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A Transactions Data Test of Stock Index Futures Market Efficiency and Index Arbitrage Profitability

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ABSTRACT

This paper investigates the efficiency of the market for stock index futures and the profitability of index arbitrage for The Chicago Board of Trade's Major Market Index contracts. The spot value of the index is computed with transactions prices for the component shares of the index obtained from the Fitch database. The tests account for transaction costs, execution lags, and the uptick rule for short sales of stocks. Results indicate that the size and frequency of boundary violations are substantially smaller than those reported by earlier studies and have declined sharply with time.

INDEX ARBITRAGE IS A strategy whereby institutions, brokerage houses, or other large investors seek to profit from the spread between prices in the spot and futures markets for stock indices. 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.

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

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

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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 the risk-free interest rate spanning the period from t to T.

Recent studies report that significant deviations of futures prices from cost-of-carry model prices, i.e., equation (1), have persisted since the introduction of index futures contracts in the early 1980s.[1] 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 disappear by the close of the following day and claims that mispricings are due to 'noise' and will disappear with time as markets mature. Other explanations suggested in the literature include: (i) the index futures market is not efficient, (ii) there is a risk premium for index arbitrage[2]; and (iii) there exist hidden costs or impediments to arbitrage not captured by the model. If mispricings are frequent and significant, then there may be some trading barriers which make true risk-free arbitrage difficult. Potential impediments to arbitrage include nontrivial transaction costs, the uptick rule in the stock market, the lack of arbitrage capital, and the position limits in the futures market. With such impediments to arbitrage, apparent mispricings may arise and persist over time.

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. However, 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 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 (1990) also use similar intraday prices in their study of the time series properties of intraday returns of stock indices and stock

[1] Other studies on this issue include Brennan and Schwartz (1987, 1990), Cornell (1985), Cornell and French (1983a), Figlewski (1984), Harris (1989a), MacKinlay and Ramaswamy (1988), Merrick (1987), Modest and Sundaresan (1983), and Stoll and Whaley (1986).

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

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. 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. In contrast, Harris (1989a) looks at the five-minute interval transactions data for his study on the S&P 500 index futures spread during the 1987 crash. 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.

The purpose of this study is to determine whether 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. The efficiency tests reported in this study seek to 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.

The results of this study suggest that previous studies significantly overestimate the size and frequency of profitable arbitrages in the index futures market by focusing on ex post tests (without imposing execution lags) and by using the reported index instead of transactions data. Also, it appears that the Major Market Index (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 1984. Our results indicate that the size of mispricing signal has become a poor predictor of the realized profit from index arbitrage.

The rest of this paper is organized as follows. Section I describes the data set. Section II describes the empirical tests. The empirical results are presented in Section III, while Section IV summarizes the results and implications.

I. Data

Results presented in this paper are based on the 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. 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. The contract is traded between 8:45 A.M. and 3:15 P.M. Chicago time. (After October 1, 1985, the CBT 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.[3] 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.[4]

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 the futures contract is used to compute the risk-free interest rate. 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.

[3] On a 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.

[4] 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). 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 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, rather than several hundreds.

II. Structure of 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:

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

where $S(t)$ 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_i^- of the ith share, and $d(t)$ equals the adjustment divisor used at t. We call $S(t)$ the ex post index value at t. $b(t)$ is the present value of the sum of 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, buying the underlying MMI stocks (proportional to $d(t)$), and holding this position until T if v is positive and $v - b(t)$ is positive. 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. Note that the 'buy and hold to maturity' strategy is only one possible strategy and may not be optimal for arbitrageurs. The trader has the right to close out his arbitrage position before maturity if he chooses, and he may do so due to market-imposed position limits or his own capital constraints. The early closing strategy, however, involves additional risk and transaction costs since an ex post reversal signal is not necessarily a positive ex ante profit opportunity and the trader has to incur one more commission to close a position in the futures market as well as one more bid-ask spread in stock markets.

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

$$\begin{aligned}\varepsilon_{xa} &= F(t^+,T) - S(t^+)e^{r(T-t)} + D(t,T) - b(t^+) \leq 0 \text{ if } v \textit{ is} \text{ positive, or}\\ &= -\left[F(t^+,T) - S(t^+)e^{r(T-t)} + D(t,T)\right] - b(t^+) \leq 0 \text{ if } v \text{ is negative.}\end{aligned} \tag{3}$$

$F(t^+,T)$ is the first futures price following an execution lag after t. $S(t^+)$ equals $\sum_{i=1}^{20} P_i(t^+)/d(t^+)$ where $P_i(t^+)$ equals the first price of the ith share following an execution lag after t and $d(t^+)$ equals the adjustment divisor used at t^+. We call $S(t^+)$ the ex ante index value at t^+. $b(t^+)$ is the time t^+ present value of the sum of transaction costs incurred in the arbitrage. ε_{xa} is, therefore, the ex ante arbitrage profit at t^+, triggered by a mispricing signal (a positive ε_{xp}) at t.

The transaction costs involved in an index 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; (iii) one 'market impact' cost, i.e., the bid-ask spread, in the stock market; and (iv) one 'market impact' cost in the futures market. Total proportional round-trip commissions range from about 0.5% to 1.0% of the underlying index value.[5] Test results will be reported for commission levels of 0.5%, 0.75%, and 1.0%. Note that 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), such as 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.[6] 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. Since the investors who already own index stocks are not subject to the uptick rule or the restriction on proceeds, empirical tests are also carried out without imposing the uptick rule and results are reported along with results obtained when the uptick rule is imposed. Next, traders are assumed to be able to borrow or lend money at the riskless rate. 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.[7] Test results will be reported for execution lags of twenty seconds, two minutes, and five minutes.

III. Empirical Results

A. Frequency and Persistence of Ex Post Violations of Futures Price Boundaries by MMI Futures Contracts

Table I reports the frequency and persistence of ex post violations of futures price boundaries for the data set of the heavily traded Major Market

[5] 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%.

[6] The Federal Reserve Board's Regulation T specifies that the proceeds of the short sales must be retained in a non-interest-bearing account to protect the brokerage firm. A couple of anonymous arbitrage traders from major brokerage firms, however, informed us that the short sale account is not strictly segregated from their other cash accounts and therefore major brokerage houses can effectively use the 100% of short sale proceeds when they do index arbitrage for their own accounts. The *Wall Street Journal* (February 16, 1989) reports that about one third of the index arbitrage action of major brokerage firms was for their own accounts before the market crash in 1987. Modest and Sundaresan (1983) also report that big traders and brokers with seats on the exchange can perhaps use 100% of short sale proceeds.

[7] *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 informed us 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.

Index futures contracts by calendar year.[8] 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 a significant percentage of mispricings in 1986 occurs only for the case of 0.5% transaction costs (8.73% or 3,548) and the frequency is much less than 33.12% or 17,777 in 1984.

We conducted an alternative ex post boundary violation test which follows the practice of earlier studies and assumes that traders can execute their orders at the reported ex post index level adjusted for bid-ask spread. The data for the reported level of the spot index are obtained from the CBT's 'Time and Sales Journal' tapes. The frequency of ex post violations is 33,799 for 0.5% transaction costs, 10,443 for 0.75% costs, and 1,983 for 1.0% costs for the entire sample period. Corresponding figures in Table I based on the transactions data are 28,374, 8,210, and 963, respectively. The sample size also increases to 190,794 when using the reported index from 172,327 when using the transactions data of component shares.[9]

The alternative test using the reported index overestimates the frequency of ex post violations. Futures prices are discarded in our transactions data test 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. Results suggest that most previous researchers overestimated the frequency of boundary violations by using the reported index instead of transactions data.

One can argue that the reported frequency in the table is misleading if persistent (or clustered) ex post violations are counted as multiple mispricing signals. Persistent violations can be evidence of underestimated transaction costs, the lack of arbitrage capital, or noise. To examine the degree to which

[8] Empirical results in Section III are reported for heavily traded contracts which are one, two, and three month contracts. These contracts account for more than 94% of total observations of MMI futures prices during the sample period. Also, detailed test results by each contract maturity are omitted to save space. There were 781 outliers identified from futures price data whose ex post violations 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 on which they appeared. All of them proved to be invalid and were discarded. Eight other futures prices represent unusually large violations, i.e., larger than five index points. Those proved to be valid and are kept in the data set.

[9] 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 two fifteen minutes during which the stock market is not open are discarded both in the replication and in our transactions data tests.

Table I

Ex Post Violations of Futures Price Boundaries and the Number of Subsequent Violations within Five Minutes of a Preceding Violation by Major Market Index Futures Contracts for July 24, 1984 to August 31, 1986

Hypothesis: $\varepsilon_{xp} = |F(t,T) - S(t)e^{r(T-t)} + D(t,T)| \leq b(t)$; 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 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 the risk-free interest rate spanning the period from t to T. Actual MMI 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 from 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.

Time Period[a]	Number of Observations	Transaction Costs[b] (%)	Number of Violations[c] (%)	Average Number of Subsequent Violations	Maximum Number of Subsequent Violations
1984	53,672	0.5	17,777 (33.12)	5.0	30
		0.75	6,558 (12.22)	4.4	30
		1.0	833 (1.55)	3.8	24
1985	78,000	0.5	7,049 (9.04)	2.3	21
		0.75	1,440 (1.85)	1.7	11
		1.0	107 (0.14)	0.8	5
1986	40,655	0.5	3,548 (8.73)	1.8	12
		0.75	212 (0.52)	1.5	10
		1.0	23 (0.06)	0.9	4
1984-6	172,327[d]	0.5	28,374 (16.47)	3.9	30
		0.75	8,210 (4.76)	3.9	30
		1.0	963 (0.56)	3.4	24

[a] Six months for 1984, twelve months for 1985, and eight months for 1986.
[b] In percentage of the underlying index value.
[c] The percentage out of total number of observations is reported in parentheses.
[d] There were 781 outliers identified from futures price data whose ex post violations 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 on which they appeared. All of them proved to be invalid and were discarded. Eight other futures prices represent unusually large violations, i.e., larger than five index points. Those proved to be valid and are kept in the data set.

the clustering of violations leads to multiple mispricing signals, Table I also reports the average number of subsequent violations that follow, within a five minute period, each observed ex post violation.

The table shows that in 1984, for 0.5% transaction costs, the number of ex post violations that follow a preceding violation within five minutes is on average five, and is as large as thirty. Each observed violation is followed by an average of about four violations during the next five minutes even for higher transaction costs of 0.75% or 1.0%. Thus, the serious persistence of violations during 1984 is not due to underestimated transaction costs.

Even when it appears that mispricings are persistent, arbitrageurs will still implement the strategy explained in Section II (i.e., take an arbitrage position when the mispricing signal is positive ($\epsilon_{xp} > 0$)). They have no incentive to wait for a subsequent mispricing because there is no reason to believe that it will be more favorable than the current one. In fact, there may be some reason to believe that the later signal will be less favorable or may never occur. The road to success in this arbitrage is to be the first trader to reach the exchange floors when the spread reaches its desired level (i.e., greater than the trader's transaction costs or the sum of transaction costs plus a buffer).

Nevertheless, the persistence of ex post violations has significantly declined over the sample years for all levels of transaction costs. It implies that the serious persistence of ex post violations observed in 1984 was mainly due to 'noise' and disappeared with time as arbitrage tradings tended to correct mispricings. For example, only two subsequent mispricings signals occur within five minutes for 0.5% transaction costs in 1985 and 1986 on average, compared to five in 1984. Given that as many as thirty transactions can occur during a five minute period in the MMI futures market, observing a subsequent violation in about three minutes after a preceding violation in 1986 does not connote a serious clustering or persistence problem. Instead, it provides us with more evidence that the MMI futures market has matured with time.

B. Ex Ante Violations of Futures Price Boundaries by MMI Futures Contracts: Profitability of MMI-based Index Arbitrage and Efficiency of MMI Futures Market

Table II shows summary statistics for ex ante violations by MMI futures contracts, assuming traders can execute their orders at the first available futures and stock prices at least twenty seconds, two minutes, or five minutes after they observe ex post mispricing signals. Results show that, as the MMI futures market matured, there were fewer ex ante 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 for 0.75% transaction costs, the frequencies of executed arbitrage trades were 1,427 in 1985 and 198 in 1986, compared to 6,523 in 1984.[10]

[10] The numbers of executed trades in Table II are slightly less than frequencies of ex post mispricing signals in Table I because some trades cannot be executed by the NYSE close due to the execution lag and some others cannot be executed due to the uptick rule for short sales of stocks. Futures prices are discarded for ex ante tests if there are no matching quotations available for the twenty component shares of the index during the closing hours to insure that tests are based on same-day prices. Traders cannot wait to see whether their trades will be fully executed before the market close when deciding whether to execute an arbitrage during the closing hours. At 3:00 P.M. the NYSE closes but the CBT closes fifteen minutes later. If they enter into a trade that is not finished yet when the NYSE closes, they either bear any overnight risk or try to *complete* it in a regional market like the Pacific Stock Exchange (PSE) which has thirty minutes to go before it closes. Note that all of those twenty MMI stocks are also listed on the PSE. The ex ante profitability of those trades is not known since the PSE transactions record is not available and hence is not included in our ex ante test results in Table II.

Table II

Summary Statistics for Ex Ante Violations (Realized Arbitrage Profits) of Futures Price Boundaries by MMI Futures Contracts and Profitability of MMI-based Index Arbitrage for July 24, 1984 to August 31, 1986

Hypothesis: $\varepsilon_{xa} = F(t^+, T) - S(t^+)e^{r(T-t)} + D(t, T) \leq b(t^+)$ if futures contracts are overpriced at t, or $-[F(t^+, T) - S(t^+)e^{r(T-t)} + D(t, T)] \leq b(t^+)$ otherwise; where $F(t^+, T)$ is the futures price at time t^+ for a contract that matures at time T; $S(t^+)$ is the ex ante index value at t^+; $b(t^+)$ is the time t^+ 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 the risk-free interest rate spanning the period from t to T. Numbers of trades are slightly less than frequencies of ex post violations (in Table I) because some trades cannot be executed within the same day the violation occurs due to the execution lag and some others cannot be executed due to the uptick rule for short sales of stocks. The slope coefficient (β) and its standard error (SE(β)) are reported from the regression of realized profits (ex ante violations) on "expected" profits (matching mispricing signals). Regressions are estimated with a two-pass GLS (Maximum Likelihood Estimates) procedure which corrects for autocorrelation in residuals.

Time Period[a]	TC(%)[b]	No. of Trades	Average Signal Size[c]	Profitable Trades (%)[d]	Average Profit	STD[e] of Profits	Range of Profits		Regression	
							Min	Max	β	SE(β)
Panel 1: Twenty second execution lag										
1984	0.5	17,713	0.52	16,382 (92)	0.50	0.40	−1.16	8.13	0.69	0.01
	0.75	6,523	0.31	5,238 (80)	0.25	0.32	−1.75	6.83	0.10	0.01
	1.0	819	0.29	531 (65)	0.12	0.34	−2.34	1.17	−0.09	0.02
1985	0.5	6,989	0.39	5,750 (82)	0.37	0.56	−1.18	8.66	0.35	0.02
	0.75	1,427	0.37	1,191 (83)	0.35	0.77	−1.21	7.09	0.16	0.02
	1.0	104	1.57	81 (78)	1.38	1.38	−1.85	3.42	0.19	0.08
1986	0.5	3,508	0.32	2,667 (76)	0.23	0.40	−1.51	7.72	0.18	0.02
	0.75	198	0.49	110 (56)	−0.02	0.83	−2.34	6.81	0.08	0.04
	1.0	21	2.19	7 (33)	−0.89	2.11	−3.25	5.89	−0.24	0.05
1984–6	0.5	28,210	0.46	24,799 (88)	0.43	0.46	−1.51	8.66	0.44	0.01
	0.75	8,148	0.32	6,539 (80)	0.26	0.45	−2.34	7.09	0.14	0.01
	1.0	944	0.47	619 (66)	0.23	0.77	−3.25	5.89	0.09	0.03
Panel 2: Two minute execution lag										
1984	0.5	17,634	0.52	15,939 (90)	0.49	0.48	−1.19	9.62	0.51	0.01
	0.75	6,490	0.31	4,957 (76)	0.23	0.43	−1.75	9.91	0.10	0.02
	1.0	814	0.29	473 (58)	0.10	0.56	−2.17	5.61	−0.08	0.03

Table II—*Continued*

Time Period[a]	TC(%)[b]	No. of Trades	Average Signal Size[c]	Profitable Trades (%)[d]	Average Profit	STD[e] of Profits	Range of Profits Min	Range of Profits Max	Regression β	Regression SE(β)
1985	0.5	6,939	0.39	5,542 (80)	0.37	0.65	−1.17	8.94	0.36	0.02
	0.75	1,418	0.37	1,083 (76)	0.32	0.83	−1.15	8.31	0.16	0.03
	1.0	103	1.56	74 (72)	1.29	1.46	−1.79	3.33	0.30	0.07
1986	0.5	3,498	0.32	2,414 (69)	0.17	0.41	−1.69	2.03	−0.03	0.02
	0.75	201	0.49	86 (43)	−0.18	0.71	−2.59	1.19	−0.19	0.03
	1.0	23	2.01	3 (13)	−1.46	1.40	−3.50	0.42	−0.06	0.12
1984-6	0.5	28,071	0.46	23,895 (85)	0.42	0.53	−1.69	9.62	0.35	0.01
	0.75	8,109	0.32	6,126 (76)	0.24	0.54	−2.59	9.91	0.02	0.01
	1.0	940	0.47	550 (59)	0.20	0.87	−3.50	5.61	0.03	0.02
Panel 3: Five minute execution lag										
1984	0.5	17,494	0.52	15,469 (88)	0.48	0.54	−1.19	9.74	0.50	0.01
	0.75	6,440	0.31	4,700 (73)	0.21	0.47	−1.63	7.76	0.48	0.02
	1.0	800	0.29	398 (50)	0.01	0.43	−2.23	5.61	−0.08	0.03
1985	0.5	6,823	0.39	5,306 (78)	0.34	0.63	−1.22	9.59	0.37	0.02
	0.75	1,391	0.36	1,002 (72)	0.28	0.84	−1.36	8.96	0.22	0.04
	1.0	92	1.60	64 (70)	1.28	1.49	−2.01	3.28	0.09	0.11
1986	0.5	3,467	0.32	2,237 (65)	0.14	0.45	−1.69	4.63	−0.06	0.02
	0.75	200	0.50	72 (36)	−0.19	0.74	−2.59	1.28	−0.21	0.03
	1.0	23	2.01	1 (4)	−1.57	1.36	−3.50	0.33	−0.09	0.12
1984-6	0.5	27,784	0.46	23,012 (83)	0.40	0.56	−1.69	9.74	0.28	0.01
	0.75	8,031	0.32	5,774 (72)	0.21	0.57	−2.59	8.96	0.04	0.01
	1.0	915	0.47	463 (51)	0.09	0.80	−3.50	5.61	−0.03	0.03

[a] Six months for 1984, twelve months for 1985, and eight months for 1986.
[b] TC(%) = Transaction costs as a percentage of the underlying index value.
[c] In terms of index points: a full index point is equivalent to $100 per contract.
[d] Profitable trades are those which result in positive ex ante profits. The percentage out of total number of trades executed is reported in parentheses.
[e] STD = standard deviation.

The table clearly shows that ex ante arbitrage profits are substantially smaller than matching ex post mispricing signals and are quite volatile, especially in 1986. There are substantial differences between the size of the ex post mispricing signal and the realized profit on the resulting ex ante trade. Also 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 for 0.5% transaction costs is 0.32 index points. The corresponding size of ex ante realized profit 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. As the execution lag is longer than two minutes, more than 50% of apparent mispricings are eliminated and the chance of an 'unprofitable arbitrage' is high (evidenced by large standard deviation of ex ante realized profits).[11]

The table also reports the frequency of profitable arbitrage trades. Results indicate that the MMI-based arbitrage has become riskier as the market has matured: the frequency of profitable trades has declined sharply with time. For 0.75% and 1.0% transaction costs, for example, the frequencies of profitable trades are less than 50% of all trades executed in 1986 even with the shortest execution lag while they are very high in earlier years. If the execution lag is five minutes, index arbitrage has just a 50% chance of success for 1.0% transaction costs as early as in 1984. Even for the lowest transaction costs, the chance of profitable index arbitrage is reduced to 65% (69%) in 1986 from 88% (90%) in 1984 for an execution lag of five (two) minutes.

Table II 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 is negative in 1986 for 0.75% or 1.0% transaction costs even for the shortest execution lag (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 profit of 0.01 index points with standard deviation of 0.43 index points) even though traders with 1.0% transaction costs observe quite frequent and large mispricing signals (0.29 index points on average).

[11] The arbitrageur, having capital constraints and knowing the risks of ex ante trading, may require a mispricing signal of *more* than the amount needed to cover transaction costs before entering into a trade. Say, a 0.5% transaction cost trader requires a buffer of 0.25%. Then the frequency of executions will be much smaller than what it otherwise would be. For example, ex ante arbitrage opportunities for him in 1986 would be only 198 instead of 3,508.

The average mispricing signal in 1986 for 1.0% transaction costs is 2.19 index points while the average ex ante arbitrage profit based on signals is −0.89 with a twenty second lag, −1.46 with a two minute lag, and −1.57 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.

The table also shows that the size of ex ante arbitrage profits is much more sensitive to the assumed execution lag in 1986 than it is in 1984. For example, when the execution lag is twenty seconds, the size of ex ante profits is 0.50 index points 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 lag) 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.

Finally, Table II reports the slope coefficient and its standard error from the regression of realized profits (ex ante violations) on "expected" profits (matching ex post mispricing signals).[12] Results indicate that the realized profits are strongly related to the signal sizes in 1984: the slope coefficient ranges from 0.50 (for a five minute lag) to 0.69 (for a twenty second lag) for 0.5% transaction costs. This strong relation has disappeared over time: the realized profits are insignificantly or even negatively related to the signal sizes in later years even for the lowest transaction costs of 0.5%. The estimated values of β (slope coefficient) in 1986 are 0.18 for a twenty second lag, −0.03 for a two minute lag, and −0.06 for a five minute lag while its standard errors are stable at 0.02. Note that the slope coefficient is negative for 1.0% transaction costs as early as in 1984 for all execution lags and that it is negative or marginally significant in 1986 for every level of transaction costs and for all lags. The estimated slope coefficients in 1986 suggest that the mispricing signal ("expected" profit) has become a poor predictor of the realized profit from index arbitrage and hence index arbitrage has become much riskier as the MMI futures market has matured.

C. Comparison of Long vs Short Arbitrage: Ex Post Mispricing Signals and Resulting Ex Ante Arbitrage Profits

Table III is constructed from results summarized in Tables I and II in order to separately report the frequencies and average sizes of observed signals and resulting ex ante arbitrage profits for long arbitrage and short arbitrage:

[12] Regressions are estimated with a two-pass GLS (Maximum Likelihood Estimate) procedure which corrects for autocorrelation in the residuals. The AUTOREG procedure in SAS is used for this purpose.

long arbitrage means that the trader buys component stocks of the index and sells futures contracts while short arbitrage means the opposite.

Results do not support the 'tax timing option' hypothesis proposed first by Cornell and French (1983a). They 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, i.e., 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. Our results, however, indicate that index futures contracts are dominantly overpriced for ex post violations. The table shows that only 7.04% of all ex post violations (1,998 out of 28,374) are signals for short arbitrage with 0.5% transaction costs. For higher transaction costs, signals for short arbitrage are less than 2% of all ex post violations. Nevertheless, results in Table III 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), our use of different sample period (1984–1986) from their sample period (1982), or lack of precision in Table III of detailed 'days to maturity' of futures contracts.

An interesting result is that short arbitrages involving short sales of shares are much 'riskier' than long arbitrages. Results show that most ex post mispricing signals requiring short sales of stocks are executable within the same day the signal occurs: 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 ex ante arbitrage profit from short arbitrages is significantly smaller and more volatile than that from long arbitrages. For example, 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 average 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. Therefore, it can be riskier for traders to wait for upticks for each of twenty stocks for short sales and attempt to take advantage of apparently underpriced futures.

Next, for 0.75% and 1.0% transaction costs, the average size of signals for short arbitrages is significantly larger than that for long arbitrages. However, corresponding ex ante profits are significantly negative with every lag time for short arbitrages with higher 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 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). These findings together suggest that the uptick rule in the spot market can be a serious constraint to short arbitrages. Finally, ex ante test results for short arbitrages are much more sensitive to the assumed lag time than results for long arbitrages.

The short sale constraint frequently leads traders to use a 'quasi' short arbitrage strategy called the 'stock replacement': large investors (e.g., managers of index funds or pension funds) who already own index stocks can sell them proportionally, put the proceeds in riskless instruments, and buy the futures contract. This strategy is not subject to the uptick rule or the restriction on proceeds but has the same economic payoffs as the 'normal' short sale of component stocks of an index. Therefore, the stock replacement strategy is also simulated for 0.5% transaction costs without imposing the uptick rule and its results are reported in the last three columns of Table III.

We find interesting results: the average size of ex ante arbitrage profits from stock replacement strategies is significantly smaller and more volatile not only than the average profit from long arbitrages but also than that from the normal short arbitrages which are subject to the uptick rule and take longer time to execute. During the entire sample period, for example, the average size of ex ante arbitrage profits for the stock replacement strategies is 0.04 index points with a standard deviation of 0.70 while the average size for the 'normal' short arbitrages is 0.17 index points with a standard deviation of 0.57 for 0.5% transaction costs and a two minute lag. The average size of corresponding ex post mispricing signals is 0.23. The matching numbers for long arbitrages are 0.44 for the average size and 0.52 for the standard deviation with the average ex post mispricing signal of 0.48. These results imply that the *main* concern to the arbitrageurs may not be the uptick rule per se but much quicker market responses to mispricing signals for underpriced futures (or overpriced spot index).

IV. Summary and Conclusions

This paper tests the efficiency of the Major Market Index futures market using transactions data for futures prices and the 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 is simulated for the period of July 24, 1984 to August 31, 1986.

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 imposing execution lags) and by using the reported

Table III

Summary Statistics for Long vs Short Arbitrage: Ex Post Violations (Mispricing Signals) and Ex Ante Violations (Realized Profits) of Futures Price Boundaries by MMI Futures Contracts for July 24, 1984 to August 31, 1986

Long arbitrage means that the trader buys component stocks of the index and sells futures contracts: short arbitrage means the opposite. Hypothesis for ex post violations: $\varepsilon_{xp} = |\, F(t,T) - S(t)e^{r(T-t)} + D(t,T)\,| \leq b(t)$; 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 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 the risk-free interest rate spanning the period from t to T. Hypothesis for ex ante violations: $\varepsilon_{xa} = F(t^+,T) - S(t^+)e^{r(T-t)} + D(t,T) \leq b(t^+)$ if futures contracts are overpriced at t, or $-[F(t^+,T) - S(t^+)e^{r(T-t)} + D(t,T)] \leq b(t^+)$ otherwise; where $F(t^+,T)$ is the futures price at time t^+ for a contract that matures at time T; $S(t^+)$ is the ex ante index value at t^+; and $b(t^+)$ is the time t^+ present value of the sum of transaction costs. An ex ante violation is the ex ante arbitrage profit at t^+ (ε_{xa}) assuming traders can execute their orders at the next available prices following an execution lag after they observe mispricing signals. The uptick rule is imposed for the first set of results for ex ante violations for short arbitrages, whereas the rule is not imposed for the second set of results for stock replacement strategies.

		Violations for Long Arbitrage					Violations for Short Arbitrage							
		Ex Post		Ex Ante			Ex Post		Ex Ante (Uptick)			Ex Ante (No Rule)		
Time Period[a]	TC(%)[b]	Freq	Size[c]	Freq	Size	STD[d]	Freq	Size	Freq	Size	STD	Freq	Size	STD
Panel 1: Twenty second execution lag														
1984-6	0.5	26,376	0.48	26,222	0.45	0.45	1,988	0.23	1,988	0.20	0.45	1990	0.10	0.58
	0.75	8,102	0.32	8,040	0.26	0.44	108	0.85	108	−0.06	0.99			
	1.0	946	0.42	927	0.26	0.68	17	3.83	17	−1.42	2.31			
1986	0.5	3,066	0.32	3,035	0.25	0.37	482	0.32	473	0.12	0.56	475	0.12	0.99

Table III—*Continued*

		Violations for Long Arbitrage					Violations for Short Arbitrage							
		Ex Post		Ex Ante			Ex Post		Ex Ante (Uptick)			Ex Ante (No Rule)		
Time Period[a]	TC(%)[b]	Freq	Size[c]	Freq	Size	STD[d]	Freq	Size	Freq	Size	STD	Freq	Size	STD
Panel 2: Two minute execution lag														
1984-6	0.5			26,086	0.44	0.52			1,985	0.17	0.57	1987	0.04	0.70
	0.75			8,002	0.25	0.53			107	−0.22	0.73			
	1.0			923	0.24	0.80			17	−2.24	0.85			
1986	0.5			3,027	0.19	0.40			471	0.05	0.45	473	0.01	0.96
Panel 3: Five minute execution lag														
1984-6	0.5			25,823	0.43	0.56			1,961	0.12	0.48	1959	−0.05	0.52
	0.75			7,926	0.22	0.56			105	−0.27	0.73			
	1.0			900	0.13	0.73			15	−2.34	0.93			
1986	0.5			3,007	0.16	0.43			460	0.00	0.52	461	−0.11	0.91

[a] Six months for 1984, twelve months for 1985, and eight months for 1986.
[b] TC(%) = Transaction costs as a percentage of the underlying index value.
[c] In terms of index points: a full index point is equivalent to $100 per contract.
[d] STD = standard deviation.

index instead of transactions data. Also, it appears that the MMI futures market has matured. The persistence of ex post violations has decreased significantly over the sample years for all levels of transaction costs as the arbitrage trading has tended to correct mispricings. The frequency and size of ex ante violations (arbitrage profits) have also declined sharply since the contract's introduction in July 24, 1984. The frequency of ex ante violations declines significantly 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. Also the ex ante arbitrage profit is substantially smaller than the triggering ex post mispricing signal. Especially in 1986, the most recent sample year in this study, only 0.5% transaction costs (the lowest level of commission assumed) still display 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 II are not riskless, as evidenced by their large standard deviations and by their substantial differences from mispricing signals. Also our regression results indicate that the size of mispricing signal has become a poor predictor of the realized profit from index arbitrage.

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 all 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 all ex post violations. Another interesting result is that the size of arbitrage profits from executable short arbitrages (whether the trader is subject to the uptick rule or not) is much smaller and more volatile than that from long arbitrages. In fact, for 0.75% and 1.0% transaction costs, the average size of ex ante arbitrage profits from 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.

Futures contracts for the MMI have the smallest volume and are the cheapest contracts available in the market. Subsequent researchers may find it worthwhile to look at futures contracts for larger 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.

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