, per unit, was worth 1500kg real rice stored in the warehouses[4]. The rice brokers in principle could have submitted their rice bills to the warehouse and received real rice in exchange. However, they mainly sold the bills in the secondary market; the Dojima rice market. Thus, the spot market at Dojima should be regarded as the exchange market of rice bills, not of real rice.

[2]A more detailed definition of this criterion is described in section IV.

[3]See Miyamoto (1988) and Schaede (1989) for further institutional descriptions of Dojima.

[4]In the late 17th century, each rice bill corresponded to a particular set of rice that the broker won at the auction. In late times, this correspondence gradually collapsed and rice bills came to take on the character of securities. See, Shimamoto (1960).

In this spot market, the rice bills were required to be delivered in exchange for cash within four days after the transaction. Because of this shortness in delivery time, the spot market was regarded as the market for real demand, not for speculation. While the traders who could join in the market were limited to officially authorized rice brokers, anybody who paid some amount of fee to the authorized traders could join in the market. However, more traders joined in the futures market which was useful for speculation.

In Dojima, there were about 30 kinds of rice bills issued by feudal lords' warehouses, and the traders' association choose one rice bill among those 30 rice bills as the standard rice. This standard rice was exactly the underlying asset for futures trade. Like the spot market, the traders in this market were formally limited to officially authorized members. However, any traders could actually join the market by paying a little amount of fee to the authorized traders. The fee associated with the futures trades was less than that of the spot trades. In addition, amount of cash needed in the futures market was relatively smaller than that in the spot market. These features of the futures market had attracted many traders, especially speculators.

In principle, the futures market traders had to close their positions by buying back or selling back before the maturity date. For example, a trader who made a long position during the trading period must close his position until the maturity date by selling same amount of the contract. The settlement by delivery was permitted in the maturity date, while a constraint designated by Tokugawa Shogunate was imposed. That is, in Dojima, the allowed amount of the settlement by delivery was strictly limited to the fixed level; 1000 rice bills for the whole market. Under this constraint, the traders in Dojima traded the rice bills thorough the futures market. Usually, net settlements were the dominant method of the settlement. These features indicate that the futures trades at Dojima was designed not for the real demand, but for the speculation.

Trading season

Both the spot and the futures market have three separate trading seasons: January 4–April 27(28), May 7–October 8 (9), and October 17–December 23 (24)[5]. These seasons were called spring market, summer market, and winter market, respectively. The markets were closed for about 10 days between any of the two trading seasons. Every time the trading season started, the futures market committee were supposed to re-select the standard rice, it was usually the case that the standard rice was selected from Big five lords' warehouses[6].

Trade practices

Trading began at 8 a.m. in the futures market, followed by the spot trading which began at 10 a.m. Both trading began with opening price presented by the board members of Dojima. In the futures market, the opening price was determined by the closing price of the previous day. On the other hand, the opening price in the spot market was determined by

[5]The dates in parentheses are those for the spot market.

[6]That is, Kaga, Chikuzen, Chugoku, Higo, Hiroshima. Each was regarded as satisfying the condition, namely credibility and liquidity.

two factors; the closing price in the previous day and the price movements of the futures market preceding the spot market. This lead-lag relationship implies that the prices at the futures market were regarded as more informative than the spot market.

In both markets, the price was fixed by an oral auction. Traders in the circuit shout the price with gestures which stand for either "ask" or "bid". There were no market makers like them at Nasdaq, and hence the price was fixed only when the ask price and the bid price matched with each other. Every time a trading deal was established, the clerk of Dojima beat out the wood stick and shouted the price. The trading records were not written down until the completion of the trade in a day. After the trade was closed, the traders submitted the record to the clearing house. The clearing house checked each traders' transaction and canceled out his buying and selling. Finally, each traders' remaining position was kept in the record.

The spot market closed around the noon. On the other hand, the futures trade had a one-hour recess at noon and continued the trading until around 2 p.m. The closing price of the futures market was fixed by a special method. First, the clerk put fire on the fuse cord. The traders were allowed to trade until the fire extinguished. The closing price of the day was determined by the price at the moment the fire went out.

Now we understand the outline of the trading activities at Dojima. Table 1 presents the summary of above descriptions. Based on this, the empirical analysis is conducted in the following sections.

III. The test of the unbiasedness hypothesis

The unbiasedness hypothesis

In this section, the unbiasedness hypothesis, which had been tested by Ito (1993) and Wakita (2001), is reexamined. Before the empirical analysis, the concept of UBH and the previous works should be introduced. The UBH itself is based on two assumptions; risk neutrality and rationality. If the futures market speculators are neutral to risks, and if they use all available information rationally, the current futures price must equal the spot price expected to be reached at the maturity date. This relationship is expressed as

$$F_{t-1} = E_{t-1}\left[S_t\right], \tag{1}$$

where the S_t is the spot price at time t, the F_{t-1} is the value of a futures contract at time $t-1$, which expires at time t. The E_{t-1} is the expectations operator conditional on information available at time $t-1$. A simple UBH test is provided by a linear regression model as

$$S_t = \alpha + \beta F_{t-1} + u_t. \tag{2}$$

The condition for unbiasedness is that $\alpha = 0$, $\beta = 1$, and the u_t should be serially uncorrelated. If this holds, then the futures prices are thought to be unbiased predictors of the spot prices in the future. In other words, the speculators in the market can use all the available information to make a rational expectation. Abovementioned historical description indeed implies that this held in Dojima at that time.

Based on this concept, Ito (1993) and Wakita (2001) had conducted the empirical analysis. The model used in Ito (1993) was almost same with the model (2); That is,

$$\ln SC_t - \ln SO_t = \alpha + \beta(\ln FC_t - \ln SO_t) + e_t, \tag{3}$$

where the SO_t and the SC_t indicate the spot prices in the beginning and the end of the trading period t respectively, and F indicates the futures prices. Based on this model, Ito (1993) ran the regressions and concluding that, in the period from 1763 to 1780, Dojima failed to satisfy the unbiasedness condition.

The results by Ito (1993) can not be accepted as one to evaluate the efficiency of Dojima appropriately, because Ito (1993) focused on very small part of Dojima's history.[7].

On the other hand, the model in Wakita (2001) is;

$$\ln S = \alpha + \beta \ln F + \varepsilon_t, \tag{4}$$

where the S is the spot price at the beginning of April, September, and December, and the F is the futures price. Tsuruoka index on which Wakita (2001) relied, covers the sufficiently long period, but contains only prices at the beginning of each month. It is the reason why Wakita (2001) had to use prices at the beginning of the month as proxies of prices at maturity dates, which were not prices at maturity dates. In addition, it should be noted that Tsuruoka index contains considerable number of wrong figures, and the prices in the period from 1819 to 1827 are not the prices at Dojima, but at another market. Therefore, the results by Wakita (2001) had also been restricted by the property of the price index[8].

Based on above discussion, it can be said that whether the UBH does hold in Dojima remains to be unanswered. The reexamination based on newly constructed price index is thus called for.

The price index

To overcome the problems with the existing price indices, we should newly construct the more reliable and highly frequent price index from the original historical documents. Our new price index is provided by "Yorozu souba nikki (Daily memorandum of commodity price indices[9])" This memorandum was written by the contemporary rice merchant who dealt in

[7]It is because the price index on which Ito (1993) relied just covers the period from 1763 to 1780.

[8]Another problem is that Wakita (2001) did not mention about the time sequence of the independent variables; the futures prices. Wakita (2001) indicated the test results in each month, that is, 12 results within a year, however, it is not clear how can we interpret the results in April, September, and December when each trading season was closed. Taking the spring market for example, if the regression was conducted between the prices both in the April, then it is not the test of UBH, rather it is the test of the arbitrage condition. In turn, if the regression was conducted between the prices of the spot market in September and the prices of the futures market in April, then it is not consistent with real trading practices in Dojima, because the "standard price" in the spring market and that of the summer market is not the same, and "roll over" across the trading seasons was prohibited in Dojima. In addition, it should be noted that the summer market was closed in October, not in September, and there exists no available price index in the period from 1830 to 1833.

[9]Actually, the Tsuruoka index was also constructed from this memorandum. In the process of newly constructing daily price index, the author found that the Tsuruoka index contains considerable numbers of

the rice and the fertilizer. This merchant joined Dojima futures market for speculation, and for this reason, he recorded the commodity price indices on his memorandum. From this memorandum, we can construct the daily price index both in the futures and the spot market during the period from 1798 to 1856.

In addition to this, there exists another price index provided by Suzuki (1935). This index covers the period from 1834 to 1864, and also contains both the futures prices and the spot prices[10]. The price index, consisted of these two indices, allow us to cover the period from 1798 to 1864.

Reexamination of the UBH

Now we conduct the empirical analysis. The model used in this paper can be expressed as follows;

$$SC_t = \alpha + \beta FO_t + u_t, \tag{5}$$

where the SC_t is the spot price in the maturity date of the trading season t, the FO indicates the futures prices in the beginning of the trading season. The condition for unbiasedness is that $\alpha = 0$, $\beta = 1$, and u_t should be serially uncorrelated.

The test results are summarized in Table 2. As Table 2 indicates, the UBH in the whole period is rejected at 1 % significance level. On the other hand, in the period from 1798 to 1835, the UBH is not rejected at 1 % significance level; That is, the speculators in Dojima could use all available information, and form a rational expectation. This period coincides with the period when the abovementioned historical description was written. The recognition held by traders at that time, that is, the futures prices were unbiased estimator of the future spot prices, is now proved to be appropriate.

Ito (1993) rejected the UBH in the period from 1763 to 1780. It means that the efficiency of Dojima, in terms of the rational expectation, was formed during the period from 1780 to 1835. Table 2 also indicates that the UBH in the period from 1840 to 1864 was rejected at 1 % significance level. The past literature, such as Miyamoto (1988), indicated that Dojima in this period suffered from trading halts caused by some traders' illegal trades. Hence, it can be said that the rational expectation in Dojima was impaired by frequent trading halts at this period.

Based on these results, we can conclude that the efficiency of Dojima, in terms of the rational expectation, was proved in the middle of Tokugawa period. Because the rational expectation is formed by the traders who reflect all available information into prices, Dojima, in this period, could reflect all available information. According to Fama (1970), "A market in which prices always 'fully reflect' available information is called 'efficient'." Thus, Dojima,

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wrong figures.

[10]This index lacks closing prices of the futures market from 1857 to 1864. The opening price of the futures market, however, was determined by the closing price in the previous day. Actually, there is no significant difference between the closing price of the time $t-1$ and the opening price of the time t; That is, the null hypothesis; the closing price of the time $t-1$ and the opening price of the time t are same in variance and mean, was accepted in 1% significance level. Hence, I substitute the closing price of the time $t-1$ for the opening prices of the time t.

in this period, indeed had this so called informational efficiency.

Then, how about another periods? Although the informational efficiency is one of the significant necessary condition of the formation of the rational expectation, the reject of the UBH in the end of Tokugawa period does not necessarily mean that Dojima, in this period, did not have the informational efficiency. Ito (1993) and Wakita (2001) did not check this point, precisely because of the lack of high-frequency price index. In the next section, we look into this issue.

IV. Weak-form Efficiency

Market efficiency

The concept of market efficiency with respect not to resource allocation, but to some information sets was first defined in a rigorous manner by Fama (1970). To check this informational efficiency is equivalent to check how much, how fast, and how accurately available information is incorporated into the prices. Financial economists often classify this informational efficiency into three categories based on what is meant as "available information"; Namely, the weak, semistrong, and strong forms. Among these criteria, this paper focuses on the most objective criterion; the weak-form efficiency. The weak-form efficiency exists if the prices fully reflect all the information contained in the history of past prices and returns. If the markets have the weak-form efficiency, then the traders cannot earn excess profits from trading rules based on the past price or return. Therefore, the returns of the investments are not predictable.

The weak-form efficiency is the most basic, but most significant criterion, because if it does not hold, then the semi-strong form or the strong form efficiency will never be satisfied. Moreover, the past price sequences were assumed to be the most accessible information for the traders in Dojima[11]. For these reasons, this paper start from this most objective criterion.

A straightforward way to check the weak-form efficiency is to calculate autocorrelation on the price sequences. If the price sequences at Dojima do not exhibit autocorrelation, we can conclude that the traders at Dojima could not exploit the information from historical price behaviors to obtain excess returns.

The test statistics

To test the market weak-form efficiency, this paper applies the Q-statistic proposed by Box and Pierce (1970). This statistic is given by

$$Q_m \equiv T \sum_{k=i}^{m} \rho^2(k) \tag{6}$$

[11]Recall that the "Yorozu souba nikki (Daily memorandum of commodity price indices)" was written by the contemporary rice merchant.

where the $\rho(k)$ is the kth order autocorrelation coefficients, and the T is the sample number of the price. Under the null hypothesis, $\rho(k) = 0$, $Q_m = T\hat{\sum}_{k=i}^{m} \rho^2(k)$ is asymptotically distributed as χ^2_m. By summing the squared autocorrelations, the Box-Pierce Q-statistic is designed to detect departures from zero autocorrelations in either directions and at all lags.

Based on this statistics, Ljung and Box (1978) provide the following finite-sample correction which yields a better fit to the χ^2_m for small sample sizes:

$$Q'_m \equiv T(T+2)\sum_{k=i}^{m} \frac{\rho^2(k)}{T-k}. \tag{7}$$

This paper calculates the Ljung and Box Q-statistics up to 5 lags, that is,

$$Q'_5 \equiv T(T+2)\sum_{k=i}^{5} \frac{\rho^2(k)}{T-k} \tag{8}$$

is calculated. The null hypothesis is offered as $H_0 : \rho(k) = 0, \forall k \leq 5$.

The results

The results of the tests are shown in Table 3. As Table 3 indicates, the null hypotheses in the spot market can not be rejected in about 80% of all periods, and those in the futures market can not be rejected in about 70% of all. Based on these results, we can conclude that both markets succeeded in reflecting the past price sequences accurately. In addition, as Table 4 indicates, there does not exist any patterns; That is, the weak-form efficiency is detected uniformly, and even in the end of the Tokugawa period when Dojima suffered from frequent trading halts. On the other hand, Table 5 indicates that the weak-form efficiency was detected more frequently in the winter market, when newly harvested rice came on the market. This indicates the liquidity level of supply, which was lower in the spring and summer market, and was higher in the winter market, could affected the trade activity in Dojima.

Concluding Remarks

It has been shown that Dojima had succeeded in forming the rational expectation in the middle of Tokugawa period, and it had the weak-form efficiency in the whole periods. The efficiency of Dojima, which was not detected by the previous works, but was observed by the contemporary traders, has been verified here.

Finding these type of efficiency at Dojima is surprising to us, because these does not necessarily hold even in contemporary modern financial markets equipped with the information and communication technology[12].

[12]The UBH has been rejected by many empirical works; Fama (1984), Baillie and Myers (1991), Bessler and Covey (1991), and Chowdhury (1991), which cover the various commodity futures market. The weak-form efficiency do not also necessarily hold in the contemporary financial markets. Lo and MacKinlay (1988) find that weekly returns on portfolios of NYSE stocks grouped according to size show reliable positive autocorrelation. See Fama (1991) for an elaboration of these issues.

Actually, this paper only showed the weak-form efficiency, and the semi-strong or strong form efficiency is remained to be unanswered. These are left as a challenging task for future inquiry.

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"Yorozu Souba Nikki (Daily memorandum of commodity price indices)," held by Kokubungaku Kenkyushiryokan Rekishishiryo Etsuranjimushitsu (Office of Archives Services in National Institute of Japanese Literature), Tokyo, Japan.

Table 1. The trading rules in Dojima

	Futures Market	Spot Market
Goods in trades	The standard rice (index)	The rice bills
Trading priods	January 4-April 27 May 7-October 8 October 17-December 23	January 4-April 28 May 7-October 9 October 17-December 24
Trading time	From 8 a.m. to 2 p.m.	From 10 a.m. to the noon
Trading system	Open-Out-Cry	Open-Out-Cry
Settlement	Net settlement	Delivery within 4 days

Table 2. Results of the test of the UBH

Period	1798-1864	1798-1835	1840-1864
α	-13.430	-5.078	-2.145
β	1.266	1.076	1.175
R-squared	0.783	0.570	0.723
F-value	22.994	0.269	17.071
P-value	0.000	0.765	0.000
D.W.	2.067	2.199	2.199

Table 3. Results of the Q-tests

periods	Futures	Spot	periods	Futures	Spot	periods	Futures	Spot	periods	Futures	Spot
1798-1	Y	Y	1810-1	Y	Y	1841-1	N	Y	1854-1	Y	Y
1798-2	Y	N	1810-2	Y	Y	1841-2	N	Y	1854-2	Y	Y
1798-3	Y	Y	1810-3	Y	Y	1841-3	N	Y	1854-3	Y	N
1799-1	Y	Y	1811-1	Y	N	1842-1	N	Y	1855-1	Y	Y
1799-2	N	Y	1811-2	Y	Y	1842-2	N	Y	1855-2	N	Y
1799-3	Y	Y	1811-3	Y	Y	1842-3	Y	Y	1855-3	Y	Y
1800-1	N	N	1812-1	Y	Y	1843-1	N	N	1856-1	Y	Y
1800-2	N	Y	1812-2	Y	Y	1843-2	N	Y	1856-2	Y	Y
1800-3	Y	Y	1812-3	Y	Y	1843-3	Y	N	1856-3	N	Y
1801-1	Y	Y	1813-1	Y	Y	1844-1	N	Y	1857-1	Y	Y
1801-2	Y	Y	1813-2	N	Y	1844-2	Y	N	1857-2	Y	Y
1801-3	Y	Y	1813-3	N	Y	1844-3	Y	Y	1857-3	Y	Y
1802-1	Y	Y	1814-1	Y	Y	1845-1	Y	Y	1858-1	Y	Y
1802-2	N	Y	1814-2	N	Y	1845-2	Y	Y	1858-2	Y	Y
1802-3	Y	Y	1814-3	Y	N	1845-3	Y	Y	1858-3	Y	Y
1803-1	Y	Y	1815-1	Y	N	1846-1	Y	Y	1859-1	Y	Y
1803-2	N	Y	1815-2	Y	Y	1846-2	Y	N	1859-2	Y	Y
1803-3	Y	Y	1815-3	Y	Y	1846-3	Y	Y	1859-3	Y	Y
1804-1	Y	Y	1816-1	N	Y	1847-1	Y	Y	1860-1	Y	Y
1804-2	N	N	1816-2	Y	Y	1847-2	N	N	1860-2	Y	Y
1804-3	Y	Y	1816-3	Y	Y	1847-3	Y	Y	1860-3	N	Y
1805-1	Y	Y	1817-1	N	N	1848-1	N	N	1861-1	Y	N
1805-2	Y	Y	1817-2	N	N	1848-2	Y	N	1861-2	Y	Y
1805-3	N	Y	1817-3	Y	N	1848-3	Y	N	1861-3	Y	Y
1806-1	Y	Y	1818-1	Y	Y	1850-1	N	Y	1862-1	N	Y
1806-2	Y	Y	1818-2	Y	Y	1850-2	N	Y	1862-2	N	Y
1806-3	Y	N	1818-3	Y	Y	1850-3	N	Y	1862-3	Y	Y
1807-1	Y	Y	1834-1	Y	N	1851-1	Y	Y	1863-1	N	N
1807-2	N	Y	1834-2	Y	Y	1851-2	N	Y	1863-2	N	Y
1807-3	Y	Y	1834-3	Y	Y	1851-3	Y	Y	1863-3	Y	Y
1808-1	Y	Y	1835-1	Y	Y	1852-1	Y	Y	1864-1	N	Y
1808-2	Y	Y	1835-2	Y	Y	1852-2	Y	N	1864-2	Y	N
1808-3	N	Y	1835-3	Y	Y	1852-3	Y	N	1864-3	Y	Y
1809-1	Y	Y	1840-1	N	Y	1853-1	N	N			
1809-2	Y	Y	1840-2	Y	N	1853-2	Y	Y			
1809-3	N	Y	1840-3	Y	Y	1853-3	Y	Y			

Note)

- The numbers attached to the years, namely 1834-1, 1834-2 and 1834-3 indicates spring, summer, winter market respectively.
- The column "Efficiency" is "Y" when the null hypotheses are not rejected in 5% significance level, and is "N" otherwise.

Table 4. Pattens of the Q-tests results in each period

periods	Futures	Spot
1798-1864	71.6%	80.9%
1798-1835	76.8%	84.1%
1840-1864	66.7%	77.8%

Note)

・The percentages were calculated by dividing the number of the periods in which the null hypotheses are not rejected, by the number of the period in total.

Table 5. Seasonal pattens of the Q-tests results

Spring market			Summer market			Winter market		
periods	Futures	Spot	periods	Futures	Spot	periods	Futures	Spot
1798-1864	70.2%	78.7%	1798-1864	61.7%	78.7%	1798-1864	83.0%	85.1%
1798-1835	87.0%	78.3%	1798-1835	60.9%	87.0%	1798-1835	82.6%	87.0%
1840-1864	54.2%	79.2%	1840-1864	62.5%	70.8%	1840-1864	83.3%	83.3%

Note)

・The percentages were calculated by dividing the number of the periods in which the null hypotheses are not rejected, by the number of the period in total.