A TRANSACTIONS DATA TEST OF STOCK INDEX FUTURES MARKET EFFICIENCY AND INDEX ARBITRAGE PROFITABILITY

DISSERTATION

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To My Family

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CHAPTER I

INTRODUCTION

Recently, much controversy has surrounded index arbitrage. Index arbitrage is a strategy whereby institutions, brokerage houses, and other large investors seek to profit from the spread between prices in the spot and futures markets for stock indices.[1] For example, an investor might purchase predetermined baskets of stocks on the floor of the New York Stock Exchange and simultaneously sell a related index futures contract on the floor of the Chicago Board of Trade, hoping to profit from the price differences on the two exchanges. Computer programs constantly monitor stock and futures prices and automatically execute buy and sell orders when it appears that a profit is possible.[2] Growing interest in index futures contracts and concern among investors, media, regulators, and some academics have surrounded two empirical questions: Is this computer-assisted strategy risk-free? Is there a significant correlation between index arbitrage profitability and stock market volatility?

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1. Some authors do not differentiate between program trading and stock index arbitrage. More precisely, program trading is trades of a large portfolio of stocks as a basket initiated by a single order. There are no offsetting trades in the futures or options markets, which differentiates this trading from index arbitrage.

2. For a brief picture of automated trading systems, see Stulz (1988), pp. 11-12.

The purpose of this study is to see if market prices for stocks and futures offered significant profit opportunities to arbitrageurs. The available historical data include minute-by-minute prices of stocks and second-by-second prices of Major Market Index futures contracts. The records are examined second-by-second and simulated orders are executed based on typical index arbitrage strategies. After describing the database, summary statistics on the profitability of these simulated index arbitrage strategies are presented and the implications for stock index futures market efficiency are discussed. The efficiency tests in this study attempt to closely approximate conditions in the cash and futures markets. Ex ante tests, allowing a range of reasonable execution lags, are conducted with transactions data for prices of futures and component shares of the index. The tests impose the 'uptick' rule for short sales in the stock market and incorporate transaction costs incurred by different classes of traders. This is the first time that transactions data with nearly contemporaneous stock and futures prices have been employed for an efficiency test of stock index futures market. With the same transactions data, this dissertation also tests whether there is any systematic relation between stock market volatility and index arbitrage profitability during the sample period, using the Spearman's rank correlation tests.

We find that:

(1). Previous studies significantly overestimate the size and frequency of profitable arbitrages in the index futures market by focusing on ex post tests (i.e. without assuming execution lags and imposing the short-sale rule) and by using the reported index instead of transactions data.

(2). Results from our ex post tests do not support the 'tax timing option' hypothesis proposed first by Cornell and French (1983a): index futures contracts are dominantly overpriced for ex post violations. Results show that only 7.04% of ex post violations are signals for short arbitrage with 0.5% transaction costs.[3] For higher transaction costs, signals for short arbitrage are less than 2% of ex post violations.

(3). The frequency and size of ex ante violations have declined sharply since the contract's introduction in July 24, 1984. It appears that the market has matured.

(4). The frequency of ex ante violations declines sharply with the assumed level of transaction costs and the assumed length of the execution lag.

(5). The size of arbitrage profits has become substantially smaller, while the standard deviation of profits has become larger. And profits realized from index arbitrage are not riskless, as evidenced by the large standard deviation of profits.

3. Short arbitrage means that the trader sells component stocks short and buys futures contracts: long arbitrage is the opposite.

(6). The frequency and size of arbitrage profits from executable short arbitrages are much smaller and more volatile than those from long arbitrages. The uptick rule in the stock market is a serious constraint to short arbitrages in the index futures market.

(7). Stock market volatility is positively correlated with the size and frequency of ex post boundary-violations, but is negatively correlated with the size of ex ante violations in MMI futures prices, at least for heavily traded, short-maturity contracts.

The rest of this dissertation is organized as follows. Section II reviews the related works and explains why those earlier studies are incomplete tests of stock index futures market efficiency. Section III describes the data set. Section IV describes the empirical tests. The empirical results are presented in Sections V, VI, and VII while Section VIII summarizes the results and implications.

CHAPTER II

RELATED WORKS AND MOTIVATION

Stock index futures can be priced by a simple arbitrage argument. If the dividends paid by the underlying basket of shares are nonstochastic, markets are perfect, and there are no taxes, the pricing equation is:[4]

$$F(t,T) = S(t)e^{r(T-t)} - D(t,T) \qquad (1)$$

where F(t,T) equals the futures price at time t for a contract that matures at time T, S(t) equals the spot index value at time t, D(t,T) equals the time T value of dividends paid on the component stocks between t and T, and r(T-t) equals risk-free interest rate spanning the period from t to T.[5]

Modest and Sundaresan (1983) modify equation (1) to incorporate the transaction costs involved in trading stocks and futures contracts. Using a sample of closing prices for the June 1982 and December 1982 S&P 500 contracts and factoring in transaction

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4. See Modest and Sundaresan (1983) for a proof.

5. An alternative specification is:

$F(t,T) = S(t)e^{(r-d)(T-t)}$ where d(T-t) equals the dividend yield spanning the period from t to T. The problem with this approach is that the dividend yield on an index is not constant over the full year. Hence this model specification may misestimate contract prices due to seasonal variations in the dividend flow.

costs, they find that futures prices mostly fluctuate within the theoretical no-arbitrage boundaries assuming that traders can use less than half of their short sale proceeds.[6] Cornell and French (1983a) show that prices of futures on the S&P 500 index and the NYSE Composite index are less than those predicted by the model. They argue that this bias is due to the 'tax timing option' which is available to those who hold stocks, but not to holders of futures contracts: since the pure cost of carry model like equation (1) does not capture the value of this option, it may overpredict the futures prices and actual futures prices will tend to be lower than what the cost of carry model predicts. Cornell (1985), however, finds that the tax timing option is not an important factor in pricing stock index futures: he argues that (i.) the timing option may not be priced because the marginal investors in the market are tax-exempt institutions or arbitrageurs or (ii.) there are some constraints (like transaction costs and the $3,000 limitation on capital loss deduction against income) which prevent investors from taking advantage of the timing option. His empirical results reveal that as the market has matured, market prices and model prices given by equation (1) have become closer and hence that the cost-of-carry model has improved as a

6. A recent empirical study by Bailey (1989) shows that the cost-of-carry model is also reasonably accurate in predicting prices of Japanese stock index futures contracts.

predictor of futures prices.[7]

Many recent studies report that significant deviations of futures prices from cost-of-carry model prices have persisted since the introduction of index futures contracts in the early 1980's.[8] Several researchers have tried to explain these significant mispricings and hence apparently frequent arbitrage opportunities in this 'infant' market. Figlewski (1984) shows that approximately 70% of arbitrage opportunities due to mispricings disappeared by the close of the following day and claims that mispricings are due to 'noise' and will disappear with time as markets mature.[9] Other explanations include i.) inefficiency of the index futures market, ii.) risk

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7. Bailey (1989) and Hemler and Longstaff (1989) compare the performance of their general equilibrium models to that of the cost of carry model in explaining the level of actual index futures prices, using samples of daily closing prices of Nikkei 225 futures contracts (Bailey) and end-of-month prices of New York Futures Exchange contracts (Hemler and Longstaff). Their results show that the equilibrium model does not better explain the actual index futures prices even though additional parameters must be estimated.

8. Other studies on this issue include Arditti, Ayaydin, and Rigsbee (1986), Brennan and Schwartz (1986,1987), Figlewski (1984,1985), Grossman (1988), Kawaller, Koch, and Koch (1987), MacKinlay and Ramaswamy (1988), Merrick (1987,1988), and Stoll and Whaley (1986).

9. If mispricings are simply due to noise, arbitrage trading should tend to correct them. However, if apparent mispricings are the result of specific factors like a 'tax timing option', they will persist over long periods.

premium to index arbitrage,[10] or iii.) hidden costs or impediments to arbitrage not captured by the model.[11]

Previous tests of stock index futures market efficiency are incomplete in several respects. First, they look at the size and frequency of violations of no-arbitrage boundaries, not at the size and frequency of arbitrage profit opportunities. A market efficiency test should be carried out as an ex ante test to see the extent to which arbitrageurs can make positive ex ante arbitrage profits after observing ex post mispricings. What appears ex post as a riskless profit opportunity is not necessarily a real ex ante exploitable profit opportunity because there is no guarantee that the prices at the next available transaction will still be favorable for the arbitrageur. Second, most previous studies use closing prices for spot and futures prices. The index futures market closes fifteen minutes later than the stock market. So comparing nonsynchronous closing prices of futures contracts and spot index may lead to a

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10. A trade based on an observed arbitrage possibility at time t will result in a risky position at time t+1. Trying to exploit the observed deviations from the boundary condition can be, ex ante, a risky venture where profits are not guaranteed.

11. If we continuously observe significant mispricings and hence apparently frequent arbitrage opportunities, then there may be some trading barriers which make true risk-free arbitrage difficult. Potential impediments to arbitrage include the nontrivial transaction costs, the uptick rule in the stock market, and the position limit in the futures market. Apparent mispricings may arise and persist over time.

significant source of error. Also, prices fluctuate within a day. To examine the profitability of index arbitrage and efficiency of the index futures market, intraday price data should be used for a more definite test. MacKinlay and Ramaswamy (1988) use intraday prices for futures and the spot index in their study on the stochastic behavior of stock index futures prices. Stoll and Whaley (1988) also use similar intraday prices in their study of the time series properties of intraday returns of stock indices and stock index futures contracts. However, both studies use the reported index quotation as a proxy for the value of the spot index. The reported index is not a perfect measure of the true value of the index because the component shares of a stock index do not trade continuously. This means that the reported index can lag the true index value while there is no significant lag in observed futures prices.[12] Thus, a spurious discrepancy between the theoretical price based on the reported index and the actual futures price will appear whenever prices of component shares of the index are changing fast with sudden ups or downs. Finally, previous authors have not incorporated the uptick rule for short sales of component shares of the index or an execution lag in their market efficiency tests.

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12. In futures markets, the liquidity provided by scalpers who are ready to buy or sell positions to the public at their bid or ask guarantees the nearly continuous transactions or immediate executions of public orders.

CHAPTER III

DATA

Results presented in this paper are based on the Major Market Index (MMI) of the American Stock Exchange and MMI futures contracts traded in the Chicago Board of Trade (CBT) for the period from July 24, 1984 to August 31, 1986. The MMI is a broad-based stock index which measures the performance of twenty blue-chip stocks listed on the New York Stock Exchange.[13] The index is calculated by summing the prices of the individual stocks and dividing that sum by a divisor. This divisor changes from time to time to account for stock splits and stock dividends. MMI futures contracts are settled at $100 times the MMI as of the close on the last trading day.[14] The contract is traded between 8:45 a.m. and 3:15 p.m. Chicago time (after October 1, 1985,

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13. The MMI tracks the Dow Jones Industrial Average (DJIA) closely, with a correlation of 0.97 over the past six years. Seventeen out of twenty component stocks of the MMI are included in the DJIA calculation. The twenty stocks are American Express, AT & T, Chevron, Coca Cola, Dow Chemical, Du Pont, Eastman Kodak, Exxon, General Electric, General Motors, IBM, International Paper, Johnson & Johnson, Merck & Co., Minnesota Mining & Mfg., Mobil Oil, Philip Morris, Proctor & Gamble, Sears, and U. S. Steel.

14. On July 7, 1985 the Chicago Board of Trade started to trade 'MMI MAXI' contracts which are similar to the MMI futures contracts but valued at $250 times the index. Both contracts were traded until September 19, 1986 when the smaller contract was discontinued. The Wall Street Journal reported prices for both contracts until May 29, 1986. Starting on June 2, 1986 it has reported only MMI MAXI quotes but misleadingly labelled 'Major Market Index'.

the CBOT opens half an hour earlier.). Contracts are traded for nominal delivery in the first three consecutive months and the next month in the March, June, September, and December quarterly cycle.[15] The last trading day is the third Friday of the contract month. The contract is quoted in minimum increments of one-eighth of an index point. MMI futures do not call for the actual delivery of stocks. Rather, maturing contracts are settled in cash at the prevailing value of the spot MMI on the last trading day. Long and short positions are marked-to-market every day a position remains open. The MMI futures contract makes index arbitrage relatively cheap, easy, and fast due to the relatively small number of component stocks and small contract size.[16] Furthermore arbitrages based on the MMI are far less complicated than S&P 500-based arbitrages. An arbitrageur attempting to sell short a basket of 500 stocks must wait for an uptick (or a

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15. On a given trading day, four types of contracts with different maturities are traded. For simplicity, these subsequently will be referred to as the one month, two month, three month, and six month contracts, respectively.

16. The minimum outlay for an MMI arbitrage is about $3 million while about $25 million is needed to operate an S&P 500-based arbitrage. See Stoll and Whaley (1986). Instead of purchasing all 500 stocks for an S&P 500-based arbitrage, traders can typically purchase a large basket of about 200 stocks to represent the S&P 500 index. This 'quasi-arbitrage' requires less capital (about $10 million), but involves the 'tracking' risk since the index futures price will not necessarily converge to the price of the basket at maturity. In practice, an arbitrage based on the MMI does not use the smaller basket since it is not difficult to buy twenty component stocks of the MMI.

zero uptick) in each of the 500 stocks for an S&P 500 arbitrage. As a result, the arbitrageur may be unable to establish a short position that properly represents the index. This difficulty is less severe for an MMI arbitrage, where the short-sale rule must be observed for only twenty stocks.[17]

Actual futures prices are obtained from the CBT's 'Time and Sales Journal' tapes. These tapes contain every reported transaction whose price differs from the previous one for each contract. Each record contains the symbol for the contract, futures price, date, and time of transaction to the nearest second. Similar data are available from 'Fitch' tapes obtained from Francis Emory Fitch, Inc. for the twenty component stocks of the MMI recorded at the instant transactions took place. Each record is time-stamped to the nearest minute.

The average of the bid and ask discounts on the Treasury bill which matures on the day that is closest to the last trading day of

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17. The precise short-sale rule is that the transaction price for a short sale must be an uptick or, if there is no change in price, the previous price must have been higher than its previous price (a zero uptick). This short-sale constraint frequently leads traders to use the 'stock replacement' strategy: large investors who already own index stocks can sell them proportionally and put the proceeds in riskless instruments. This strategy has the same economic payoffs as the normal 'short-sale' of component stocks of an index. See Stoll and Whaley (1986).

the futures contract is used to compute the risk-free interest rate.[18] The dividend and splits data are collected from Moody's Dividend Record and Value Line. The actual dividends subsequently realized over the life of the contract are used as a proxy for the expected dividend to be paid on the MMI on a per contract per day basis. That is, it is assumed that dividends paid and ex-dividend dates over the life of the futures contract are known at t with certainty. The deferred value of dividends, D(t,T) in equation (1), is computed using the Treasury bill rates. This is an approximation which may not equal the market's anticipation of future dividends. Discrepancies caused by this approximation of dividends are likely to be minimal because the MMI stocks are closely-followed blue-chip shares and hence their future dividends are fairly predictable and slow to change.[19]

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18. Any possible bias in our empirical tests due to our ignorance of the precise bid-ask spread in T-bill rates is likely to be negligible. We investigated the average size of the bias in calculating equilibrium futures prices (i.e., equation (1)). For one month contracts, for example, the average number of days to maturity during our sample period was 16.2 days, the average bid rate (annualized) was 0.07776533, and the average ask rate (annualized) was 0.07677254. The average level of MMI was 253.40 and the realized annual dividend yield for the MMI was 4.69%. Consequently, the difference between calculated equilibrium futures price using the bid rate and that using the ask rate was 0.0112 index points. The bias in our tests, therefore, is only 0.0056 index points since we use the 'average' of bid and ask discounts on the T bill. Biases for longer-maturity contracts are also negligible (0.0096 index points for two month contracts, 0.0131 index points for three month contracts, and 0.0242 index points for six month contracts).

19. Classic papers on dividends, like Lintner (1956) and Fama and Babiak (1968), show that dividends are highly predictable.

CHAPTER IV

STRUCTURE OF EMPIRICAL TESTS

1. Efficiency Tests of the MMI Futures Market

For each contract traded during the sample period of July 24, 1984 to August 31, 1986, the theoretical futures price is computed using equation (1) and compared to the actual market price on a second-by-second basis within a day. For the ex post test, the hypothesis is:

$$\epsilon_{xp} = |F(t,T) - S(t)e^{r(T-t)} + D(t,T)| - b(t) \leq 0 \qquad (2)$$

S(t) equals $\sum_{i=1}^{20} P_i(t_i') / d(t')$ where t_i' equals t if the ith share is traded at time t, otherwise t_i' equals the closest time prior to t when the ith share is traded, $P_i(t_i')$ equals the price at time t′ of the ith share, and d(t′) equals the adjustment divisor used at t′. We call S(t) the ex post or 'backward looking' index value at t. b(t) is the present value of the sum of the transaction costs incurred in the arbitrage.

Let $F(t,T) - S(t)e^{r(T-t)} + D(t,T)$ equal v. The trading strategy to profit from a mispriced futures contract which does not satisfy equation (2) consists of selling a futures contract and buying the underlying MMI stocks (proportional to d(t′)) and hold this position until T if v is positive and v - b(t) is positive.[20] If v is negative and |v| - b(t) is positive, then sell short the underlying index stocks and buy the futures contract. In either case, the net profit from the arbitrage will be a positive ϵ_{xp} because the futures price will converge to the spot index value at T .

Traders are not guaranteed to execute their orders at the observed prices and an ex post violation (i.e., a positive ϵ_{xp}) is merely a 'mispricing signal' to traders for action. For the ex ante test, therefore, the hypothesis is instead:

$$\epsilon_{xa} = |F(t+1,T) - S(t+1)e^{r(T-t)} + D(t,T)| - b(t+1) \leq 0 \quad (3)$$

F(t+1) is the first futures price at least an execution lag after t. S(t+1) equals $\sum_{i=1}^{20} P_i(t+1) / d(t+1)$ where $p_i(t+1)$ equals the first price of the ith share at least an execution lag after t and d(t+1) equals the adjustment divisor used at t+1. We call S(t+1) the ex ante

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20. The 'buy and hold to maturity' strategy is only one possible strategy and may not be optimal to arbitrageurs. The trader has the right to close out his arbitrage position before maturity if he chooses, and may do so due to institutionally- or self-imposed position limits. If the costs of closing out an existing position is less than those of opening a new position, then the early-closing option has value. An early-closing strategy, however, involves an additional risk and transaction costs since an ex post reversal signal is not necessarily a positive ex ante profit opportunity due to possible market corrections after the signal and traders have to incur one more commission to close a position in the futures market as well as one more bid-ask spread in stock markets. See Brennan and Schwartz (1986).

or 'forward looking' index value at t. b(t+1) is the time t+1 present value of the sum of transaction costs incurred in the arbitrage. ϵ_{xa} is, therefore, the ex ante arbitrage profit at t+1, triggered by a mispricing signal (a positive ϵ_{xp}) at t.

The transaction costs involved in an index futures arbitrage include i.) round-trip commissions to buy and sell the stocks in the spot market, ii.) one commission to open a position in the futures market, and iii.) one 'market impact' cost (i.e., bid-ask spread) in the stock market.[21] Total proportional round-trip commissions range from about 0.5% to 1.0% of the underlying index value.[22] Test results will be reported for commission levels of 0.5%, 0.75%, and 1.0%.[23]

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21. If the arbitrage position is held to the maturity of a futures contract (as assumed in this section), the trader does not incur additional market impact costs in the spot market since the component stocks can be sold or bought at market closing prices which is equal to the terminal futures price. If the arbitrage position is closed prior to maturity, the trader incur two additional costs: one commission to close the position in the futures market and one 'market impact' cost in the stock market.

22. Stoll and Whaley (1986) estimate the transaction costs to be approximately 0.5% to 0.75% of the underlying index value. Goldman Sachs (1985) provides an alternative estimate of 0.6% to 1.0%.

23. Proxies for transaction costs used in this study may underestimate the true costs incurred in index arbitrages by ignoring some costs noted by Phillips and Smith (1980). They investigate the structure of trading costs in the market and indicate that several costs are generally ignored in most empirical studies. Those costs include the opportunity cost of seats on the exchanges.

It is assumed that traders can use 100% of short-sale proceeds and can borrow stocks for short sale. The short sale rule (i.e., traders must wait until an uptick (or a zero uptick) for every twenty MMI component stocks for short sales) is imposed. Traders are assumed to be able to borrow or lend money at the riskless rate.[24] Finally, a range of alternative execution lags is assumed: twenty seconds to five minutes is market practitioners' estimate of the time lag between observing mispricing signals and executing orders at the spot and futures markets simultaneously.[25] Test results will be reported for execution lags of twenty seconds, two minutes, and five minutes.[26]

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24. Capital charges incurred in the actual markets may be higher than Treasury bill rates. Phillips and Smith (1980) estimate that net capital charges incurred in the options markets are higher than the NY call rate.

25. Time (November 10, 1986, p. 68) reports that the execution lag is no more than twenty seconds for index arbitrages. It seems to overestimate the speed of execution by arbitrageurs. A couple of arbitrage practitioners inform the author that two to three minutes is a reasonable upper bound for heavily traded stocks like those of the MMI. Stulz (1988) reports that it takes up to five minutes if the arbitrage involves trades of at most two thousand shares per stock, otherwise execution may take longer: the specialist receives the order through the SuperDot system within two minutes from the time that index arbitrageur direct the order and execution is guaranteed within three minutes from receipt of the order by the specialist.

26. In the New York Stock Exchange, orders reach the specialist post by floor brokers walking to the post or through the exchange's automated order routing system called SuperDot which is an improved version of the previous DOT (Designated Order Turnaround) system. The

(Footnote continues on next page)

2. Test of the Correlation between the Trading Volume in the Index Futures Market and Volatility of Component Share Prices

To test if there is a significant correlation between daily stock market volatility and the daily trading volume in the futures market during the sample period, nonparametric analysis is conducted using the Spearman's rank correlation test. The proxy used for stock market volatility is the daily variance of returns on the spot index measured across five minute intervals. We match the proxy for stock market volatility and the daily trading volume in the futures market, and calculate rank correlation coefficients and p-values.

(Footnote continued from previous page)

SuperDot system was launched in November 1984. Member firms can transmit orders through their own links to the NYSE's common message switch and the SuperDot system then routes the order to the appropriate trading post for display and execution. If a large number of orders enter into the system, however, significant delays in executing orders and/or limited access to arbitrageurs are possible as the exchange experienced during the afternoon of October 19, 1987 when 470,100 orders were received through the system. If this 'liquidity' problem occurs frequently, index arbitrage activities would be slow due to concerns about delays and the consequent ineffective execution of orders in the spot market. This may also make some index arbitrageurs unwilling to trade in the index futures market, resulting in another liquidity problem. Prior to October 19, 1987, the record number of system orders through SuperDot was 270,000. Therefore, during our sample period of 1984 through 1986, difficulties in liquidity in both markets caused by insufficient capacity of the system never occurred.

3. Test of the Correlation between Spot Market Volatility and Boundary Violations of Index Futures Prices

To test if there is any systematic relation between stock market volatility and index arbitrage profitability during the sample period, nonparametric analysis is conducted using the Spearman's rank correlation test. The proxy used for stock market volatility is the daily variance of returns on the spot index measured across five minute intervals. Six alternative proxies are used to represent index arbitrage profitability. These are i.) daily average size of ex post violations (index point per mispricing signal), ii.) daily average size of ex ante violations (index point per execution), iii.) daily average size of profits from 'profitable' arbitrages, ex ante, (index point per arbitrage),[27] iv.) daily frequency of ex post violations as a percentage of daily observations, v.) daily frequency of ex ante executions as a percentage of daily observations, and vi.) daily frequency of profitable arbitrages, ex ante, as a percentage of daily observations. We match the proxy for stock market volatility and one proxy at a time for index arbitrage profitability, and calculate rank correlation coefficients and p-values. Obviously, this procedure

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27. Profitable index arbitrages are arbitrages which result in positive ex ante profits while unprofitable arbitrages are arbitrages which result in negative ex ante profits.

provides only a crude and indirect test of the link between index arbitrages and stock market volatility.

CHAPTER V

EMPIRICAL RESULTS FOR BOUNDARY TESTS

1. Summary of Alternative Efficiency Tests of MMI Futures Prices

Table 1 summarizes results of the alternative boundary-violation tests for the data set of the heavily-traded Major Market Index futures contracts (one, two, and three month contracts which account for more than 94% of total observations).[28] The first set of results, Panel A, is based on the reported level of the spot index. These tests follow the practice of earlier studies and assume that traders can execute their orders at the reported ex post index level adjusted for bid-ask spread.[29] Panel B reports results based on transactions data for our improved tests, which impose the short-sale rule and alternative execution lags.[30]

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28. Six month contracts are infrequently traded and there are only 443 observations during eight months in 1986. These contracts will, however, be discussed when it is relevant.

29. A detailed tabulation of replication results for each contract by sample year is provided in Appendix.

30. MMI futures contracts are traded between 8:45 a.m. and 3:15 p.m. while the MMI stocks are traded between 9:00 a.m. and 3:00 p.m. Chicago time. (after October 1, 1985 , both exchanges open half an hour earlier.) After 3:00 p.m. traders are not guaranteed to buy or short sell all of the twenty component stocks which are needed to create a riskless arbitrage. Also, futures markets open fifteen minutes earlier than the NYSE. So futures quotations for the above

(Footnote continues on next page)

As noted earlier, the boundary condition tests should be done for ex ante violations. Results indicate that the frequency of profitable arbitrages in the MMI futures prices under our improved tests is substantially smaller than that based on the reported index value. With 0.5% transaction costs and a twenty second execution lag, for example, 14.39% of the total number of observations correspond to profitable arbitrages in Panel B, while the comparable figure in Panel A is 17.71%. Longer execution lags (two and five minutes), of course, reduce the frequency of profitable arbitrages, which becomes 13.87% for a two minute lag and 13.35% for a five minute lag. Further, the average size of ex ante violations (i.e., arbitrage profits) is substantially lower and the frequency of executable arbitrages is smaller in terms of percentages of total observations when using transactions data as in Panel B rather than that using the reported index as in Panel A. The bias associated with the reported spot index can be large, especially for higher transaction costs. For example, the average size of ex ante violations is 0.09 index points and the frequency of ex ante violations is 0.53% for 1.0% transaction costs

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two fifteen minutes during which the stock market was not open are discarded both in the replication and in our transactions data tests. Also in transactions data tests, futures prices are discarded for ex ante tests if there are no matching quotations available for twenty component shares of the index during the closing hours to insure that tests are based on same-day prices.

and a five minute execution lag while matching numbers are 0.30 index points and 1.04% frequency in Panel A.

Nevertheless, Panel A overestimates the frequency of ex post violations. Futures prices are discarded in our transactions data tests unless there exist matching prices for all twenty component shares during the opening hours every trading day. When the reported index is used, however, it will report the index value even if not all twenty stocks are traded yet. Thus, spurious discrepancies (i.e., ex post violations) between the theoretical price based on the reported index and the actual futures price will appear during the early opening hours. Table 1 suggests that previous researchers overestimated the frequency of boundary violations as well as the size of arbitrage profits by focusing on ex post tests (i.e., without imposing execution lags and short-sale rule) and by using the reported index instead of transactions data.

2. Ex Post Violations of Futures Price Boundaries by MMI Futures Contracts

Table 2 reports the frequency and average size of ex post violations by contract maturity and calendar year. The results show that more ex post violations are found for contracts with longer maturities. With 0.5% transaction costs, for example, 13.89% of all observations correspond to ex post arbitrage opportunities for one month contracts, 19.46% for two month contracts, 26.36% for three month contracts, and 68.94% for six month contracts for the entire sample period.[31]

The fourth panel in the table provides summary statistics for all heavily-traded contracts which are one, two, and three month contracts. It shows that the frequency of ex post violations has decreased dramatically over the sample years. Mispricing signals are infrequent (i.e., less than 1% of observations) in 1986, the most recent year in the sample, for traders with high transaction costs. Note that only the 0.5% transaction costs still display a significant percentage of mispricings in 1986. Except for the infrequently-traded six month contracts, it is not clear, however, whether the average size of mispricing signals has also decreased with time: the average size of mispricing signals has decreased for 0.5% transaction costs while it has increased for higher transaction costs.

One should be cautious in interpreting results for six month contracts. Large and frequent ex post violations for six month contracts are not necessarily 'signals' for action to traders. Index arbitrageurs would be unwilling to execute their orders based on ex

31. MacKinlay and Ramaswamy (1988) study intraday (but reported) spot index quotation and intraday futures price data and report qualitatively similar results: the longer the maturity is, the bigger and more frequent violations are observed. A plausible explanation for this finding is that transaction cost band should be wider for longer maturity contracts because early closing is more likely and discrepancies caused by our approximation of expected future dividends are likely to be larger for longer maturity contracts.

post violations for these infrequently-traded and low-volume contracts because they worry about possibly large differences between the execution price and the observed ex post price due to low liquidity. In the absence of an auctioneer who functions like a NYSE specialist, liquidity in futures markets is maintained by 'locals' who frequently trade into and out of positions in a few minutes and might not be willing to take positions for infrequently-traded contracts. Recall that there were only 443 transaction records during eight months in 1986 for the six month contract.

3. Comparison of Signals for Long Arbitrage and Short Arbitrage

Table 3 is constructed from results in Table 2 in order to separately report the frequency and average size of observed signals for long arbitrage and short arbitrage. Results do not support the 'tax timing option' hypothesis proposed first by Cornell and French (1983a): index futures contracts are dominantly overpriced for ex post violations.[32] Summary statistics for heavily-traded contracts (the

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32. We need a cautious interpretation here. Results in Table 3 do not necessarily imply that the tax-timing option hypothesis is invalid. According to the model by Cornell and French (1983a), the value of the tax timing option is an increasing function of the maturity of futures contracts, converging to zero as the maturity declines and a decreasing function of the dividend yield. Discrepancies between their model and our results, therefore, may be due to our use of the MMI, whose dividend yield is higher than that of S&P 500 or NYSE Composite Index used by Cornell and French (1983a) or our use of different sample period (1984-1986) from their sample period (1982).

fourth panel in the table) show that only 7.04% (i.e., 1998 out of 28357) of ex post violations are signals for short arbitrage with 0.5% transaction costs. For higher transaction costs, signals for short arbitrage are less than 2% of ex post violations.

The table also shows that signals for short arbitrage are much more volatile than those for long arbitrage: their standard deviations are relatively larger in most cases except for six month contracts. Again, it is not clear whether the average size of short arbitrage signals is larger or smaller than its counterpart.

4. Ex Ante Violations of Futures Price Boundaries by MMI Futures Contracts[33]

Table 4 reports the frequency and average size of ex ante arbitrage profits for heavily-traded contracts by calendar year, assuming traders can execute their orders at the first available futures and stock prices at least twenty seconds, two minutes, and five minutes after they observe ex post mispricing signals.[34] Results show that, as the MMI futures market matured, there were fewer

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33. Empirical results are, hereafter, reported for summary statistics for heavily-traded contracts of one, two, and three month maturities. Detailed test results by each contract maturity including 6 month contracts are omitted to save space. They will be discussed, however, when relevant.

34. Numbers of executed positions are smaller than matching numbers of ex post mispricings due to the same-day arbitrage constraint and the uptick rule for short sales of stocks.

arbitrage opportunities for traders with higher transaction costs (0.75% and 1.0%). For example, Panel 1 (results with a twenty second lag) shows that with 0.75% transaction costs, the frequency of ex ante executions was 1,427 out of 78,000 and 198 out of 40655 in 1985 and 1986 respectively, compared to 6,523 out of 53672 observations in 1984.

Compared to the results in Table 2, this table also clearly shows that ex ante arbitrage profits are substantially smaller and more volatile than matching ex post mispricing signals, especially in 1986. The standard deviations of arbitrage profits are quite large relative to their means, even for 0.5% transaction costs. Therefore ex ante arbitrage profits are not 'riskless'. These findings are most pronounced in panel 3 where the execution lag is five minutes. For example, the average size of ex post mispricing signals in 1986 (the fourth panel in Table 2) for 0.5% transaction costs is 0.32 index points with a standard deviation of 0.45. The corresponding size of ex ante violation in Table 4 is 0.23 with a standard deviation of 0.40 for a twenty second lag, 0.17 with a standard deviation of 0.41 for a two minute lag, and 0.14 with a standard deviation of 0.45 for a five minute lag. Table 4 also shows that the average size of ex ante arbitrage profits has declined by more than 54% (from 0.50 to 0.23 index points) during the sample period with a twenty second execution lag, 65% (from 0.49 to 0.17 index points) with a two minute lag, and 71% (from 0.48 to 0.14 index points) with a five minute lag even for the lowest transaction costs of 0.5% since the introduction of MMI futures contract in July 1984. In fact, the average ex ante arbitrage profit was negative in 1986 for 0.75% or 1.0% transaction costs even for the shortest execution lag assumed (twenty seconds). When the lag is five minutes, the average arbitrage profit for 1.0% transaction costs is negligible as early as in 1984 (average ex ante violation of 0.01 index points with standard deviation of 0.43 index points) as well as for the entire sample period (average ex ante violation of 0.09 with standard deviation of 0.80) even though traders with 1.0% transaction costs observe quite frequent and large mispricing signals, as we see in Table 2.

One thing to note is that in the fourth panel of Table 2, the average mispricing signal in 1986 with 1.0% transaction costs was 2.01 index points while the average ex ante arbitrage profit based on signals here in Table 4 is -0.89 points with a twenty second lag, -1.46 points with a two minute lag, and -1.57 points with a five minute lag. Similar results (significantly positive mispricing signals, but negative ex ante arbitrage profits) are reported in 1986 for 0.75% transaction costs even with a twenty second lag. This implies that the MMI futures market has matured with time and responded to ex post mispricings quickly enough to eliminate profit opportunities for higher transaction costs.

Figure 1 presents the average size of ex post mispricing signals and corresponding ex ante arbitrage profits for 0.5% transaction costs each month during twenty six months of our sample period. Results are shown for alternative execution lags assumed and for the most heavily-traded one month contract. The figure clearly shows that the MMI futures market has matured with time. During the months in 1984, the size of ex ante profits even with the longest lag time assumed (five minutes) is not much different from the size of matching ex post signals and is quite large. The size of ex ante profits is, however, close to zero or negative in fifteen months out of twenty months since January 1985, even for the shortest lag time assumed (twenty seconds), even though matching ex post signals are quite large. For longer lag time (two minutes and five minutes), the monthly average size of ex ante profits is significantly negative throughout 1986.

Finally, this table as well as Figure 1 shows that the size of ex ante arbitrage profits is much more sensitive to the assumed execution lag in 1986 than it was in 1984. For example, when the execution lag is twenty seconds, the size of ex ante profits is 0.50 in 1984 for 0.5% transaction costs with the corresponding ex post mispricing signal of 0.52. As we assume longer lags, the size becomes 0.49 (for a two minute lag) and 0.48 (for a five minute) in 1984: the market was not responding quickly to ex post mispricing signals. Market response is much quicker in 1986: the size of ex ante profits is 0.23 for a twenty second lag, 0.17 for a two minute lag, and 0.14 for a five minute lag while the matching ex post mispricing signal is 0.32.

5. Comparison of Ex Ante Violations for Long and Short Arbitrages

Another interesting result is that short arbitrages involving short sales of shares are much 'riskier' than long arbitrages. Table 5 is constructed from results in Table 4 in order to separately report the frequency and average size of ex ante violations for long arbitrages and short arbitrages. Results show that most ex post mispricing signals requiring short sales of stocks were executable within the same day the signal occurred: short arbitrages based on the MMI are less complicated as the short sale rule must be observed for only twenty stocks and the arbitrageur can establish a short position that properly represents the index within a day the signal occurs. However, the average size of arbitrage profits from short arbitrages was significantly smaller and more volatile than that from long arbitrages due to price corrections before short sales could be made. Panel 2, for example, shows that the average size of ex ante arbitrage profits for long arbitrages is 0.44 index points with a standard deviation of 0.52 while the size for short arbitrages is 0.17 index points with a standard deviation of 0.57, during the entire sample period, for 0.5% transaction costs and a two minute lag. An arbitrageur attempting to sell short a basket of twenty stocks must wait for an uptick (or a zero uptick) in each of the twenty stocks for an MMI arbitrage. Thus, a short position will take more time to establish than a long position in the spot market.[35] Clearly, it is riskier for traders to wait for upticks for each of twenty stocks for short sales and attempt to take advantage of apparently underpriced futures.

One thing to recall from Table 3 is that, with 0.75% and 1.0% transaction costs, the average size of signals for short arbitrages is significantly larger than that for long arbitrages. Here in Table 5, however, ex ante profits are negligible at best or significantly negative for short arbitrages with high transaction costs. Also, with 0.5% transaction costs, the average size of the signals is the same (0.32 index points) for both long and short arbitrages in 1986 (as we see in Table 3) while the average ex ante profits from short arbitrages are negligible if the execution lag is longer than two minutes (in fact, 0.05 for a two minute lag and zero on average for a five minute lag).

Finally, ex ante test results for short arbitrages are much more sensitive to the assumed lag time than results for long

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35. Assuming transaction costs of 0.5% and an execution lag of twenty seconds, with results for most heavily-traded one month contracts, the average time it took to establish a short position in the stock market (i.e., short sell a basket of twenty MMI stocks) after observing a signal for short arbitrage was 132 seconds while it took 98 seconds on average to establish a long position (i.e., buy twenty MMI stocks) for long arbitrage during our sample period; when the execution lag is two minutes, it took, on average, 236 seconds (for short positions) and 201 seconds (for long positions); it took, on average, 425 seconds (for short positions) and 385 seconds (for long positions) for a five minute lag.

arbitrages and the size of arbitrage profits for short arbitrages has declined more sharply with time as the MMI index futures market has matured.

6. Frequencies of Profits and Losses for Index Arbitrages

Table 6 is constructed from results in Table 4 to show that index arbitrages using the MMI futures contracts have become riskier as the market has matured: the frequency and average size of profitable index arbitrages have declined with time while those of unprofitable arbitrages have increased with time. For 0.75% and 1.0% transaction costs, for example, the probability of a profitable index arbitrage was less than 50% of all executions in 1986 even with the shortest lag time assumed while it was very high in earlier years. If the execution lag is five minutes, the index arbitrage has just a 50% chance of success with 1.0% transaction costs as early as in 1984. Even for the lowest transaction costs, the chance of profitable index arbitrages is reduced to 65% in 1986 from 88% in 1984, with an execution lag of five minutes.

7. Comparison of Success Rates for Long Arbitrages and Short Arbitrages

Table 7 is constructed from results in Table 5 to further show that short arbitrages are much riskier than long arbitrages. When the assumed execution lag is twenty seconds, for example, the frequency of profitable arbitrages is 89% and the average profit is 0.53 index points for long arbitrages for the entire sample period while matching numbers for unprofitable arbitrages are 11% and -0.14 index points with 0.5% transaction costs. In contrast, the frequency of profitable arbitrages is 77% and the average profit is 0.35 index points for short arbitrages for the entire sample period while matching numbers for unprofitable arbitrages are 23% and -0.31 index points with 0.5% transaction costs. When the execution lag is longer, the success rate is significantly lower for both strategies. This finding is, however, more pronounced for short arbitrages.

CHAPTER VI

EMPIRICAL RESULTS ON THE CORRELATION BETWEEN THE TRADING VOLUME IN THE MMI FUTURES MARKET AND SPOT MARKET VOLATILITY

1. Monthly Trend of the Trading Volume in the MMI Futures Market and Spot Market Volatility

Figure 2 illustrates the daily average trading volume of MMI futures contracts of all maturities each month during our sample period.[36] It shows that the daily average trading volume was relatively large (11,000 to 19,000 contracts a day on average) during months in 1984 and early months (January and February) in 1985 after MMI contracts were first introduced on July 24, 1984. The volume declined sharply, however, during March to August of 1985. The emergence of bigger contracts, MMI Maxi, on July 6, 1985 boosted the trading volume sharply again to about 20,000 contracts a day. It is interesting to ask why the volume was very low during March to August of 1985. A plausible explanation for the decline is that the market learned that index arbitrage is risky. Recall that in Figure 1, the

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36. Daily trading volume data are collected from the Wall Street Journal. Trading volume in Figure 2 is measured as the volume for MMI contracts plus 2.5 times the volume for MMI Maxi contracts since the size of MMI Maxi contracts is two and one half as large as that of MMI contracts. MMI contracts were introduced on July 24 1984. MMI Maxi contracts were introduced on July 6 1985. Starting on June 2 1986, the Wall Street Journal has reported only the MMI Maxi volume. Also, it did not report the MMI volume for several days before August 1 1984. Consequently, empirical tests are conducted, for this chapter, using available data for August 1 1984 to May 29 1986.

size of ex ante profits was negative throughout the first half of 1985 even for a twenty second lag and 0.5% transaction costs. In contrast, trading was much heavier during months in 1984 when the size of ex ante profits was quite large even with a five minute lag. Traders might have learned that the market had matured enough not to allow the big and frequent arbitrage profit opportunities. The trading volume has been declining again since the early months in 1986 during which the size of ex ante profits was again negative.

Figure 3 pictures the daily average variance of returns on the spot MMI measured across five minute intervals each month during our sample period. The spot market experienced a gradual decline in its volatility during April to August of 1985 when the trading volume in the MMI futures market plunged into the lowest level. The volatility had dramatically increased during September 1985 to April 1986 when the trading volume in the futures market increased sharply.[37] Note that the curvature of Figure 3 is quite similar to that of Figure 2.

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37. Our measure of volatility indicates that the introduction of MMI futures contracts contributes to the (temporal) increase in volatility of the spot MMI. MMI contracts were introduced on July 24, 1984. When we include trading days (for component shares of the MMI) of July 1 to July 23, the monthly average variance of return for July 1984 is 47E-8. In contrast, it is 57E-8 when we exclude those trading days during which MMI futures contracts were not introduced yet.

2. Results of Nonparametric Correlation Tests

To provide distribution free results on the relation between the trading volume in the MMI futures market and volatility of component share prices, Table 8 reports estimates of Spearman's rank correlation coefficients. Results indicate that the daily trading volume in the MMI futures market is positively correlated with spot market volatility. The rank correlation is very high: 0.70835 (with p-value of 0.0001) using the period during which only MMI contracts were traded and 0.72352 (with p-value of 0.0001) using both MMI and MMI Maxi Contracts. We measure the trading volume as the volume of MMI contracts plus 2.5 times the volume of MMI Maxi contracts since the size of MMI Maxi contracts is two and one half as large as that of MMI contracts. The correlation is 0.45122 (with p-value of 0.0001) when the trading volume is measured as the MMI volume plus the MMI Maxi volume.

CHAPTER VII

EMPIRICAL RESULTS ON THE RELATION BETWEEN STOCK MARKET VOLATILITY AND AVERAGE SIZE AND FREQUENCY OF BOUNDARY VIOLATIONS IN INDEX FUTURES PRICES

To provide distribution free results on the relation between arbitrage opportunities in the MMI futures market and the volatility of component share prices, Table 9 reports estimates of Spearman's rank correlation coefficients. Results indicate that index arbitrage opportunities are correlated with stock market volatility. For one month and three month contracts, there are significant positive correlations between the measure of stock market volatility and the average size of ex post violations, the frequency of ex post violations, and the frequency of ex ante executions. Correlations are, however, negative between stock market volatility and the size of ex ante violations (arbitrage profits), and become significant as the execution lag is longer, except for infrequently-traded six month contracts. This is an interesting finding in the following sense: the more volatile the spot market is on a given trading day, the larger the number and the size of ex post mispricing signals are observed. The actual ex ante arbitrage profits based on those signals are, however, smaller when the spot market is more volatile. Furthermore, significant positive correlations between stock market volatility and the frequency of profitable arbitrages are observed for one month and two month contracts when the execution lag is very short, but become insignificant when the execution lag is longer. Reasonably 'quick' market corrections for mispricings are a plausible explanation for these findings. Such patterns are very clear for one month contracts. The one month contract is the most heavily traded contract in the market: sixty-two percent of total observations in this study are for one month contracts (112,654 out of 182,891). Clearly, stock market volatility is correlated with arbitrage opportunities for heavily-traded 'on the run' contracts.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

This dissertation tests the efficiency of the Major Market Index futures market using transactions data for futures prices and for prices of the twenty component stocks. The simple cost-of-carry model is adapted to incorporate transaction costs for different classes of traders, alternative execution lags, and the short-sale rule. Using this model of stock index futures prices, a typical index arbitrage strategy was simulated for the period of July 24, 1984 to August 31, 1986. With the same transactions data, this dissertation also tests whether there is any significant relation between stock market volatility and index arbitrage profitability during the sample period, using the Spearman's rank correlation tests.

Results show that previous studies significantly overestimate the size and frequency of profitable arbitrages in the index futures market by focusing on ex post tests (without assuming execution lags and imposing the short-sale rule) and by using the reported index instead of transactions data. Also, it appears that the MMI futures market has matured. The frequency and size of ex ante violations (arbitrage profits) have declined sharply since the contract's introduction in July 24, 1984. The frequency of ex ante violations declines sharply with the assumed level of transaction costs and the assumed length of the execution lag. The size of arbitrage profits has become substantially smaller, while the standard deviation of profits has become larger. Especially in 1986, the most recent sample year in this study, only traders with transaction costs of 0.5% (the lowest level of commission assumed) still displayed some evidence of profitable arbitrages while the average size of index arbitrage profits for 0.75% and 1.0% transaction costs is negative for all execution lags assumed even though corresponding ex post mispricing signals are quite large. The estimated arbitrage profits, however, cannot be unambiguously attributed to index futures market inefficiency: profits realized from strategies described in Section IV are not riskless, as evidenced by their large standard deviation.

Results from our ex post tests do not support the 'tax timing option' hypothesis proposed first by Cornell and French (1983a): index futures contracts are dominantly overpriced for ex post violations. Results show that only 7.04% of ex post violations are signals for short arbitrage with 0.5% transaction costs. For higher transaction costs, signals for short arbitrage are less than 2% of ex post violations. Another interesting result is that the frequency and size of arbitrage profits from executable short arbitrages are much smaller and more volatile than those from long arbitrages. In fact, for 0.75% and 1.0% transaction costs, the average size of ex ante arbitrage profits form short arbitrages is significantly negative throughout the sample period and for every lag time assumed, while corresponding ex post mispricing signals for them are very large and larger than those for long arbitrages. The uptick rule in the stock market is a serious constraint to short arbitrages in the index futures market.

The nonparametric statistics provide evidence that the stock market volatility is positively correlated with the size and frequency of ex post boundary-violations, but is negatively correlated with the size of ex ante violations in MMI futures prices, at least for heavily traded, short-maturity contracts.

Futures contracts for the MMI have the smallest volume and are the cheapest contracts available in the market and it has been only five years since they were introduced in July 24, 1984. Subsequent researchers may find it worthwhile to look at 'older' futures contracts for large indices like the S&P 500, Value Line, or NYSE Composite. One can also investigate whether increased transaction costs for the opportunity cost of seats and higher capital charges may eliminate ex ante arbitrage profits for traders faced with the lowest transaction costs.

Table 1

Comparison of Results: Summary of the Alternative Efficiency Tests of Major Market Index Futures Prices

Panel A: Results based on the reported level of the spot index, with no short-sale rule and no execution lag imposed[i] (Sample size = 190794[j])

Level of Transaction Costs[a]	Ex post Violations[b] Freq(%)[c]	Size[d]
0.5%	33799(17.71%)	0.48
0.75%	10443(5.47%)	0.37
1.0%	1983(1.04%)	0.30

Panel B: Results based on transactions data of twenty component stocks of the Major Market Index from Fitch database, with the short-sale rule and an alternative execution lag imposed[i] (Sample size = 172327[j])

1) twenty second execution lag[k]

Level of Transaction Costs[a]	Ex post Violations[e] Freq(%)[c]	Size[d]	Ex Ante Violations[f] Positions Executed[c,h]	Size[d]	Profitable Arbitrages[g] Freq(%)[c]	Size[d]
0.5%	28374(16.47%)	0.46	28210(16.37%)	0.43	24799(14.39%)	0.52
0.75%	8210(4.76%)	0.32	8148(4.73%)	0.26	6539(3.79%)	0.36
1.0%	963(0.56%)	0.48	944(0.55%)	0.23	619(0.36%)	0.51

2) two minute execution lag[k]

Level of Transaction Costs[a]	Ex post Violations[e] Freq(%)[c]	Size[d]	Ex Ante Violations[f] Positions Executed[c,h]	Size[d]	Profitable Arbitrages[g] Freq(%)[c]	Size[d]
0.5%	28374(16.47%)	0.46	28071(16.29%)	0.42	23895(13.87%)	0.53
0.75%	8210(4.76%)	0.32	8109(4.71%)	0.24	6126(3.55%)	0.37
1.0%	963(0.56%)	0.48	940(0.55%)	0.20	550(0.32%)	0.57

(Table 1 continued on the next page.)

Table 1--Continued

3) five minute execution lag[k]

Level of Transaction Costs[a]	Ex post Violations[e] Freq(%)[c]	Size[d]	Ex Ante Violations[f] Positions Executed[c,h]	Size[d]	Profitable Arbitrages[g] Freq(%)[c]	Size[d]
0.5%	28374(16.47%)	0.46	27784(16.12%)	0.40	23012(13.35%)	0.54
0.75%	8210(4.76%)	0.32	8031(4.66%)	0.21	5774(3.35%)	0.37
1.0%	963(0.56%)	0.48	915(0.53%)	0.09	463(0.27%)	0.54

a. Percentage of the underlying index value.

b. Traders can make positive arbitrage profits assuming they can execute orders at the reported index level (adjusted for bid-ask spread) and observed futures prices.

c. Percentage out of observations in parentheses.

d. In terms of index points: one index point = $100.

e. Traders can make positive arbitrage profits (i.e., positive ϵ_{xp}) assuming they can execute orders at the observed stock prices (adjusted for bid-ask spread) and futures prices.

f. The ex ante arbitrage profits at t+1 (i.e., ϵ_{xa} in equation (3)) triggered by mispricing signals (positive ϵ_{xp} at t) assuming traders can execute their orders at the next available prices at least an execution lag after they observe mispricing signals.

g. Traders can make positive ex ante arbitrage profits assuming they can execute their orders at the next available prices at least an execution lag after they observe mispricing signals.

h. Less than frequencies of ex post violations because some could not be executed within the same day the violation occurred and some others could not be executed due to the uptick rule for short sales of stocks.

i. Sample period is from July 24, 1984 to August 31, 1986. Actual futures prices and the reported level of the spot index are obtained from the CBT's 'Time and Sales Journal' tapes; the true value of the spot index is computed with transactions prices for the component shares of the index obtained from the Fitch database; the dividend data are collected form Moody's Dividend Record and Value Line; the average of the bid and ask discounts on the T bill is used to compute the risk-free interest rates.

j. For heavily-traded contracts (one, two, and three month contracts which account for more than 94% of total observations). Also, there were 781 outliers identified from futures price data whose mispricing signals were larger than ten index points. They were double-checked with the highs and lows for futures contracts and for index values quoted in The Wall Street Journal for days they appeared on. All of them were proven to be invalid and discarded. The sample size in Panel B is smaller than that in Panel A because futures prices are discarded in our transactions data tests unless there exist matching prices for all twenty component shares during the opening hours every trading day. When the reported index is used, however, it will report the index value even if not all twenty stocks are traded yet.

k. An execution lag is the lag time between t and t+1.

Table 2

Summary Statistics on Ex Post Violations of Futures Price Boundaries by Major Market Index Futures Contracts[a]

Contracts	Time Period[b]	Observa-tions	Level of Transaction Costs[c]	Ex Post Violations[g] Freq(%)[d]	Size[e]	SD[f]	Min	Max
1 Month	1984	38587	0.5%	11095(28.75%)	0.54	0.36	0.00	6.04
			0.75%	4454(11.54%)	0.29	0.28	0.00	5.44
			1.0%	461(1.19%)	0.30	0.40	0.00	4.85
	1985	49756	0.5%	2432(4.89%)	0.24	0.25	0.00	2.94
			0.75%	187(0.38%)	0.16	0.24	0.00	2.30
			1.0%	2(0.00%)	1.60	0.09	1.54	1.66
	1986	24311	0.5%	2122(8.73%)	0.28	0.34	0.00	7.48
			0.75%	77(0.32%)	0.49	1.06	0.01	6.57
			1.0%	12(0.05%)	1.16	2.09	0.06	5.66
	1984-6	112654	0.5%	15649(13.89%)	0.46	0.37	0.00	7.48
			0.75%	4718(4.19%)	0.29	0.31	0.00	6.57
			1.0%	475(0.42%)	0.32	0.53	0.00	5.66
2 Month	1984	11114	0.5%	4829(43.45%)	0.46	0.37	0.00	3.31
			0.75%	1417(12.75%)	0.32	0.31	0.00	2.77
			1.0%	230(2.07%)	0.29	0.32	0.00	2.23
	1985	20069	0.5%	2676(13.33%)	0.52	0.59	0.00	9.68
			0.75%	801(3.99%)	0.46	0.79	0.00	9.02
			1.0%	62(0.31%)	2.13	1.40	0.00	8.36
	1986	12388	0.5%	976(7.88%)	0.38	0.65	0.00	9.43
			0.75%	94(0.76%)	0.56	1.69	0.00	8.52
			1.0%	8(0.06%)	3.88	3.93	0.05	7.60
	1984-6	43571	0.5%	8481(19.46%)	0.47	0.49	0.00	9.68
			0.75%	2312(5.31%)	0.38	0.63	0.00	9.02
			1.0%	300(0.69%)	0.76	1.29	0.00	8.36

(Table 2 continued on the next page.)

Table 2--Continued

Contracts	Time Period[b]	Observations	Level of Transaction Costs[c]	Ex Post Violations[g] Freq(%)[d]	Size[e]	SD[f]	Min	Max
3 Month	1984	3971	0.5%	1853(46.66%)	0.53	0.42	0.00	3.03
			0.75%	687(17.30%)	0.39	0.32	0.00	2.43
			1.0%	142(3.58%)	0.29	0.29	0.00	1.83
	1985	8175	0.5%	1941(23.74%)	0.42	0.39	0.00	4.32
			0.75%	452(5.53%)	0.31	0.48	0.00	3.68
			1.0%	43(0.53%)	0.79	0.94	0.01	3.04
	1986	3956	0.5%	450(11.38%)	0.40	0.33	0.00	2.15
			0.75%	41(1.04%)	0.28	0.33	0.00	1.40
			1.0%	3(0.08%)	0.43	0.29	0.11	0.68
	1984-6	16102	0.5%	4244(26.36%)	0.47	0.40	0.00	4.32
			0.75%	1180(7.33%)	0.35	0.39	0.00	3.68
			1.0%	188(1.17%)	0.41	0.55	0.00	3.04
1,2,3-Month Contracts	1984	53672	0.5%	17777(33.12%)	0.52	0.37	0.00	6.04
			0.75%	6558(12.22%)	0.31	0.29	0.00	5.44
			1.0%	833(1.55%)	0.29	0.36	0.00	4.85
	1985	78000	0.5%	7049(9.04%)	0.40	0.46	0.00	9.68
			0.75%	1440(1.85%)	0.37	0.66	0.00	9.02
			1.0%	107(0.14%)	1.58	1.38	0.00	8.36
	1986	40655	0.5%	3548(8.73%)	0.32	0.45	0.00	9.43
			0.75%	212(0.52%)	0.48	1.30	0.00	8.52
			1.0%	23(0.06%)	2.01	3.02	0.05	7.60
	1984-6	172327	0.5%	28374(16.47%)	0.46	0.41	0.00	9.68
			0.75%	8210(4.76%)	0.32	0.44	0.00	9.02
			1.0%	963(0.56%)	0.48	0.87	0.00	8.36

(Table 2 continued on the next page.)

Table 2--Continued

Contracts	Time Period[b]	Observa-tions	Level of Transaction Costs[c]	Ex Post Violations[g] Freq(%)[d]	Size[e]	SD[f]	Min	Max
6 Month	1984	5014	0.5%	3903(77.84%)	1.32	0.81	0.00	8.22
			0.75%	3109(62.01%)	0.97	0.71	0.00	7.68
			1.0%	1911(38.11%)	0.80	0.57	0.00	7.14
	1985	5107	0.5%	3081(60.33%)	0.64	0.59	0.00	5.42
			0.75%	1226(24.01%)	0.48	0.66	0.00	4.78
			1.0%	287(5.62%)	0.58	1.02	0.00	4.15
	1986	443	0.5%	299(67.49%)	0.58	0.46	0.00	3.40
			0.75%	67(15.12%)	0.46	0.45	0.00	2.63
			1.0%	8(1.81%)	0.55	0.68	0.01	1.86
	1984-6	10564	0.5%	7283(68.94%)	1.00	0.79	0.00	8.22
			0.75%	4402(41.67%)	0.83	0.73	0.00	7.68
			1.0%	2206(20.88%)	0.77	0.65	0.00	7.14

a. Hypothesis tested: $\epsilon_{xp} = |F(t,T) - S(t)e^{r(T-t)} + D(t,T)| - b(t) \leq 0$
where F(t,T) is the futures price at time t for a contract that matures at time T, S(t) is the ex post or 'backward looking' index value at t, b(t) is the present value of the sum of transaction costs at t, D(t,T) is the time T value of dividends paid on component stocks between t and T, and r(T-t) is risk-free interest rate spanning the period from t to T. Actual futures prices are obtained from the CBT's 'Time and Sales Journal' tapes; the spot value of the index is computed with transactions prices for the component shares of the index obtained from the Fitch database; the dividend data are collected form Moody's Dividend Record and Value Line; the average of the bid and ask discounts on the T bill is used to compute the risk-free interest rates.

b. 6 months for 1984, 12 months for 1985, and 8 months for 1986.

c. Percentage of the underlying index value.

d. Percentage out of observations in parentheses.

e. In terms of index points: one index point = $100.

f. SD = standard deviation.

g. Traders can make positive arbitrage profits (i.e., positive ϵ_{xp}) assuming they can execute orders at the observed stock prices (adjusted for bid-ask spread) and futures prices.

Table 3

Summary Statistics on Ex Post Violations of Futures Price Boundaries by Major Market Index Futures Contracts: Long Arbitrage vs Short Arbitrage Signals[a,f,g]

Contracts	Time Period[b]	Observations	Level of Transaction Costs[c]	Signal for Long Arbitrage Freq	Size[d]	SD[e]	Signal for Short Arbitrage Freq	Size[d]	SD[e]
1 Month	1984	38587	0.5%	10619	0.55	0.36	476	0.29	0.40
			0.75%	4377	0.29	0.27	77	0.29	0.68
			1.0%	458	0.28	0.33	3	2.63	2.00
	1985	49756	0.5%	1548	0.29	0.27	884	0.14	0.17
			0.75%	185	0.14	0.10	2	2.24	0.09
			1.0%	0	*	*	2	1.60	0.09
	1986	24311	0.5%	1850	0.28	0.27	272	0.24	0.65
			0.75%	71	0.33	0.35	6	2.44	3.22
			1.0%	9	0.25	0.14	3	3.91	2.97
	1984-6	112654	0.5%	14017	0.49	0.36	1632	0.20	0.37
			0.75%	4633	0.29	0.27	85	0.49	1.19
			1.0%	467	0.28	0.32	8	2.85	2.15
2 Month	1984	11114	0.5%	4793	0.46	0.37	36	0.24	0.18
			0.75%	1425	0.32	0.31	2	0.10	0.08
			1.0%	230	0.29	0.32	0	*	*
	1985	20069	0.5%	2565	0.53	0.57	111	0.32	0.93
			0.75%	794	0.45	0.73	7	1.56	3.34
			1.0%	60	2.05	1.15	2	4.67	5.22
	1986	12388	0.5%	826	0.37	0.30	150	0.42	1.50
			0.75%	88	0.21	0.23	6	5.67	4.33
			1.0%	4	0.20	0.14	4	7.55	0.06
	1984-6	43571	0.5%	8184	0.47	0.44	297	0.36	1.21
			0.75%	2297	0.36	0.50	15	3.01	4.10
			1.0%	294	0.65	0.93	6	6.59	2.77

(Table 3 continued on the next page.)

Table 3--Continued

Contracts	Time Period[b]	Observa-tions	Level of Transaction Costs[c]	Signal for Long Arbitrage: Freq	Size[d]	SD[e]	Signal for Short Arbitrage: Freq	Size[d]	SD[e]
3 Month	1984	3971	0.5%	1845	0.53	0.41	8	0.83	1.00
			0.75%	683	0.38	0.31	4	0.89	1.08
			1.0%	140	0.28	0.26	2	1.03	1.13
	1985	8175	0.5%	1940	0.42	0.39	1	0.01	*
			0.75%	452	0.31	0.48	0	*	*
			1.0%	43	0.79	0.94	0	*	*
	1986	3956	0.5%	390	0.40	0.32	60	0.40	0.36
			0.75%	37	0.27	0.29	4	0.39	0.68
			1.0%	2	0.30	0.27	1	0.68	*
	1984-6	16102	0.5%	4175	0.47	0.40	69	0.44	0.49
			0.75%	1172	0.35	0.39	8	0.64	0.87
			1.0%	185	0.40	0.55	3	0.91	0.83
1,2,3-Month Contracts	1984	53672	0.5%	17257	0.52	0.37	520	0.29	0.40
			0.75%	6475	0.31	0.29	83	0.31	0.70
			1.0%	828	0.28	0.31	5	1.99	1.75
	1985	78000	0.5%	6053	0.43	0.47	996	0.16	0.35
			0.75%	1431	0.36	0.62	9	1.71	2.91
			1.0%	103	1.52	1.24	4	3.14	3.50
	1986	40655	0.5%	3066	0.32	0.29	482	0.32	0.98
			0.75%	196	0.27	0.29	16	3.14	3.82
			1.0%	15	0.24	0.15	8	5.33	3.05
	1984-6	172327	0.5%	26376	0.48	0.39	1998	0.23	0.58
			0.75%	8102	0.32	0.37	108	0.85	2.03
			1.0%	946	0.42	0.63	17	3.83	3.07

(Table 3 continued on the next page.)

Table 3--Continued

Contracts	Time Period[b]	Observations	Level of Transaction Costs[c]	Signal for Long Arbitrage Freq	Size[d]	SD[e]	Signal for Short Arbitrage Freq	Size[d]	SD[e]
6 Month	1984	5014	0.5%	3625	1.33	0.82	278	1.09	0.64
			0.75%	2880	1.00	0.71	229	0.64	0.60
			1.0%	1796	0.83	0.55	115	0.39	0.68
	1985	5107	0.5%	2771	0.64	0.60	310	0.65	0.42
			0.75%	1100	0.48	0.69	126	0.42	0.29
			1.0%	259	0.62	1.06	28	0.19	0.18
	1986	443	0.5%	298	0.58	0.46	1	0.62	*
			0.75%	67	0.46	0.45	0	*	*
			1.0%	8	0.55	0.68	0	*	*
	1984-6	10564	0.5%	6694	1.01	0.80	589	0.85	0.58
			0.75%	4047	0.85	0.74	355	0.56	0.52
			1.0%	2063	0.80	0.64	143	0.35	0.62

a. Hypothesis tested: $\epsilon_{xp} = |F(t,T) - S(t)e^{r(T-t)} + D(t,T)| - b(t) \leq 0$
where F(t,T) is the futures price at time t for a contract that matures at time T, S(t) is the ex post or 'backward looking' index value at t, b(t) is the present value of the sum of transaction costs at t, D(t,T) is the time T value of dividends paid on component stocks between t and T, and r(T-t) is risk-free interest rate spanning the period from t to T. Actual futures prices are obtained from the CBT's 'Time and Sales Journal' tapes; the spot value of the index is computed with transactions prices for the component shares of the index obtained from the Fitch database; the dividend data are collected form Moody's Dividend Record and Value Line; the average of the bid and ask discounts on the T bill is used to compute the risk-free interest rates.

b. 6 months for 1984, 12 months for 1985, and 8 months for 1986.

c. Percentage of the underlying index value.

d. In terms of index points: one index point = $100.

e. SD = standard deviation.

f. Traders are not guaranteed to execute their orders at the observed prices and an ex post violation (i.e., a positive ϵ_{xp}) is merely a 'mispricing signal' to traders for action

g. Long Arbitrage means that the trader buys component stocks in the index and sells futures contracts: short arbitrage is the opposite.

Table 4

Summary Statistics on Ex Ante Violations of Futures Price Boundaries by Major Market Index Futures Contracts[a,b]

Contracts	Time Period[c]	Observa-tions	Level of Transaction Costs[d]	Ex Ante Violations[h]: Positions Executed[e]	Size[f]	SD[g]	Min	Max
Panel 1: twenty second execution lag								
1,2,3-Month Contracts	1984	53672	0.5%	17713	0.50	0.40	-1.16	8.13
			0.75%	6523	0.25	0.32	-1.75	6.83
			1.0%	819	0.12	0.34	-2.34	1.17
	1985	78000	0.5%	6989	0.37	0.56	-1.18	8.66
			0.75%	1427	0.35	0.77	-1.21	7.09
			1.0%	104	1.38	1.38	-1.85	3.42
	1986	40655	0.5%	3508	0.23	0.40	-1.51	7.72
			0.75%	198	-0.02	0.83	-2.34	6.81
			1.0%	21	-0.89	2.11	-3.25	5.89
	1984-6	172327	0.5%	28210	0.43	0.46	-1.51	8.66
			0.75%	8148	0.26	0.45	-2.34	7.09
			1.0%	944	0.23	0.77	-3.25	5.89
Panel 2: two minute execution lag								
1,2,3-Month Contracts	1984	53672	0.5%	17634	0.49	0.48	-1.19	9.62
			0.75%	6490	0.23	0.43	-1.75	9.91
			1.0%	814	0.10	0.56	-2.17	5.61
	1985	78000	0.5%	6939	0.37	0.65	-1.17	8.94
			0.75%	1418	0.32	0.83	-1.15	8.31
			1.0%	103	1.29	1.46	-1.79	3.33
	1986	40655	0.5%	3498	0.17	0.41	-1.69	2.03
			0.75%	201	-0.18	0.71	-2.59	1.19
			1.0%	23	-1.46	1.40	-3.50	0.42
	1984-6	172327	0.5%	28071	0.42	0.53	-1.69	9.62
			0.75%	8109	0.24	0.54	-2.59	9.91
			1.0%	940	0.20	0.87	-3.50	5.61

(Table 4 continued on the next page.)

Table 4--Continued

Contracts	Time Period[c]	Observa-tions	Level of Transaction Costs[d]	Ex Ante Violations[h]: Positions Executed[e]	Size[f]	SD[g]	Min	Max
Panel 3: five minute execution lag								
1,2,3-Month Contracts	1984	53672	0.5%	17494	0.48	0.54	-1.19	9.74
			0.75%	6440	0.21	0.47	-1.63	7.76
			1.0%	800	0.01	0.43	-2.23	5.61
	1985	78000	0.5%	6823	0.34	0.63	-1.22	9.59
			0.75%	1391	0.28	0.84	-1.36	8.96
			1.0%	92	1.28	1.49	-2.01	3.28
	1986	40655	0.5%	3467	0.14	0.45	-1.69	4.63
			0.75%	200	-0.19	0.74	-2.59	1.28
			1.0%	23	-1.57	1.36	-3.50	0.33
	1984-6	172327	0.5%	27784	0.40	0.56	-1.69	9.74
			0.75%	8031	0.21	0.57	-2.59	8.96
			1.0%	915	0.09	0.80	-3.50	5.61

a. Hypothesis tested: $\epsilon_{xa} = |F(t+1,T)-S(t+1)e^{r(T-t)}+D(t,T)| - b(t+1) \leq 0$
where F(t+1,T) is the futures price at time t+1 for a contract that matures at time T, S(t+1) is the ex ante or 'forward looking' index value at t, b(t+1) is the time t+1 present value of the sum of transaction costs, D(t,T) is the time T value of dividends paid on component stocks between t and T, and r(T-t) is risk-free interest rate spanning the period from t to T. Actual futures prices are obtained from the CBT's 'Time and Sales Journal' tapes; the spot value of the index is computed with transactions prices for the component shares of the index obtained from the Fitch database; the dividend data are collected form Moody's Dividend Record and Value Line; the average of the bid and ask discounts on the T bill is used to compute the risk-free interest rates.

b. An execution lag is the lag time between t and t+1.

c. 6 months for 1984, 12 months for 1985, and 8 months for 1986.

d. Percentage of the underlying index value.

e. Less than frequencies of ex post violations because some could not be executed within the same day the violation occurred and some others could not be executed due to the uptick rule for short sales of stocks. The number of positions executed with a twenty second lag is a bit smaller, for 0.75% and 1.0% transaction costs in 1986, than matching numbers with longer lags because a few outliers identified from futures price data are discarded. See footnote j for Table 1.

f. In terms of index points: one index point = $100.

g. SD = standard deviation.

h. The ex ante arbitrage profits at t+1 (i.e., ϵ_{xa} in equation (3)) triggered by mispricing signals (positive ϵ_{xp} at t) assuming traders can execute their orders at the next available prices at least an execution lag after they observe mispricing signals.

Table 5

Summary Statistics on Ex Ante Violations of Futures Price Boundaries by Major Market Index Futures Contracts: Long Arbitrages vs Short Arbitrages[a,b,h,i]

Contracts	Time Period[c]	Observations	Level of Transaction Costs[d]	Long Arbitrages Freq[e]	Long Arbitrages Size[f]	Long Arbitrages SD[g]	Short Arbitrages Freq	Short Arbitrages Size[f]	Short Arbitrages SD[g]
Panel 1: twenty second execution lag									
1,2,3-Month Contracts	1984	53672	0.5%	17193	0.51	0.40	520	0.31	0.33
			0.75%	6440	0.25	0.32	83	0.06	0.38
			1.0%	814	0.13	0.32	5	-1.48	0.38
	1985	78000	0.5%	5994	0.40	0.58	995	0.17	0.43
			0.75%	1418	0.35	0.76	9	0.00	1.17
			1.0%	100	1.45	1.32	4	-0.51	1.89
	1986	40655	0.5%	3035	0.25	0.37	473	0.12	0.56
			0.75%	182	0.04	0.54	16	-0.69	2.22
			1.0%	13	-0.31	0.86	8	-1.83	3.14
	1984-6	172327	0.5%	26222	0.45	0.45	1988	0.20	0.45
			0.75%	8040	0.26	0.44	108	-0.06	0.99
			1.0%	927	0.26	0.68	17	-1.42	2.31
Panel 2: two minute execution lag									
1,2,3-Month Contracts	1984	53672	0.5%	17115	0.50	0.48	519	0.26	0.35
			0.75%	6408	0.24	0.43	82	0.03	0.40
			1.0%	809	0.11	0.54	5	-1.55	0.37
	1985	78000	0.5%	5944	0.40	0.64	995	0.18	0.69
			0.75%	1409	0.33	0.83	9	-0.45	0.54
			1.0%	99	1.41	1.36	4	-1.54	0.37
	1986	40655	0.5%	3027	0.19	0.40	471	0.05	0.45
			0.75%	185	-0.08	0.58	16	-1.35	0.99
			1.0%	15	-0.63	0.93	8	-3.02	0.46
	1984-6	172327	0.5%	26086	0.44	0.52	1985	0.17	0.57
			0.75%	8002	0.25	0.53	107	-0.22	0.73
			1.0%	923	0.24	0.80	17	-2.24	0.85

(Table 5 continued on the next page.)

Table 5--Continued

Contracts	Time Period[c]	Observations	Level of Transaction Costs[d]	Long Arbitrages Freq[e]	Long Arbitrages Size[f]	Long Arbitrages SD[g]	Short Arbitrages Freq	Short Arbitrages Size[f]	Short Arbitrages SD[g]
Panel 3: five minute execution lag									
1,2,3-Month Contracts	1984	53672	0.5%	16978	0.49	0.54	516	0.22	0.36
			0.75%	6358	0.21	0.47	82	-0.04	0.40
			1.0%	795	0.02	0.41	5	-1.55	0.43
	1985	78000	0.5%	5838	0.38	0.64	985	0.12	0.50
			0.75%	1384	0.28	0.84	7	-0.31	0.51
			1.0%	90	1.34	1.45	2	-1.38	0.49
	1986	40655	0.5%	3007	0.16	0.43	460	0.00	0.52
			0.75%	184	-0.09	0.61	16	-1.43	0.99
			1.0%	15	-0.76	0.89	8	-3.08	0.50
	1984-6	172327	0.5%	25823	0.43	0.56	1961	0.12	0.48
			0.75%	7926	0.22	0.56	105	-0.27	0.73
			1.0%	900	0.13	0.73	15	-2.34	0.93

a. Hypothesis tested: $\epsilon_{xa} = |F(t+1,T) - S(t+1)e^{r(T-t)} + D(t,T)| - b(t+1) \leq 0$
where F(t+1,T) is the futures price at time t+1 for a contract that matures at time T, S(t+1) is the ex ante or 'forward looking' index value at t, b(t+1) is the time t+1 present value of the sum of transaction costs, D(t,T) is the time T value of dividends paid on component stocks between t and T, and r(T-t) is risk-free interest rate spanning the period from t to T. Actual futures prices are obtained from the CBT's 'Time and Sales Journal' tapes; the spot value of the index is computed with transactions prices for the component shares of the index obtained from the Fitch database; the dividend data are collected form Moody's Dividend Record and Value Line; the average of the bid and ask discounts on the T bill is used to compute the risk-free interest rates.

b. An execution lag is the lag time between t and t+1.

c. 6 months for 1984, 12 months for 1985, and 8 months for 1986.

d. Percentage of the underlying index value.

e. The number of long arbitrages executed with a twenty second lag is a bit smaller, for 0.75% and 1.0% transaction costs in 1986, than matching numbers with longer lags because a few outliers identified from futures price data are discarded. See footnote j for Table 1.

f. In terms of index points: one index point = $100.

g. SD = standard deviation.

h. An ex ante violation is the ex ante arbitrage profit at t+1 (i.e., ϵ_{xa} in equation (3)) triggered by a mispricing signal (a positive ϵ_{xp} at t) assuming traders can execute their orders at the next available prices at least an execution lag after they observe mispricing signals.

i. Long Arbitrage means that the trader buys component stocks in the index and sells futures contracts: short arbitrage is the opposite.

Table 6

Frequency and Size of Realized Profits and Losses for Index Arbitrages Based on Major Market Index and Futures Contracts on Major Market Index[a,b]

Contracts	Time Period[c]	Observa-tions	Level of Transac-tion Costs[d]	Positions Executed[e]	profitability of arbitrages[h]: Profits Freq(%)[f]	Profits Size[g]	Losses Freq(%)[f]	Losses Size[g]
Panel 1: twenty second execution lag								
1,2,3-Month Contracts	1984	53672	0.5%	17713	16382(92%)	0.55	1331(8%)	-0.13
			0.75%	6523	5238(80%)	0.34	1285(20%)	-0.13
			1.0%	819	531(65%)	0.30	288(35%)	-0.21
	1985	78000	0.5%	6989	5750(82%)	0.49	1239(18%)	-0.16
			0.75%	1427	1191(83%)	0.44	236(17%)	-0.12
			1.0%	104	81(78%)	1.88	23(22%)	-0.40
	1986	40655	0.5%	3508	2667(76%)	0.37	841(24%)	-0.23
			0.75%	198	110(56%)	0.41	88(44%)	-0.55
			1.0%	21	7(33%)	1.09	14(67%)	-1.88
	1984-6	172327	0.5%	28210	24799(88%)	0.52	3411(12%)	-0.16
			0.75%	8148	6539(80%)	0.36	1609(20%)	-0.15
			1.0%	944	619(66%)	0.51	325(34%)	-0.29
Panel 2: two minute execution lag								
1,2,3-Month Contracts	1984	53672	0.5%	17634	15939(90%)	0.56	1695(10%)	-0.17
			0.75%	6490	4957(76%)	0.35	1533(24%)	-0.15
			1.0%	814	473(58%)	0.35	341(42%)	-0.24
	1985	78000	0.5%	6939	5542(80%)	0.50	1397(20%)	-0.18
			0.75%	1418	1083(76%)	0.47	335(24%)	-0.15
			1.0%	104	74(72%)	1.97	29(28%)	-0.46
	1986	40655	0.5%	3498	2414(69%)	0.37	1084(31%)	-0.27
			0.75%	201	86(43%)	0.35	115(56%)	-0.58
			1.0%	23	3(13%)	0.31	20(87%)	-1.73
	1984-6	172327	0.5%	28071	23895(85%)	0.53	4176(15%)	-0.20
			0.75%	8109	6126(76%)	0.37	1983(24%)	-0.17
			1.0%	940	550(59%)	0.57	390(41%)	-0.33

(Table 6 continued on the next page.)

Table 6--Continued

Contracts	Time Period[c]	Observations	Level of Transaction Costs[d]	Positions Executed[e]	Profitability of arbitrages[h]: Profits Freq(%)[f]	Profits Size[g]	Losses Freq(%)[f]	Losses Size[g]
Panel 3: five minute execution lag								
1,2,3-Month Contracts	1984	53672	0.5%	17494	15469(88%)	0.57	2025(12%)	-0.20
			0.75%	6440	4700(73%)	0.35	1740(27%)	-0.19
			1.0%	800	398(50%)	0.30	402(50%)	-0.28
	1985	78000	0.5%	6823	5306(78%)	0.50	1517(22%)	-0.21
			0.75%	1391	1002(72%)	0.46	389(28%)	-0.19
			1.0%	92	64(70%)	2.03	28(30%)	-0.44
	1986	40655	0.5%	3467	2237(65%)	0.38	1230(35%)	-0.30
			0.75%	200	72(36%)	0.47	128(64%)	-0.57
			1.0%	23	1(4%)	0.33	22(96%)	-1.65
	1984-6	172327	0.5%	27784	23012(83%)	0.54	4772(17%)	-0.23
			0.75%	8031	5774(72%)	0.37	2257(28%)	-0.21
			1.0%	915	463(51%)	0.54	452(49%)	-0.36

a. Hypothesis tested: $\epsilon_{xa} = |F(t+1,T) - S(t+1)e^{r(T-t)} + D(t,T)| - b(t+1) \leq 0$

where F(t+1,T) is the futures price at time t+1 for a contract that matures at time T, S(t+1) is the ex ante or 'forward looking' index value at t, b(t+1) is the time t+1 present value of the sum of transaction costs, D(t,T) is the time T value of dividends paid on component stocks between t and T, and r(T-t) is risk-free interest rate spanning the period from t to T. Actual futures prices are obtained from the CBT's 'Time and Sales Journal' tapes; the spot value of the index is computed with transactions prices for the component shares of the index obtained from the Fitch database; the dividend data are collected form Moody's Dividend Record and Value Line; the average of the bid and ask discounts on the T bill is used to compute the risk-free interest rates.

b. An execution lag is the lag time between t and t+1.

c. 6 months for 1984, 12 months for 1985, and 8 months for 1986.

d. Percentage of the underlying index value.

e. Less than frequencies of ex post violations because some could not be executed within the same day the violation occurred and some others could not be executed due to the uptick rule for short sales of stocks. The number of positions executed with a twenty second lag is a bit smaller, for 0.75% and 1.0% transaction costs in 1986, than matching numbers with longer lags because a few outliers identified from futures price data are discarded. See footnote j for Table 1.

f. Percentage out of positions executed in parentheses.

g. In terms of index points: one index point = $100.

h. Profitable index arbitrages are arbitrages which result in positive ex ante profits while unprofitable arbitrages are arbitrages which result in negative ex ante profits.

Table 7

Frequency and Size of Realized Profits and Losses for Index Arbitrages Based on Major Market Index and Futures Contracts on Major Market Index : Long Arbitrages vs Short Arbitrages[a,b,f,g]

Contracts	Time Period[c]	Observa-tions	Level of Transac-tion Costs[d]	Long Arbitrages Profits Freq	Long Arbitrages Profits Size[e]	Long Arbitrages Losses Freq	Long Arbitrages Losses Size[e]	Short Arbitrages Profits Freq	Short Arbitrages Profits Size[e]	Short Arbitrages Losses Freq	Short Arbitrages Losses Size[e]
Panel 1: twenty second execution lag											
1,2,3-	1984	53627	0.5%	15937	0.55	1256	-0.12	445	0.40	75	-0.22
Month			0.75%	5178	0.34	1262	-0.12	60	0.22	23	-0.37
Contracts			1.0%	531	0.30	283	-0.19	0	*	5	-1.48
	1985	78000	0.5%	4976	0.51	1018	-0.13	774	0.31	221	-0.29
			0.75%	1188	0.44	230	-0.11	3	1.03	6	-0.52
			1.0%	80	1.87	20	-0.24	1	2.28	3	-1.44
	1986	40655	0.5%	2349	0.37	686	-0.19	318	0.36	155	-0.38
			0.75%	105	0.36	77	-0.39	5	1.47	11	-1.68
			1.0%	6	0.29	7	-0.83	1	5.89	7	-2.93
	1984-6	172327	0.5%	23262	0.53	2960	-0.14	1537	0.35	451	-0.31
			0.75%	6471	0.36	1569	-0.13	68	0.35	40	-0.75
			1.0%	617	0.50	310	-0.20	2	4.09	15	-2.15
Panel 2: two minute execution lag											
1,2,3-	1984	53627	0.5%	15523	0.57	1592	-0.17	416	0.38	103	-0.23
Month			0.75%	4900	0.35	1508	-0.15	57	0.22	25	-0.41
Contracts			1.0%	473	0.35	336	-0.22	0	*	5	-1.55
	1985	78000	0.5%	4815	0.53	1129	-0.16	727	0.34	268	-0.26
			0.75%	1080	0.47	329	-0.14	3	0.11	6	-0.72
			1.0%	74	1.97	25	-0.28	0	*	4	-1.54
	1986	40655	0.5%	2122	0.38	905	-0.24	292	0.32	179	-0.40
			0.75%	84	0.35	101	-0.44	2	0.25	14	-1.58
			1.0%	3	0.31	12	-0.87	0	*	8	-3.02
	1984-6	172327	0.5%	22460	0.54	3626	-0.18	1435	0.35	550	-0.30
			0.75%	6064	0.38	1938	-0.16	62	0.22	45	-0.81
			1.0%	550	0.57	373	-0.25	0	*	17	-2.24

(Table 7 continued on the next page.)

Table 7--Continued

Contracts	Time Period[c]	Observa-tions	Level of Transac-tion Costs[d]	Long Arbitrages: Profits Freq	Long Arbitrages: Profits Size[e]	Long Arbitrages: Losses Freq	Long Arbitrages: Losses Size[e]	Short Arbitrages: Profits Freq	Short Arbitrages: Profits Size[e]	Short Arbitrages: Losses Freq	Short Arbitrages: Losses Size[e]
Panel 3: five minute execution lag											
1,2,3-Month Contracts	1984	53627	0.5%	15079	0.58	1899	-0.20	390	0.36	126	-0.22
			0.75%	4651	0.36	1707	-0.19	49	0.22	33	-0.44
			1.0%	398	0.30	397	-0.27	0	*	5	-1.55
	1985	78000	0.5%	4645	0.52	1193	-0.19	661	0.30	324	-0.25
			0.75%	999	0.46	385	-0.19	3	0.11	4	-0.62
			1.0%	64	2.03	26	-0.37	0	*	2	-1.38
	1986	40655	0.5%	1978	0.39	1029	-0.28	259	0.33	201	-0.42
			0.75%	70	0.48	114	-0.43	2	0.24	14	-1.66
			1.0%	0	*	14	-0.84	0	*	8	-3.08
	1984-6	172327	0.5%	21702	0.55	4121	-0.22	1310	0.32	651	-0.30
			0.75%	5720	0.38	2206	-0.20	54	0.21	51	-0.79
			1.0%	463	0.54	437	-0.29	0	*	15	-2.34

a. Hypothesis tested: $\epsilon_{xa} = |F(t+1,T) - S(t+1)e^{r(T-t)} + D(t,T)| - b(t+1) \leq 0$
where F(t+1,T) is the futures price at time t+1 for a contract that matures at time T, S(t+1) is the ex ante or 'forward looking' index value at t, b(t+1) is the time t+1 present value of the sum of transaction costs, D(t,T) is the time T value of dividends paid on component stocks between t and T, and r(T-t) is risk-free interest rate spanning the period from t to T. Actual futures prices are obtained from the CBT's 'Time and Sales Journal' tapes; the spot value of the index is computed with transactions prices for the component shares of the index obtained from the Fitch database; the dividend data are collected form Moody's Dividend Record and Value Line; the average of the bid and ask discounts on the T bill is used to compute the risk-free interest rates.

b. An execution lag is the lag time between t and t+1.

c. 6 months for 1984, 12 months for 1985, and 8 months for 1986.

d. Percentage of the underlying index value.

e. In terms of index points: one index point = $100.

f. Long Arbitrage means that the trader buys component stocks in the index and sells futures contracts: short arbitrage is the opposite.

g. Profitable index arbitrages are arbitrages which result in positive ex ante profits while unprofitable arbitrages are arbitrages which result in negative ex ante profits.

Table 8

Nonparametric Statistics on the Correlation of Daily Spot Market Volatility and Trading Volume of Major Market Index Futures Contracts[a,b]

A. Correlation using the period during which only MMI contracts were traded	
	0.70835 (0.0001)
B. Correlation using both MMI and MMI Maxi Contracts (Trading volume is measured as MMI volume + 2.5 x MMI Maxi volume since the size of MMI Maxi is two and one half as large as that of MMI.)	
	0.72352 (0.0001)
C. Correlation using both MMI and MMI Maxi Contracts. (Trading volume is measured as MMI volume + MMI Maxi volume)	
	0.45122 (0.0001)

a. Stock market volatility is measured by the daily variance of returns on the spot index measured across five minute internal.

b. The reported test statistic is the Spearman's rank correlation coefficient with p statistics in parentheses next to each estimate. Correlations are estimated with data for the period of August 1 1984 to July 6 1985 (Panel A) and August 1 1984 to May 29 1986 (Panel B and Panel C). MMI Maxi contracts were introduced on July 6 1985. Starting on June 2 1986, the Wall Street Journal has reported only MMI Maxi volume. It did not report MMI volume for several days before August 1 1984.

Table 9

Nonparametric Statistics on the Correlation between Spot Market Volatility and the Size and Frequency of Boundary Violations in MMI Futures Prices[a,b,c]

Panel 1: twenty second execution lag

	Ex Post Violations[d]		Ex Ante Violations[e]		Profitable Arbitrages[f]	
Contracts	Size	Freq	Size	Freq	Size	Freq
1 Month	0.11936	0.08534	-0.05276	0.08054	0.07973	0.06740
	(0.0076)	(0.0568)	(0.2394)	(0.0723)	(0.0753)	(0.1327)
2 Month	0.06253	0.03391	-0.00823	0.03411	0.08300	0.05457
	(0.1880)	(0.4755)	(0.8625)	(0.4729)	(0.0803)	(0.2507)
3 Month	0.18037	0.09934	-0.05762	0.09306	0.08294	0.04621
	(0.0013)	(0.0788)	(0.3088)	(0.0998)	(0.1425)	(0.4145)
6 Month	0.00267	-0.05883	-0.05680	-0.05414	-0.01634	-0.07924
	(0.9612)	(0.2837)	(0.3007)	(0.3239)	(0.7661)	(0.1485)

Panel 2: two minute execution lag

	Ex Post Violations		Ex Ante Violations		Profitable Arbitrages	
Contracts	Size	Freq	Size	Freq	Size	Freq
1 Month	0.11936	0.08534	-0.07743	0.08367	0.08293	0.06872
	(0.0076)	(0.0568)	(0.0840)	(0.0618)	(0.0642)	(0.1252)
2 Month	0.06253	0.03391	-0.07401	0.02939	0.04193	0.02528
	(0.1880)	(0.4755)	(0.1190)	(0.5364)	(0.3776)	(0.5948)
3 Month	0.18037	0.09934	-0.14371	0.08276	0.02972	0.00549
	(0.0013)	(0.0788)	(0.0108)	(0.1434)	(0.5999)	(0.9229)
6 Month	0.00267	-0.05883	-0.08105	-0.06085	-0.05522	-0.08056
	(0.9612)	(0.2837)	(0.1394)	(0.2675)	(0.3143)	(0.1418)

(Table 9 continued on the next page.)

Table 9-Continued

Panel 3: five minute execution lag

Contracts	Ex Post Violations Size	Ex Post Violations Freq	Ex Ante Violations Size	Ex Ante Violations Freq	Profitable Arbitrages Size	Profitable Arbitrages Freq
1 Month	0.11936	0.08534	-0.13941	0.08944	0.05336	0.04207
	(0.0076)	(0.0568)	(0.0018)	(0.0458)	(0.2341)	(0.3484)
2 Month	0.06253	0.03391	-0.10093	0.03389	0.03433	0.01484
	(0.1880)	(0.4755)	(0.0333)	(0.4758)	(0.4701)	(0.7548)
3 Month	0.18037	0.09934	-0.14560	0.07537	0.03680	0.00782
	(0.0013)	(0.0788)	(0.0098)	(0.1828)	(0.5159)	(0.8903)
6 Month	0.00267	-0.05883	-0.07090	-0.05907	-0.04860	-0.09315
	(0.9612)	(0.2837)	(0.1962)	(0.2818)	(0.3759)	(0.0892)

a. The frequency is measured as the percentage of daily violations out of daily observations; the size is measured as daily average basis; stock market volatility is measured by the daily variance of returns on the spot index measured across five minute internal.

b. The reported test statistic is the Spearman's rank correlation coefficient with p statistics in parentheses beneath each estimate. Correlations are estimated with data for the period of July 24, 1984 to August 31, 1986 assuming 0.5 percent of the underlying index value is the transaction costs incurred in the MMI-based arbitrage.

c. An execution lag is the lag time between t and t+1.

d. Traders can make positive arbitrage profits (i.e., positive ϵ_{xp}) assuming they can execute orders at the observed stock prices (adjusted for bid-ask spread) and futures prices.

e. The ex ante arbitrage profits at t+1 (i.e., ϵ_{xa} in equation (3)) triggered by mispricing signals (positive ϵ_{xp} at t) assuming traders can execute their orders at the next available prices at least an execution lag after they observe mispricing signals.

f. Arbitrages which result in positive ex ante profits.

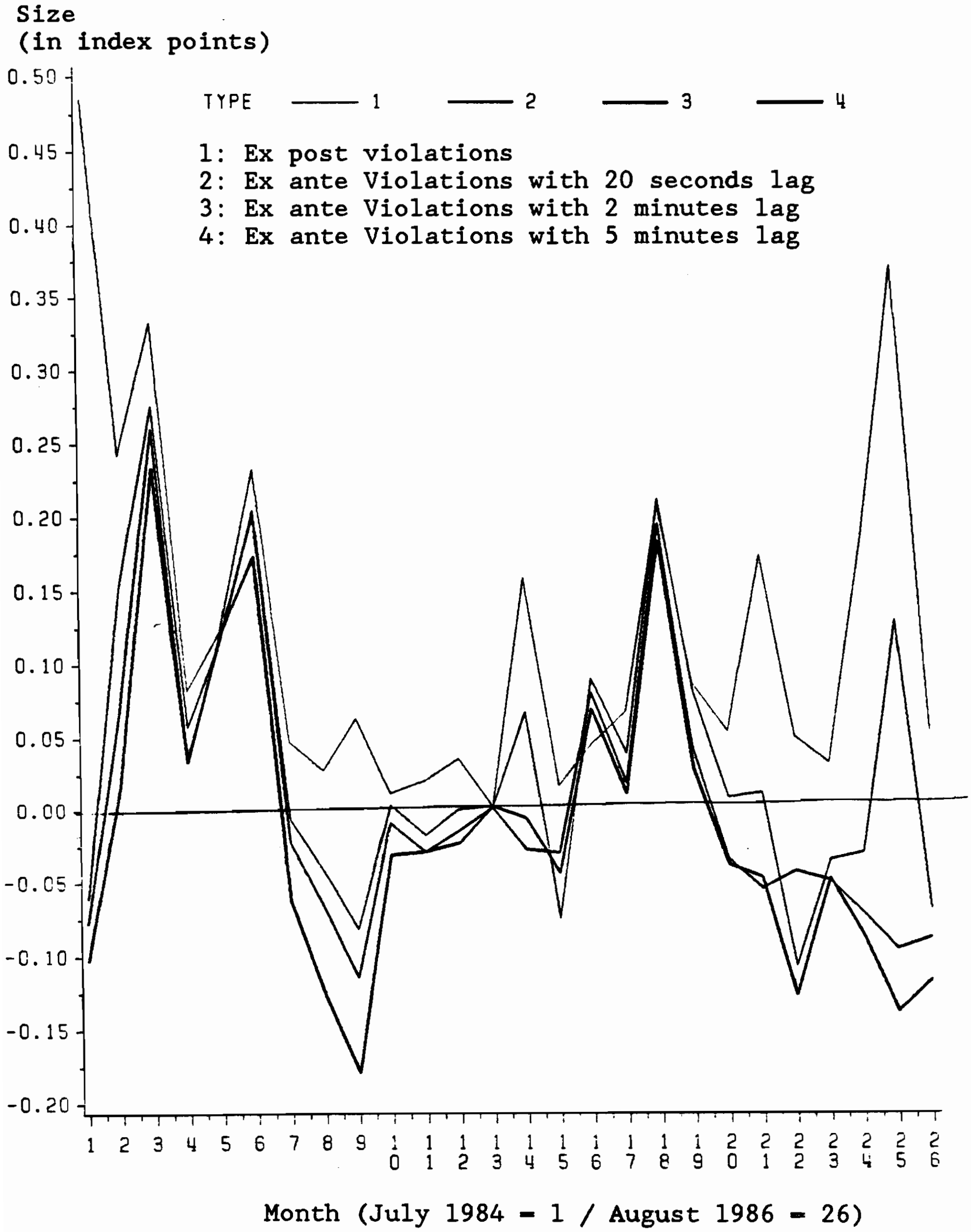

Figure 1 The Monthly Average Size of Violations of Futures Price Boundaries By One Month Major Market Index Futures Contracts for 0.5% Transaction Costs

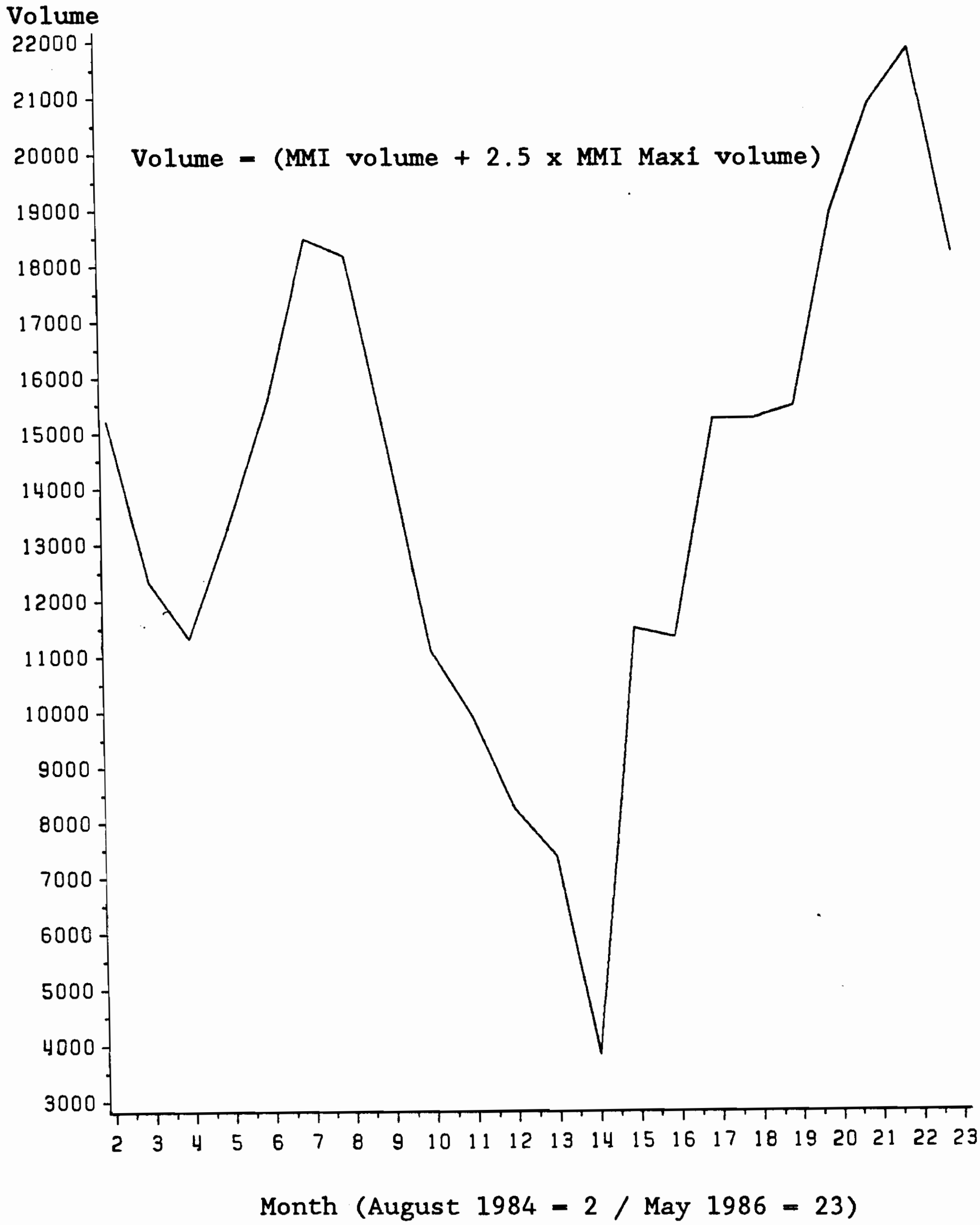

Figure 2 The Daily Average Trading Volume of Major Market Index Futures Contracts during Each Month of Our Sample Period

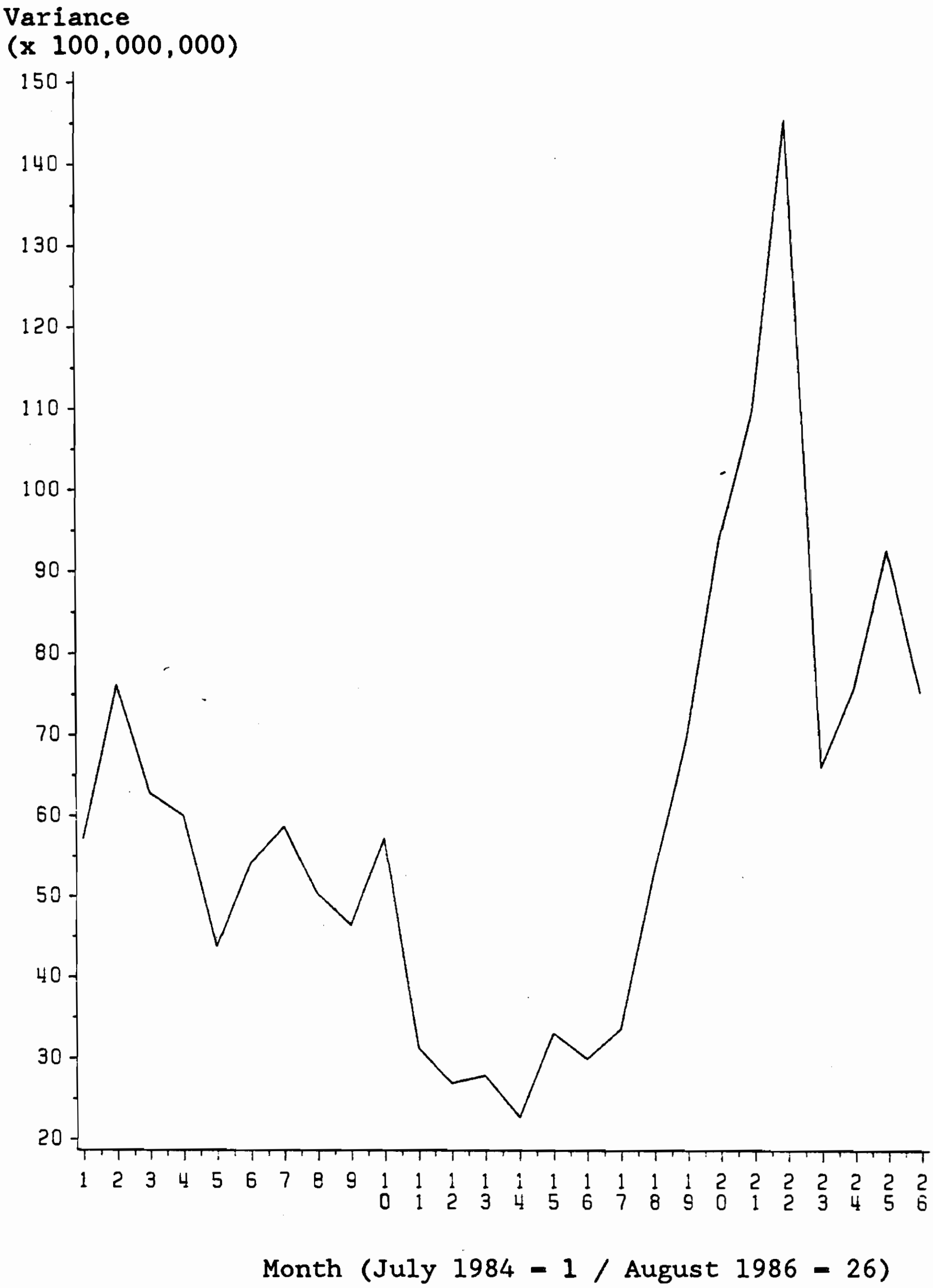

Figure 3 The Average of Daily Variance of Return on Major Market Index Measured Across Five Minute intervals during Each Month of Our Sample Period

Appendix

Summary Statistics on Ex Post Violations (Based on the Reported Spot Index) of Futures Price Boundaries by Major Market Index Futures Contracts[a]

Contracts	Time Period[b]	Observa-tions	Level of Transaction Costs[c]	Ex Post Violations[g] Freq(%)[d]	Size[e]	SD[f]	Min	Max
1 Month	1984	41890	0.5%	12234(29.21%)	0.58	0.41	0.00	6.03
			0.75%	5383(12.85%)	0.36	0.32	0.00	5.43
			1.0%	1021(2.44%)	0.27	0.34	0.00	4.83
	1985	54954	0.5%	4093(7.50%)	0.25	0.25	0.00	2.94
			0.75%	306(0.56%)	0.21	0.27	0.00	2.23
			1.0%	18(0.03%)	0.39	0.47	0.01	1.66
	1986	27561	0.5%	1784(6.47%)	0.30	0.37	0.00	7.36
			0.75%	104(0.38%)	0.42	0.89	0.00	6.44
			1.0%	10(0.04%)	1.29	2.22	0.09	5.53
	1984-6	124405	0.5%	18111(14.56%)	0.48	0.41	0.00	7.36
			0.75%	5793(4.66%)	0.35	0.34	0.00	6.44
			1.0%	1049(0.84%)	0.28	0.41	0.00	5.53
2 Month	1984	12123	0.5%	5417(44.68%)	0.47	0.38	0.00	3.23
			0.75%	1573(12.98%)	0.34	0.33	0.00	2.69
			1.0%	279(2.30%)	0.31	0.32	0.00	2.15
	1985	22130	0.5%	3889(17.57%)	0.50	0.45	0.00	9.74
			0.75%	1194(5.40%)	0.41	0.38	0.00	9.08
			1.0%	262(1.18%)	0.19	0.57	0.00	8.42
	1986	14078	0.5%	879(6.24%)	0.34	0.31	0.00	2.26
			0.75%	84(0.60%)	0.26	0.31	0.00	1.54
			1.0%	9(0.06%)	0.22	0.25	0.02	0.81
	1984-6	48331	0.5%	10185(21.07%)	0.47	0.40	0.00	9.74
			0.75%	2851(5.90%)	0.37	0.36	0.00	9.08
			1.0%	550(1.14%)	0.25	0.46	0.00	8.42

(Appendix continued on the next page.)

Appendix--Continued

Contracts	Time Period[b]	Observations	Level of Transaction Costs[c]	Ex Post Violations[g] Freq(%)[d]	Size[e]	SD[f]	Min	Max
3 Month	1984	4382	0.5%	2019(46.07%)	0.58	0.51	0.00	3.28
			0.75%	770(17.57%)	0.48	0.49	0.00	2.68
			1.0%	206(4.70%)	0.50	0.54	0.00	2.08
	1985	9116	0.5%	3060(33.57%)	0.49	0.40	0.00	2.80
			0.75%	969(10.63%)	0.35	0.32	0.00	2.17
			1.0%	165(1.81%)	0.28	0.30	0.00	1.55
	1986	4560	0.5%	424(9.30%)	0.48	0.44	0.00	2.72
			0.75%	60(1.32%)	0.52	0.48	0.00	1.88
			1.0%	13(0.29%)	0.51	0.29	0.03	1.04
	1984-6	18058	0.5%	5503(30.47%)	0.52	0.45	0.00	3.28
			0.75%	1799(9.96%)	0.41	0.41	0.00	2.68
			1.0%	384(2.13%)	0.41	0.46	0.00	2.08
6 Month	1984	5469	0.5%	4221(77.18%)	1.41	0.88	0.00	8.28
			0.75%	3368(61.58%)	1.09	0.77	0.00	7.74
			1.0%	2255(41.23%)	0.89	0.63	0.00	7.20
	1985	5565	0.5%	3763(67.62%)	0.66	0.44	0.00	4.54
			0.75%	1702(30.58%)	0.39	0.34	0.00	3.95
			1.0%	353(6.34%)	0.28	0.29	0.00	3.35
	1986	474	0.5%	274(57.81%)	0.54	0.48	0.00	3.33
			0.75%	62(13.08%)	0.47	0.47	0.01	2.56
			1.0%	8(1.69%)	0.65	0.63	0.10	1.79
	1984-6	11508	0.5%	8258(71.76%)	1.04	0.80	0.00	8.28
			0.75%	5132(44.60%)	0.85	0.73	0.00	7.74
			1.0%	2616(22.73%)	0.81	0.63	0.00	7.20

(Appendix continued on the next page.)

Appendix--Continued

Contracts	Time Period[b]	Observations	Level of Transaction Costs[c]	Ex Post Violations[g] Freq(%)[d]	Size[e]	SD[f]	Min	Max
1,2,3-Month Contracts	1984	58395	0.5%	19670(33.68%)	0.55			
			0.75%	7726(13.23%)	0.37			
			1.0%	1506(2.58%)	0.31			
	1985	86200	0.5%	11042(12.81%)	0.40			
			0.75%	2469(2.86%)	0.36			
			1.0%	445(0.52%)	0.23			
	1986	46199	0.5%	3087(6.68%)	0.34			
			0.75%	248(0.54%)	0.39			
			1.0%	32(0.07%)	0.67			
	1984-6	190794	0.5%	33799(17.71%)	0.48			
			0.75%	10443(5.47%)	0.37			
			1.0%	1983(1.04%)	0.30			

a. Hypothesis tested: $\epsilon_{xp} = |F(t,T) - S(t)e^{r(T-t)} + D(t,T)| - b(t) \leq 0$
where F(t,T) is the futures price at time t for a contract that matures at time T, S(t) is the ex post or 'backward looking' index value at t, b(t) is the present value of the sum of transaction costs at t, D(t,T) is the time T value of dividends paid on component stocks between t and T, and r(T-t) is risk-free interest rate spanning the period from t to T. Actual futures prices are obtained from the CBT's 'Time and Sales Journal' tapes; the spot value of the index is based on the reported level of spot index from the same CBT's tapes; the dividend data are collected form Moody's Dividend Record and Value Line; the average of the bid and ask discounts on the T bill is used to compute the risk-free interest rates.

b. 6 months for 1984, 12 months for 1985, and 8 months for 1986.

c. Percentage of the underlying index value.

d. Percentage out of observations in parentheses.

e. In terms of index points: one index point = $100.

f. SD = standard deviation.

g. Traders can make positive arbitrage profits (i.e., positive ϵ_{xp}) assuming they can execute orders at the observed stock prices (adjusted for bid-ask spread) and futures prices.

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