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There has been tremendous growth in interest rate futures markets since their beginning in 1975, both in terms of trading volume and the proliferation of new types of contracts. This paper focuses on the Treasury bill futures market and uses a descriptive statistic which was devised by Holbrook Working for the express purpose of analyzing price movements in commodity futures markets. When applied to the Treasury bill futures market, the statistic has been able to discover patterns of price movements that could not be detected by either the more traditional Box-Jenkins techniques or by spectral analysis.

Futures trading in Treasury bills began in the International Monetary Market (IMM) division of the Chicago Mercantile Exchange in January 1976. The tremendous success of T-bill futures contracts has resulted in a proliferation of research studies which have attempted to measure the performance of the market [8, 9].

Before one attempts to measure how well markets are working, one should have an exact definition of good market performance or efficiency. For example, some researchers have tested the hedging effectiveness of the futures market by examining the stability of the relationship between futures price movements and cash price movements [18, 12, 17]. Others have emphasized tests of the term structure [29, 22, 4, 11, and 25], while some have considered market efficiency by examining the arbitrage possibilities between the futures market and cash market [30, 29, 35, and 10]. Two other recent studies [26 and 31] establish the equilibrium price of a futures contract using an approach similar to the one used for deriving the value of a call option [2].

Vignola and Dale explain Treasury bill futures pricing using the concept of “price of storage” or “cost-of-carry” [34, 36], first developed for agricultural commodity futures by Holbrook Working [38]. A growing body of theoretical and empirical literature supports Vignola and Dale’s cost-of-carry hypothesis of Treasury bill futures pricing (see [5, 33, 21, 32, and 28]).

Recent studies have focused on explaining why deliveries against T-bill futures contracts have been so high relative to agricultural commodities. Arak contends that the increasing number of deliveries against Treasury bill futures is the result of tax considerations [1]. On the other hand, Dale analyzed Treasury bill futures price movements in terms of a mathematical concept called Brownian motion and correctly predicted that low transportation costs would lead to both increasing deliveries against established contracts and to a poor performance for new financial futures contracts that virtually duplicate the terms of established contracts [14]. This study uses a completely different approach from that used in all previous work. A specially designed descriptive statistic called Working’s W-statistic is used to examine the markets.

Working’s W-Statistic

Working is the one who is responsible primarily for our understanding of the relationship between futures prices and cash prices [37, 38, 39], for an explanation of the dynamics of futures pricing [42], and for an explanation of the mechanism and economic function of futures market hedging [40]. Thus, the specific statistic that he devised to examine futures market efficiency deserves serious attention.
Two types of price movements are tested for here. Continuity refers to gradual, sluggish price movements that occur when a market does not respond to new information as quickly as an ideal market would. Reaction refers to sharp up and down price swings caused by speculators. To test for such autocorrelated price movements, Working developed his statistic, which was subsequently used by Brinegar [6, 7] and Larson [23, 24]. Essentially, this statistic may be used to examine whether the markets exhibit random behavior.\(^1\) It may be used to detect both the long-term continuity price movements and the short-term reaction price movements, and it can distinguish between them.\(^2\) Working originally called his statistic \(H\). Since the letter \(H\) now means several other things in statistics, this study refers to the statistic as \(W\). \(W\) may stand for the name of the person who devised it; it may be used to show how markets are working; and, when excessive reaction tendencies are found, it may serve as a warning. The \(W\)-statistic tests the overall efficiency of the market.

There are actually two statistics, \(W\) and \(W'\) given by:

\[
(1) \quad W_{m, mk} = \left( \frac{\sqrt{k} \sum R_i}{N} \right)^2 \frac{S_{ki}}{B} - 1,
\]

and

\[
(2) \quad W'_{m, mk} = \left( \frac{\sqrt{k} \sum R_i}{N} \right)^2 \frac{S_{ki}}{N} - 1
\]

where:

\(N\) = number of segments, each containing \(m\) steps
\(k\) = number of subsegments per segment
\(R_i\) = range of the \(i^{th}\) segment

\(S_{ki}\) = sum of the ranges of the \(k\) subsegments of the \(i^{th}\) segment

\(B\) = expected values of the numerators, for a random difference series.

The standard error for \(W\) or \(W'\) is given by:

\[
\alpha_w = \alpha_{w'} = \frac{1}{\sqrt{N}} \frac{(0.298 + 0.187)}{\sqrt{m}} \sqrt{1 - 1/k}
\]

Both \(W\) and \(W'\) are tested for significance in the same way as is a standard normal deviate.\(^3\) \(W'\) is defined so that it is slightly more sensitive to large price changes than is \(W\). In effect, the tests measure intra-interval serial correlation (see [13, pp. 191-92]). On an intuitive level, the \(W\) statistic can be viewed as a comparison of the number of trend reversals that occur over time in the price series under study compared to the number of trend reversals that would be expected to occur in a random difference series.\(^4\) Since a random difference series can in principle exhibit almost any type of behavior, the more data that are available, the more reliable is the test.

The dominant contract, i.e., the one with the highest open interest, is used to obtain a price series that reflects the most important market characteristics. The price series in this study began with the March 1976 T-bill futures contract, which was used until the June 1976 contract became dominant, and June 1976 was used until the September 1976 contract became dominant, etc. This procedure created discrete price jumps, which necessitated splicing the series.\(^5\) In addition to these quantitative tech-

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1. Phillipe Berthet and Claude Brinegar assisted Working in developing the \(W\)-statistic. Larson referred to it as the index of continuity, which is a good verbal description of the test [23, 24].

2. It was Brinegar who, using the \(W\)-statistic, actually discovered the existence of continuity tendencies in futures markets [6]. Working subsequently gave a complete economic interpretation of Brinegar's statistical discovery [41, p. 1433; 42, p. 195; 43, p. 54; 44].

3. For a detailed discussion of the \(W\)-test, as well as for tables of values for the \(B\) of equations (1) and (2), see Brinegar [7]. There are some assumptions involved, such as whether price changes are distributed normally or of constant absolute size, that need not concern us here. The results were insensitive to these assumptions.

4. The \(W\) test is more useful than other nonparametric tests because by considering specific subintervals of the intervals being studied, this test makes it possible to determine graphically the nature of the deviation from the ideal, as will be explained shortly.

5. Various splicing methods were devised and tested. The one ultimately used on both the futures contracts and cash bills was a simple linear transformation of the data, applied 10 days before and after the date of the splice. The results were insensitive both to the method of splicing used and to the assumed underlying price distribution (see footnote 3).
niques, there are graphic techniques that can be used to determine the approximate duration of each type of price movement.

Results

Figures 1 and 2 show the results of the W and W' tests for the first three years of trading in the T-bill futures market. For comparison purposes, the tests were applied also to the spot market. Figures 3 and 4 show the two years before futures trading began, Figures 5 and 6 show the period since futures trading began, and Figures 7 and 8 show the combined five-year period. The charts for W and W' are similar. However, as previously mentioned, W' is more sensitive to large price movements. Since interest rates have been highly volatile in recent years, this study concentrates on the W' charts.

In a so-called ideal market, there are the same number of trend reversals as there would be in a random difference series. In this case, W = W' = 0, and the charts shown would all have horizontal lines. If markets are slow to react to new information, then W' > 0. These continuity movements, that were discussed earlier, are represented by upward sloping lines on the charts, with peaks at the approximate location of the length of the trend. If the markets exhibit more trend reversals than would a random difference series because of destabilizing speculation, reaction price movements described earlier would result. Then W' < 0, and the charts would show lines extending downward below zero. One of the greatest concerns to many people interested in futures markets is the possibility that speculators may destabilize markets. In this regard, it is significant that Figures 1 through 8 show only a few negative values. In all cases, these values were smaller than their standard errors. Thus the W and W' tests show no evidence that speculators have destabilized the Treasury bill futures market. The W-test gives no warning.

Continuity price movements are another matter. Figure 2 clearly shows a tendency for the existence of price trends of about 32 trading days in length. Figures 4 and 6, however, show that the same tendencies have existed in the spot market both before and after the advent of futures trading. Although Figure 3, the chart for the five-year period 1974-78, does not show a clear interval length, it unquestionably does show the presence of continuity price movements. Continuity price movements also have been shown to exist in many types of agricultural commodities (see [7, p. 42]). These results particularly resemble those for the 1937-41 corn futures market. The existence of continuity movements in the spot market before trading even began in futures is shown in Figure 4, although the close congruence of Figures 2 and 4 indicates that the futures market has not altered the spot market. Some explanation for the continuity price movements clearly is needed.

According to the cost-of-carry hypothesis mentioned earlier [34, 36], the T-bill futures market is dominated by roughly three dozen primary dealers, many of whom openly admit that they tend to run with the herd. A correlation has been found between continuity and net long positions held by large-scale traders [7, p. 49]. Hobson's study showed that large speculators had substantial long holdings in T-bill futures when his big survey was made [19]. Two points arise from the foregoing discussion. First, since the period of study was characterized by rising interest rates, these results may indicate that throughout this period people revised their interest rate expectations too slowly in relation to changing economic conditions. Second, the lack of evidence of reaction price movements indicates that even if dealers do run with the herd, the net effects are felt on an intraday basis, which, because of data limitations, are out of reach of this study.

One interesting question is whether profitable trading opportunities arise in the T-bill futures market as a result of the existence of continuity. When a variety of mechanical trading rules were tested, the results showed that in the long run commission costs produced losses in each case [15, 16]. This finding is not surprising since the use of the W-statistic revealed that when trends occur they tend to last for 32 trading days. This does not imply that they occur often enough to create profitable trading opportunities, nor does it mean that 32-day-price trends occur sequentially. In fact, both standard time series analysis
Figure 1
W-Test for T-Bill Futures Market
(Closing Prices) 1976-1978

Figures 1-4 are combined on p. 84
Figure 2
W'-Test for T-Bill Futures Market
(Closing Prices) 1976-1978
Figure 3
W-Test for T-Bill Spot Market
(Closing Prices) 1974-1975
Figure 4
W'-Test for T-Bill Spot Market
(Closing Prices) 1974-1975

Subinterval in days
1
2
4
8
16
32
64

Interval (Days)
Figure 5
W-Test for T-Bill Spot Market (Closing Prices) 1976-1978

Figures 5-8 are combined on p. 85
Figure 6
W'-Test for T-Bill Spot Market
(Closing Prices) 1976-1978
Figure 7
W-Test for T-Bill Spot Market
(Closing Prices) 1974-1978
Figure 8
W'-Test for T-Bill Spot Market
(Closing Prices) 1974-1978
and spectral analysis gave the appearance of random price movements.

In summary, the W-statistic served its purpose well. It did not yield any evidence that specula-
tors have destabilized the futures market. Also, since the spot market charts for the periods
before and after futures trading began are so similar, there is no evidence that the advent of
futures trading has had any effect on price movements in the spot market. Finally, the simi-
larly between charts of the T-bill futures and those of agricultural commodities is consistent
with the cost-of-carry market pricing hypothesis of Vignola and Dale, wherein cost-of-carry
plays the same role in financial futures as cost of
storage does in agricultural commodity futures.

Conclusions

This paper has described Working's W-statistic
and its use in examining price movements in the
Treasury bill futures market. No evidence of
speculative destabilization in the futures market
was found; however, there was evidence of
continuity, or sluggishness, of price movements.
This finding seems to be a universal charac-
teristic of futures markets, if not of speculative
markets in general.

Two other points are worth emphasizing.
First, the W-statistic was not used to test for
intraday price movements; hourly data are
needed for such tests. Second, the futures mar-
ket exhibited the same type of behavior as had
existed and still exists in the cash market. These
observations tend to reinforce the views of those
who believe that futures markets simply mirror
the spot market. In any case, as the market
evolves, the W-statistic should continue to be a
tool useful to understanding the workings of the
market.

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