Program Trading and Intraday Volatility

Lawrence Harris
University of Southern California

George Sofianos
James E. Shapiro
New York Stock Exchange, Inc.

Program trading and intraday changes in the S&P 500 Index are correlated. Future prices and, to a lesser extent, cash prices lead program trades. Index arbitrage trades are followed by an immediate change in the cash index, which ultimately reverses slightly. No reversal follows nonarbitrage trades. The cumulative index changes associated with buy-and-sell trades and with arbitrage and nonarbitrage trades all are similar. Price decompositions suggest that the results are not due to microstructure effects. Program trades in this 1989-1990 sample do not seem to have created major short-term liquidity problems. The results are stable within the sample.

Many practitioners, regulators, and public commentators have expressed concerns about potential destabilizing effects of program trading. They argue that program trades–especially index arbitrage programs–increase intraday volatility and decrease liquidity.[1] The mechanism typically hypothesized is

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[1] Birinyl Associates, for example, routinely attribute stock price volatility to program trading; for one instance see *New York Times* March 6, 1992, p. C6.

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that index arbitrage programs take liquidity from the cash market as they transmit excess volatility from the index futures market.

Despite the considerable attention given to program trades in public policy debates, little formal research has been conducted to characterize their relation to prices. A deeper understanding of this relation would provide useful information for resolving public policy debates about program trading. In particular, public policy prescriptions will depend on whether program trades lead or follow price changes and on whether the price changes associated with program trading typically reverse over time. Regulators will be especially interested in the extent to which program trades respond to new information or add new information to the price process.

To help answer these questions, we examined a sample of all intraday program trades conducted by New York Stock Exchange member firms in 1989 and 1990. We find that both index arbitrage and nonarbitrage program trades are correlated with intraday changes in the futures price and the cash index. Changes in the futures price and, to a lesser extent, changes in the cash index lead program trades. The program trades, in turn, lead changes in the futures price and cash index. The cash-futures basis starts widening a few minutes ahead of index arbitrage program trade times and reaches a peak at the reported submission time. Within 10 minutes after submission, the basis returns to its normal value, indicating that the cash and futures markets remained closely integrated in this sample. These results suggest that index arbitrage trades tend to adjust cash market prices to information first revealed in the futures market.

A $10 million program trade is associated, on average, with a cumulative 30-minute intraday change in the S&P 500 cash index of 0.03 percent. Linear extrapolation implies that a $100 million trade would be associated with about a one point move in the S&P 500. Buy and sell index arbitrage and nonarbitrage program trades have roughly the same cumulative association with changes in the cash index and the futures price.

Even though the cumulative associations of index arbitrage and nonarbitrage program trades with the S&P 500 are similar, the two types of program trades exhibit different short-run dynamics with respect to the index. In the case of nonarbitrage trades, the index reaches its final level quickly with no reversal. Index arbitrage trades have a stronger short-run relation with the index in the few minutes after the trade, and the index subsequently reverses slightly. The absence of large reversals suggests that program trades do not create major short-term liquidity problems and that price changes after program trades therefore mostly reflect new information. The relations between program trades and the futures price and the cash index are stable over the two-year sample period.

The correlation of program trading with the cash stock index may be partly spurious. Even if program trading had no effect on true underlying volatility, program trades could artificially increase measured cash index volatility for two reasons: bid-ask bounce and nonsynchronous trading.

Bid-ask bounce is the movement of individual stock prices from the bid to the ask when a buy order follows a sell order and vice versa. Usually, the number of stocks that last traded at the bid is about equal to the number of stocks that last traded at the ask. An index of last-trade stock prices then approximately equals the corresponding index of midquote prices, and little bid-ask bounce will occur. When widespread simultaneous selling or buying occurs, however, the last-trade index will differ from the midquote index. The change in the index will be exaggerated by the movement of individual stock prices inside their spreads. The average program trade in our sample involved 172 stocks, all typically either bought or sold. A program trade may therefore move a disproportionate number of stocks toward one of the quotes, causing bid-ask bounce to appear in the index. This bid-ask bounce is not a source of fundamental volatility but merely an artifact of the process by which liquidity demands are routinely satisfied.

The second reason the correlation between program trading and intraday volatility may be overstated concerns *nonsynchronous trading*. An index poorly reflects its true underlying value when values are changing quickly but not all stocks have traded. A program trade may simultaneously refresh a large number of stale prices so that the index realizes its underlying value. Program trades may therefore seem to be correlated with volatility when in reality they may be correlated only with the realization of earlier volatility.

To evaluate the magnitude of these two microstructure-based sources of spurious volatility, we use disaggregate stock price and quote data for June 1989 to decompose the index into three components: a proxy for bid-ask bounce, a proxy for price staleness due to nonsynchronous trading, and the remainder, a midquote index that is a proxy for the true underlying index. The decomposition is exact in the sense that the sum of these three components exactly equals the index. The components, however, are only estimates of the quantities in which we are interested. Removing the bounce decreases intraday volatility; removing the effect of nonsynchronous trading slightly increases volatility.

The decomposition shows that bid-ask bounce and nonsynchronous trading are not economically significant components of the relation between program trading and index changes in June 1989. Given these results and the cost of computing the decomposition, we did not repeat this analysis for the two-year sample. It is unlikely that bid-ask bounce and nonsynchronous trading explain the temporal relations between program trades and index changes observed in the two-year sample.

This study is related to several other empirical studies of program trading and of index volatility. Duffee, Kupiec, and White (1990) survey the issues and evidence concerning program trading and volatility. Feinstein and Goetzman (1988, 1991), Sofianos (1993b), Stoll (1987), and Stoll and Whaley (1987, 1988a, 1988b, 1990) consider the effects of derivative contract expirations. Harris (1989a) and Kleidon (1992) examine the effect of nonsynchronous trading and nonsynchronous information assimilation on cash indices. Harris (1989b) compares the volatility of S&P 500 stocks to non-S&P 500 stocks. Chan and Chung (1993) and MacKinlay and Ramaswamy (1988) examine the intraday arbitrage spreads and their relation to cash and futures price volatility. Froot and Perold (1990) document a decrease in intraday index return autocorrelations concurrent with the growth of stock index futures and associated arbitrage activity. None of these studies examine actual program trading data.

Grossman (1988) and Moser (1991) use daily program trading data to examine the relation between volatility and program trading. They find no relation, probably because they use daily aggregate data rather than intraday data.

Furbush (1989), Neal and Furbush (1989), and Neal (1992, 1993) examine disaggregated intraday program trading data. The first two studies examine data only from a few days surrounding the October 1987 Crash. Neal (1992, 1993) examines the same program trading data used in this study but over a shorter three-month sample period. Although Neal's empirical method and sample period are different from those employed in this study, the findings of the two studies are similar.

The remainder of the article is organized as follows. Section 1 presents a decomposition of the last-trade index and discusses the implications of bid-ask bounce and nonsynchronous trading for the relation between program trading and volatility. Section 2 describes the data and the construction of the variables used in the empirical study. Section 3 presents some initial empirical characterizations of the sample. Section 4 describes the event-study methods used throughout this study. Sections 5 and 6 present empirical results from the event-study analyses. The article concludes with a summary and qualifications in Section 7.

1. Decomposition of the Index

This section describes how bid-ask bounce and nonsynchronous trading may affect the relation between program trading and changes in a cash index computed from last-trade prices. These effects are identified by decomposing the last-trade index as follows:

$$I_t = (I_t - QL_t) + (QL_t - QC_t) + QC_t \tag{1}$$

where I_t is the index computed from last-trade prices, QC_t is the index of quote midpoints (the average of bid and asked quotes) computed from current quotes, and QL_t is the index of quote midpoints computed from last-trade quotes (the quotes that were current when the last transaction in each stock took place).[2]

The first component of this decomposition represents the bid-ask bounce in the last-trade price index. This interpretation is apparent by letting A_t and B_t represent, respectively, the last-trade asked index and the last-trade bid index so that $A_t - B_t$ is the composite last-trade index bid-ask spread and $(A_t + B_t)/2 = QL_t$. The bid-ask bounce component, $I_t - QL_t$, can then be further decomposed into the following product:

$$I_t - QL_t = [2(I_t - B_t)/(A_t - B_t) - 1](A_t - B_t)/2 \tag{2}$$

The factor in square brackets is an indicator of the relative location of the last-trade index between the bid and asked quote indices. It equals –1 when all stocks in the index last traded at the bid and 1 when all index stocks last traded at the ask. Variation in the bid-ask bounce component results whenever a cross-sectional imbalance of sell or buy orders causes the trade index to move away from the midquote index.

A simple calculation shows that the bid-ask bounce may have a large effect on intraday volatility. The typical stock in the S&P 500 has a quoted spread of about 0.5 percent.[3] The spread for the index is therefore also about 0.5 percent. If a program trade moves the index from midquote to one-half the distance to the bid or ask, that would be a 0.125 percent change in the index. Such a change in the S&P 500 at 400 equals half a point. Although this is a small change compared to daily index changes, it would be a significant source of intraday volatility.

The second component in Equation (1), the difference between the current and last-trade midquote indices, measures price staleness

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[2] Note that QL_t *is* not just the lagged current quote Index QC_{t-1}.

[3] The quoted spread overstates the effective spread at the NYSE because approximately one-third of all trades take place inside the quotes. Execution prices for large program trades effected through market orders. however, may be worse than this statistic suggests.

due to nonsynchronous trading. Since quotes are often changed between trades (possibly several times), the current midquote should be closer to the underlying true value of the index than the last-trade quote index.[4] The latter is a measure of the last-trade value of the index abstracting from bid-ask bounce. Since market makers revise quotes (and customers enter limit orders) in response to changes in fundamental value, this second component should be correlated with current and leading changes in the unobserved true value of the index. However, because market makers do not always respond to changes in fundamentals by instantaneously adjusting their quotes, the difference between the two midquote indices is an imperfect measure of price staleness.

The remaining component in (1), the current midquote index, QC_t, is a proxy for the unobserved true value of the index. This index should be uninfluenced by bid-ask bounce and should be relatively immune to the effects of nonsynchronous trading if quotations are kept current. Variation in this component should represent changes in information fundamentals and, possibly, large-scale order flow imbalances arising out of liquidity and/or noise trades such as are identified in Biais, Hillion, and Spatt (1994).

This article also examines the relation between program trading and futures prices. A decomposition of the cash-futures basis can be derived by subtracting the futures price, F_t, from both sides of (1). The result is

$$I_t - F_t = (I_t - QL_t) + (QL_t - QC_t) + (QC_t - F_t) \qquad (3)$$

where $I_t - F_t$ is the cash-futures basis and $QC_t - F_t$ will be referred to as the true proxy basis.

Equations (1) and (3) contain eight variables of interest: four indices of the value of the S&P 500 stocks (the futures price, the last-trade index, the current midquote index, and the last-trade midquote index); two measures of the cash-futures basis; and two index components common to both decompositions (the price staleness and the bid-ask bounce components). Program trading may be correlated with changes in any or all of these series.

The signed program trades should be correlated with changes in the bounce because buy programs cause more prices to be observed at the asked quote and sell programs cause more prices to be observed at the bid quote. Program trades, by updating prices, reduce price staleness as defined in this article. Program trades, therefore, should be correlated with the price staleness component.

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[4] This conclusion implicitly assumes that the informational and noninformational component of the spread are symmetric.

Program trading should be correlated with the last-trade index and with the last-trade midquote index because the former includes bid-ask bounce and both tend to be stale. Changes in all cash indices and changes in the futures price also will be correlated with program trading if the program trading order flow conveys information that is not yet reflected in the prices and quotes.

As for the temporal relationship between program trades and changes in the futures price and the cash indices, the following conjecture is made. Since transaction costs are commonly thought to be lower in the futures market, many orders triggered by economy-wide information are sent first to the futures market. When the basis widens to the point that arbitrage becomes profitable, index arbitrage program trades carry the effects of these initial information-based trades to the cash market. On average, returns to the futures contract therefore should lead program trades, which in turn should lead cash index returns. Cases under which large cash transactions cause changes in futures prices are possible but infrequent.

2. Data Description

Two data sets are examined in this study. The first data set focuses on June 1989, whereas the second data set covers the two-year period 1989-1990. Both data sets include corresponding series for futures prices and program trading activity. The June 1989 data set uses individual stock trade prices and quotes to construct the index decomposition described above.’ The decomposition is then used to evaluate the significance of the bid-ask bounce and nonsynchronous trading components. No index decomposition is constructed for the two-year data set. Instead, the two-year data use the published minute-by-minute S&P 500 cash index values to examine relations among the cash index, futures prices, and program trades.[6]

The individual trade and quote data used in the one-month sample consist of all NYSE trades and quotes in June 1989 for the NYSE S&P 500 stocks present in the sample both at the beginning and end of the month. The sample consists of 457 stocks, comprising 95.6 percent of the value of the S&P 500 and 73.7 percent of the value of all NYSE common stocks.[7] Like the S&P 500 index, all computed indices are

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[5] The stock price and quote data come from the NYSE’s daily Consolidated Trade (CT) and Consolidated Quote (CQ) files.

[6] The S&P 500 cash values and futures prices come from Bridge Information Systems. The program trading data are discussed below.

[7] Five stocks are excluded from the sample because the primary exchange listing of the stock changed (one stock), because the stock was added or removed from the S&P 500 list (two stocks), or because the symbol changed (two stocks). Adjustments are made for four stocks that split during the sample

value-weighted. The correlation between one-minute returns of the constructed NYSE last-trade S&P 500 and the published S&P 500 cash index is 0.87.[8]

The futures price series consists of the time and sales (price) records of the Chicago Mercantile Exchange market reporters for the near-delivery S&P 500 contract. In June 1989, the near-delivery contract was the June contract, until it expired on June 16 when the September contract became the nearest contract. The two-year sample includes nine different contracts.

Futures prices, individual stock prices, and published index values all are reported to the nearest second. When constructing one-minute time series, we used the last price observed within each one-minute interval. The NYSE last-trade S&P 500 for minute t is constructed from the last-trade price in each stock as of the end of minute t. The last-trade midquote index for minute t is constructed from the average of the bid and asked quotes that stood when the last trade in each stock took place. The current midquote index for minute t is constructed from the last set of quotations for each stock as of the end of minute t.

The program trading data are supplied by the New York Stock Exchange, Inc. Since May 2, 1988, all members and member firms of the NYSE have been required to file daily reports of their program trading. The NYSE definition of program trading includes a wide range of portfolio trading strategies involving the simultaneous or nearly simultaneous purchase or sale of 15 or more stocks with a total aggregate value of $1 million or more.

The data examined in this study consist of all reported program trades executed at the NYSE. For each trade, the date, the time the order was sent to the NYSE, whether it was a buy program or a sell program, the number of shares traded, the number of stocks involved, the total value of the trade, the strategy (e.g., index arbitrage, exchange for physical), and the type of order (e.g., market-on-close, opening)

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period. A small number of stopped orders, "G" trades, and Rule 127 block trades arc excluded from the sample. "G" trades are certain trades where the member firm is required by Rule 11(a)(1) of the 1934 Securities and Exchange Act to yield to public customer orders. Rule 127 block trades are blocks crossed outside the prevailing quotes in accordance with the Exchange's Rule 127. For more information on Rule 127 see Hasbrouck, Sofianos. and Sosebee (1993). Filters are used to adjust or delete obviously incorrect quotes and prices.

[8] The correlation of one-minute changes in our constructed NYSE proxy S&P 500 with the published S&P 500 seems low given that the proxy includes 95.6 percent of the S&P 500 market value. The data probably arc slightly misaligned in time. The stock price data arc time stamped within the exchange, whereas the published S&P 500 data arc time stamped after the stock price data are transmitted to and processed by Bridge Information Systems. Five-minute changes In these two indices have a much higher correlation of .98. An examination of the serial cross-correlations between one-minute changes in the two series shows that the constructed series slightly leads the published series. The first leading correlation is .50, whereas the first lagged correlation is only .30. The large value of both cross-correlations reflects the autocorrelation induced by nonsynchronous trading. The maximum absolute deviation between the two series within any minute is only 0.28 index points.

are reported. We group program trades into four types: buy index arbitrage, buy nonarbitrage, sell index arbitrage, and sell nonarbitrage.[9] Each type of program trading activity is aggregated over one-minute intervals.

The accuracy of the reported program trade submission times is crucial for this study because the program trades must be properly aligned with their associated price changes. The New York Stock Exchange has taken considerable care to ensure the accuracy of these data to the minute. The Appendix provides a full discussion of the NYSE collection and audit systems. The timing of the data seems to be accurate.

Unfortunately, the reported submission times differ from the times at which the various individual stock trades are executed. The submission time is the desired variable for analyzing why program trades may have been submitted. The execution time is the desired variable for analyzing the effects that program trades may have had on prices.

The difference between the submission and execution times is due to the time it takes for orders to be routed through the various electronic and/or manual order submission systems and for specialists and/or floor brokers to execute the orders. Exchange traffic statistics suggest that the average time from receipt to the complete execution of a large program trade of market orders in our sample was about two minutes. More complex orders such as buy-minus and sell-plus orders take longer to execute.[10] A detailed description of the time lags in these systems appears in the Appendix.

3. Initial Characterization of the Data

The two-year sample contains 50,760 program trades (Table 1). The average program trade contains 172 stocks with an aggregate value of $6.6 million. About half of the reported program trading dollar volume is index arbitrage. The average values of index arbitrage and nonarbitrage program trades are $5.9 and $7.6 million, respectively. Index arbitrage buy-and-sell program trades are about equally common and involve roughly the same average numbers of stocks and aggregate values. The same is true for nonarbitrage buy-and-sell pro-

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[9] The index arbitrage trades include all trades with a strategy identifier of index arbitrage or index substitution. The identifier is assigned by the program trader from a list of strategies provided by the exchange. All other strategy identifiers were classified as nonarbitrage. We discarded 57 trades with missing strategy identifiers.

[10] Buy-minus and sell-plus orders are called *tick orders*. A buy-minus order can be executed only on a down tick, and a sell-plus order can be executed only on an uptick. Information on buy-minus and sell-plus orders was not available for most of the sample period. (The NYSE started collecting this information in January 1990.) Sofianos (1993a) reports that, in the first six months of 1990, 24 percent of S&P 500 index arbitrage dollar volume consisted of sell short, sell-plus and buy-minus orders.

Table 1
Program trading statistics for January 1989 through December 1990

	N	Mean	Minimum	Maximum
		Index arbitrage program trades		
Dollar value per program trade (millions)				
Buy programs	13,994	16.4	$1.0	**$580**
Sell programs	15,192	15.5	$1.0	**$635**
Number of stocks per program trade				
Buy programs	13,994	201	15	1,571
Sell programs	15,192	154	15	1,055
Number of shams per program trade (thousands)				
Buy programs	13,994	142	12	12,728
Sell programs	15.192	122	14	13,702
		Nonarbitrage program trades		
Dollar value per program trade (millions)				
Buy programs	11,645	$7.3	$1.0	$1,144
sell programs	9,929	$8.0	$1.0	$589
Number of stocks per program trade				
Buy programs	11,645	153	15	1,268
Sell programs	9,929	180	15	1,600
Number of shares per program trade (thousands)				
Buy programs	11,645	176	12	18,366
Sell programs	9,929	193	12	13,543

The program trading data arc compiled from the dally program trading reports of NYSE member firms and include only program trades executed on the NYSE from January 1, 1989, through December 31, 1990. This two-year sample contains 50,760 program trades.

gram trades. The June 1989 subsample is generally representative of the larger sample.[11]

Standard deviations of one- and five-minute returns (log price relatives) for the various intraday indices appear in Table 2. In the June 1989 sample, the one-minute standard deviation of the last-trade index is 54 percent greater than that of the last-trade midquote index. The excess volatility suggests that bid-ask bounce accounts for a significant fraction of the last-trade index volatility in one-minute returns.[12] The one-minute standard deviation of the current midquote index is almost 10 percent greater than that of the last-trade midquote index. This difference suggests that nonsynchronous quoting smooths the last-trade midquote index.[13] In both samples, ratios of five-minute return

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[11] It contains 2314 program trades. The average program trade contains 178 stocks with an aggregate dollar value of $8.9 million.

[12] In the five-minute returns, the last-trade index standard deviation is only 27 percent larger than the last-trade midquote index standard deviation. The smaller value of this ratio In the five-minute returns shows that the one-minute last-trade cash Index returns have a strong transitory component, presumably the bid-ask bounce.

[13] Standard deviations (not reported) of index returns by size subgroups show that volatilities of the smaller stock indices are influenced more by bid-ask bounce and staleness than those of the larger stock indices.

Table 2
Intraday return standard deviations for the S&P 500 futures contract

	Standard deviations (in hundredths of a percent)		Ratio of five-minute to one-minute return variances
	One-minute returns	Five-minute returns	
January 1989 through December 1990			
S&P 500	2.1	7.3	12.5
Near futures contract	4.5	10.1	5.0
June 1989			
NYSE S&P 500			
Last-trade index	1.7	5.7	11.0
Current midquote index	1.2	4.7	16.6
Last-trade midquote index	1.1	4.5	17.2
Near futures contract	3.4	1.3	4.1

The last-trade index is a value-weighted index of all 457 S&P 500 stocks listed on the NYSE in June 1989. The current midquote for a stock is the average of its most recent bid and asked quotes. The last-trade midquote is the average of the bid and asked quotes in effect at the time of the last trade. The midquote indices are value·weighted indices of the midquotes. The two-year sample (505 trading days) contains 196,585 one-minute observations and 39,316 five-minute observations. The June 1989 sample (22 trading days) contains 8,580 one-minute observations and 1,716 five-minute observations.

variances to one-minute return variances confirm that the cash indices have positive autocorrelation and that the futures price is largely uncorrelated.

Table 3 presents one-minute autocorrelations at various lags for futures and cash index returns. Futures returns are largely uncorrelated except for some small negative serial correlation (–0.06) at the first lag. The negative correlation is probably due to bid-ask bounce in the pit. Effective spreads in the near futures contract in June 1989 typically were 0.05 or 0.10 index points. The last-trade cash index is

Table 3
One-minute intraday autocorrelations of futures and various index returns for June 1989

Lag	S&P 500 futures returns	Last-trade index returns	Current midquote index returns	Last-trade midquote index returns
1	–0.06	0.40	0.69	0.71
2	0.02	0.25	0.56	0.60
3	0.03	0.21	0.48	0.52
4	0.03	0.18	0.40	0.44
5	0.01	0.14	0.35	0.40
6	0.00	0.13	0.29	0.34
7	0.01	0.10	0.24	0.29
8	–0.01	0.08	0.19	0.24
9	0.00	0.06	0.16	0.18

The last-trade index is a value-weighted index of all 457 S&P 500 stocks listed on the NYSE In June 1989. The last-trade midquote is the average of the bid and asked quotes in effect at the time of the last trade. The midquote indices are value-weighted indices of the midquotes. There are 8,580 observations in this 22-day June 1989 sample.

Table 4
Transition probabilities for index arbitrage program trades, January 1989 through December 1990

	Current minute, %			
	Buy Program trades	Sell program trades	No program trades	All program trades
Buy program trades				
Minute 1	25.1	3.2	72.5	100.8
Minute 2	22.2	3.8	74.8	100.8
Minute 3	19.5	4.4	76.9	100.8
Minute 4	16.8	4.8	79.1	100.7
Minute 5	14.8	5.8	80.1	100.7
Sell program trades				
Minute 1	2.5	22.8	75.2	100.5
Minute 2	3.0	20.4	77.2	100.6
Minute 3	3.2	18.1	79.2	100.5
Minute 4	3.5	16.0	81.0	100.5
Minute 5	3.9	14.8	81.8	100.5
No program trades				
Minute 1	4.2	4.9	91.1	100.2
Minute 2	4.3	5.0	90.8	100.1
Minute 3	4.5	5.1	90.6	100.2
Minute 4	4.6	5.2	90.4	100.2
Minute 5	4.1	5.2	90.3	100.2

The program trading data are compiled from the daily program trading reports of NYSE member firms and include only program trades executed on the NYSE from January 1, 1989, through December 31, 1990. There are 197,455 one-minute observations in the two·year sample. The transition probabilities add up to slightly more than 100 percent because in a few one-minute periods both buy and sell index arbitrage program trades were repotted.

positively correlated because, at least in part, of the nonsynchronous trading problem and nonsynchronous information assimilation [see Harris (1989a) and Kleidon (1992)]. These results (and similar unreported results for the full sample) suggest that the futures market discovers index values faster than does the cash index market. The absence of significant negative serial correlation in the futures returns suggests that their high volatility is not due to short-term liquidity problems.

Table 3 also presents autocorrelation coefficients for one-minute returns in the current and last-trade midquote indices. These midquote indices have more positive serial correlation than does the last-trade index. The differences are due to the bid-ask bounce in the last-trade index. The bounce reduces the positive serial covariance and increases the variance; both effects reduce positive autocorrelation. The last-trade midquote index is more highly autocorrelated than the current midquote index because the former is based on prices that are more stale. The small difference between autocorrelations for the last-trade midquote and the current midquote indices suggests that nonsynchronous information assimilation may be a more important cause of autocorrelation than is nonsynchronous trading.

Table 5
The episodic nature of program trades, January 1989 through December 1990

	Frequency distributions of number of trades by episode type, %			
	Index arbitrate		Nonarbitrage	
	Buy	Sell	Buy	Sell
1 trade	**50.2**	**52.8**	**69.0**	**70.2**
2	**18.2**	**19.4**	**17.7**	**16.1**
3	**10.3**	**10.0**	**6.1**	**6.3**
4	**6.5**	**5.7**	**3.6**	**3.2**
5	**4.3**	**4.0**	**1.4**	**1.4**
6	**2.9**	**2.4**	**0.8**	**1.1**
7	**2.1**	**1.4**	**0.3**	**0.4**
8	**1.5**	**1.3**	**0.3**	**0.5**
9	**1.0**	**0.6**	**0.3**	**0.3**
10	**0.6**	**0.5**	**0.2**	**0.2**
11 trades or more	**2.3**	**1.8**	**0.3**	**0.3**
Total	**100.0**	**100.0**	**100.0**	**100.0**
Mean number of trades per episode	**2.6**	**2.4**	**1.6**	**1.6**
Mean episode duration in minutes	**2.4**	**2.2**	**1.2**	**1.2**
Number of episodes	**4,013**	**4,562**	**5,166**	**4,335**

An *episode* is defined as all sequences of same-type program trades (buy index arbitrage, buy nonarbitrage, sell index arbitrage, sell nonarbitrage) that are separated by more than five minutes of no program trading. Episodes starting between 9:30 and 10:00 A.M. and episodes starting after 3:55 P.M. were discarded to make the episode sample consistent with the regression sample.

The one-minute program trading time series for the four groups of program trades (buy arbitrage, sell arbitrage, buy nonarbitrage, sell nonarbitrage) have a lot of zeros. Program trades took place in only 17 percent of the one-minute intervals in the full sample. As a consequence, these series display very little autocorrelation.

Table 4 presents conditional transition probabilities for index arbitrage program trades. About 74 percent of all arbitrage program trades are not followed by another trade in the next minute (Table 4). When a program trade does immediately follow another program, however, it usually is on the same side of the market. This asymmetry is present for at least five minutes after a program trade. These results suggest that some index arbitrage program trades take place in episodes.

Table 5 further characterizes the episodic nature of program trades. We defined an episode to be all sequences of same-type program trades (buy arbitrage, sell arbitrage, buy nonarbitrage, sell nonarbitrage) that are separated by more than five minutes of no program trades. Although about half of all episodes involve only one program trade, 20 percent of episodes involve four or more program trades. The mean number of trades per episode is 2.5 for index arbitrage, and the mean duration of an episode is 2.3 minutes. Not surprisingly, both statistics are lower for nonarbitrage trades; nonarbitrage trades do not seem to be conditioned on current price conditions.

4. Empirical Event-Study Methods

The relations between program trades and the various analysis variables (futures and index returns, the cash-futures basis, and various index components) are likely to differ depending on whether the program trades are related to index or nonarbitrage strategies and on whether the trades are buy or sell. Index arbitrage trades, for example, should be more closely related to the futures basis than are nonarbitrage trades. This study tries to isolate the association between the various analysis variables and four types of program trades: buy arbitrage, sell arbitrage, buy nonarbitrage, sell nonarbitrage.

The relations between the four types of program trades and the analysis variables are examined using event-study plots. The methods used throughout this article, however, differ from those typically used in event studies. In a typical event study, the value of an analysis variable (e.g., an index return) at the time of an event (e.g., a sell index arbitrage program trade) is averaged across all such events. The result is a measure of the average contemporaneous relation between the event and the variable. Their temporal relation is characterized by computing separate averages of lagged and leading values of the analysis variable where the lags and leads are defined relative to the time of the event.

These methods are inappropriate, however, when the events are clustered in time, as the results of the previous section suggest. When the program trades cluster, the relation of the analysis variable to one trade is difficult to disentangle from the relation of the analysis variable to other nearby trades.

This study addresses this clustering problem by using regression methods to characterize the average relation between the four types of program trading events and the analysis variables. Each analysis variable is regressed on five leads, 30 lags, and contemporaneous values of one-minute time series of buy nonarbitrage, sell nonarbitrage, buy index arbitrage, and sell index arbitrage program trades.

The resulting series of regression coefficients characterize the average relation of the analysis variable with the various types of program trading events, after controlling for the effects of clustered program trading events of all types. If there were no clustering and if the time series of program trades simply consisted of an (0, 1) indicator variable for the occurrence of a program trade, the regression coefficients would be identically equal to the event-time means computed in typical event studies. Rather than using a (0, 1) indicator for program trades, this study uses the aggregate value of the program trading, measured in $10 million units. Accordingly, the regression coefficients represent the mean relation (per $10 million) of program trading to the analysis variable.[14]

The regression model includes five one-minute leads of the program trading time series to characterize how program trading lags the analysis variables. Thirty one-minute lags of the program trading time series are included to characterize the lagged relation of the analysis variables to program trading. Given the lag structure of the regressions and the exclusive focus of this study on intraday relations, program trades that occurred in the first 30 and last 5 minutes of the trading day are dropped from the sample.[15]

This regression event-study method is not designed to determine causality, which cannot be determined only from correlations. The regressions are merely designed to represent, in the clearest manner possible, the average relation between program trading and the analysis variables of interest after accounting for clustered effects. We thus refer to this analysis as an event-study analysis rather than as a transfer function analysis. Although structurally identical, the latter suggests causality not supported by any prior information in our possession.

5. Event Analysis of the June 1989 Sample

This section characterizes the effect of bid-ask bounce and nonsynchronous trading on the relation between program trades and index returns in the June 1989 subsample. The results demonstrate that, for most purposes, these processes can be ignored when studying the larger sample.

Figure 1 plots event-time cumulatives of changes in the last-trade index (I_t), in the last-trade midquote index (QL_t), in the current midquote index (QC_t), and in the futures price (F_t) surrounding sell-and-buy index arbitrage and nonarbitrage program trades. The cumulatives are sums of the event-study regression coefficients. They represent the average price path associated with program trades after the effects of clustering have been disentangled. The event-time indices all decline around sell programs and rise around buy programs. The cumulatives for buys and sells are generally symmetric. The two midquote indices lag the trade index. The lag suggests that program trades often hit the existing quote so that bid-ask bounce causes the index to change before stock quotes change. The current quote index leads the last quote index (the index of quote midpoints that stood at the

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[14] We also estimated regressions using a (0, 1) indicator variable for the various types of program trades, and it does not make much difference to the results.

[15] The lengths of the lags and leads were chosen to characterize as much of the relation between intraday program trading and price changes as possible while minimizing the data lost when leads or lags span the beginning or end of the trading day.

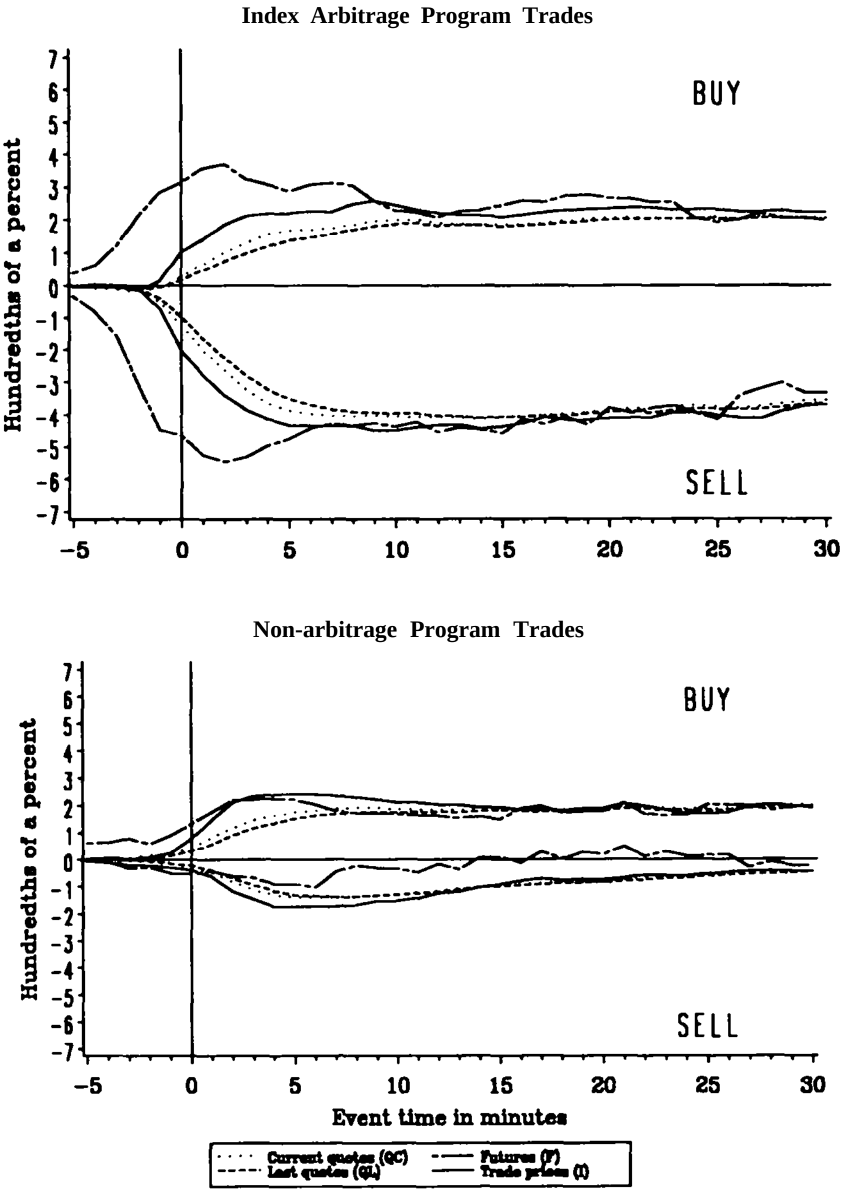

Figure 1
Event-time indices surrounding program trades for June 1989
Cumulated estimated index returns (in hundredths of a percent) surrounding $10 million program trades. The estimates arc obtained from regressions of several intraday time series of one-minute index returns on 5 leads and 30 lags of Index arbitrage buy-and-sell and nonarbitrage buy-and-sell program trades. The sample includes all program trades reported by member firms to the NYSE In the 22 trading days in June 1989, except those trades occurring in the first 30 minutes and last 5 minutes of the trading day. The indices plotted are the NYSE S&P 500 last-trade price index, the NYSE S&P 500 last-trade midquote index, the NYSE S&P 500 current midquote index, and the nearest CME S&P 500 futures contract.

time of the last transaction in each stock) because the current quote index reflects all quote revisions made since the last transaction in each stock. Since the three constructed indices generally move closely together, bid-ask bounce and nonsynchronous trading effects do not significantly affect the relation between program trading and the cash index.

Figure 2 plots event-time estimates of two measures of the basis surrounding index arbitrage program trades. The cash index basis $(I_t - F_t)$ is equal to the midquote basis $(QC_t - F_t)$,[16] plus the bid-ask bounce component $(I_t - QL_t)$, and the price staleness component $(QL_t - QC_t)$. These event-time estimates are the appropriate event-study regression coefficients plus the estimated intercept. They represent the average value of the basis associated with program trades after the effects of clustering have been disentangled. As expected, the basis widens, reaching a peak a few minutes before the index arbitrage trade submission time, and falls sharply after the trade. Since both basis measures move close together, bid-ask bounce and price staleness does not significantly affect the relation between program trading and the basis.

Figure 2 also plots event-time estimates of the bid-ask bounce and price staleness components surrounding index arbitrage program trades. The bid-ask bounce component falls to a minimum shortly after the submission of a program sell and rises to a maximum shortly after the submission of a program buy. In both cases, average event-time bounce starts to move from zero before the reported submission time of the trade. This result is somewhat surprising, since the reported submission times should lag the execution times. Perhaps submission times for some trades are reported late. Alternatively, arbitrage programs may be more likely when the bounce is large. The absolute bounce increases from its initial value near zero faster before the reported program trade than it returns to zero afterward. The difference is probably due to nonsynchronous trading. After the program trade, the bounce in an individual stock does not change until another order is executed on the other side of the spread.

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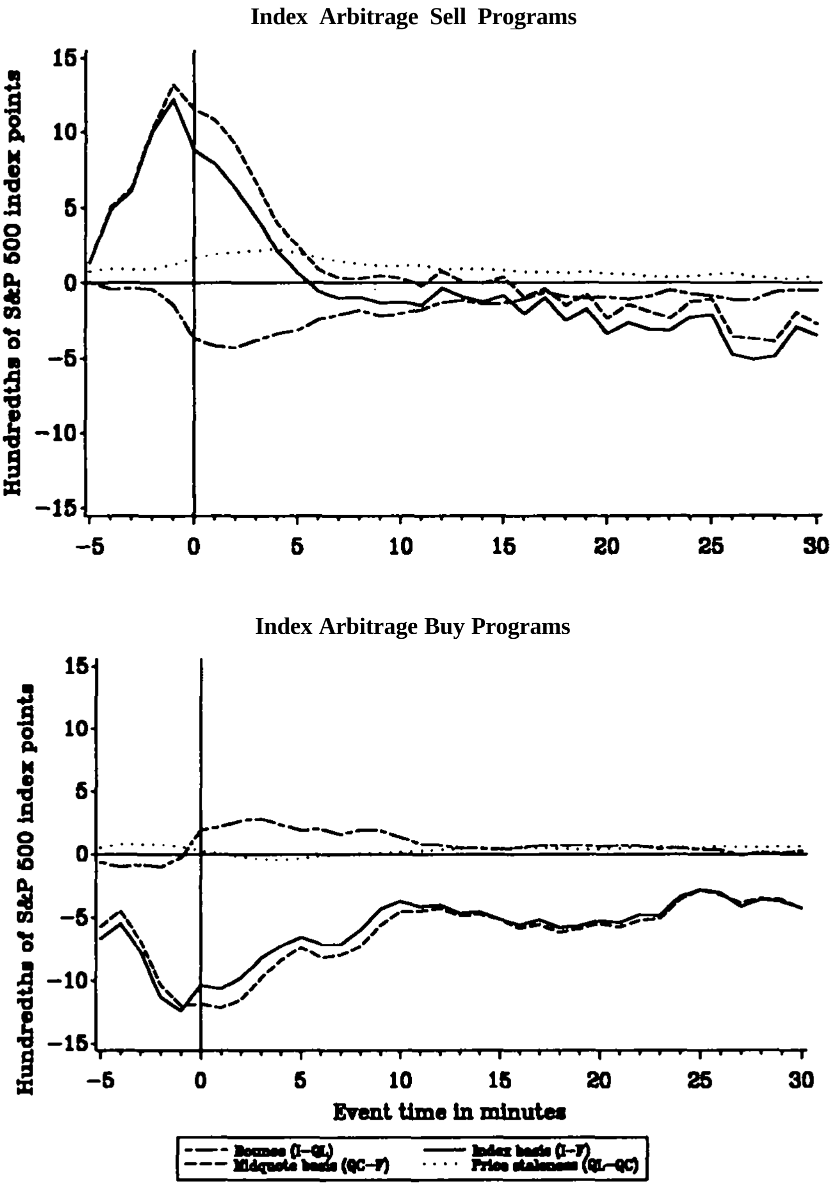
[16] The expected carrying cost component of the cash-futures basis decreases over time as the contract approaches maturity and as dividends are paid. The event-time estimates of the basis are computed net of an estimate of the carrying coat component. The estimate is computed by regressing the basis measured at one-minute intervals on the number of calendar days to contract maturity. Separate intercepts are used for the June contract and for the September contract that became the near contract when the June contract expired on June lb. Since the same adjustment is used for all data in a given day, the intraday pattern of event-time means is unchanged. The adjustment affects only the level of the event-time basis. Analogous procedures to detrend the basis are used in the two-year sample. This method of dealing with carrying costs differs from the one in MacKinlay and Ramaswamy (1988); they compare the futures price with the cost-of-carry futures price (based on the cash index). Had we specified carrying costs instead of estimating them, we would have arrived at the same conclusions. The average basis, however, may have been shifted up or down by a small amount.


Index Arbitrage Sell Programs

Index Arbitrage Buy Programs

Figure 2
Event-time basis and index components surrounding index arbitrage program trades for June 1989
Estimated basis and Index components (in hundredths of S&P 500 index points) surrounding $10 million index arbitrage program trades. The estimates plotted are the sell index arbitrage regression coefficients (plus the intercept) obtained from regressions of the minute-by-minute time series of the basis and the index components on 5 leads and 30 lags of index arbitrage buy-and-sell and nonarbitrage buy-and-sell program trades. The basis is the value of the NYSE S&P 500 last trade minus the price of the nearest S&P 500 futures contract plus an estimate of the expected carrying cost.

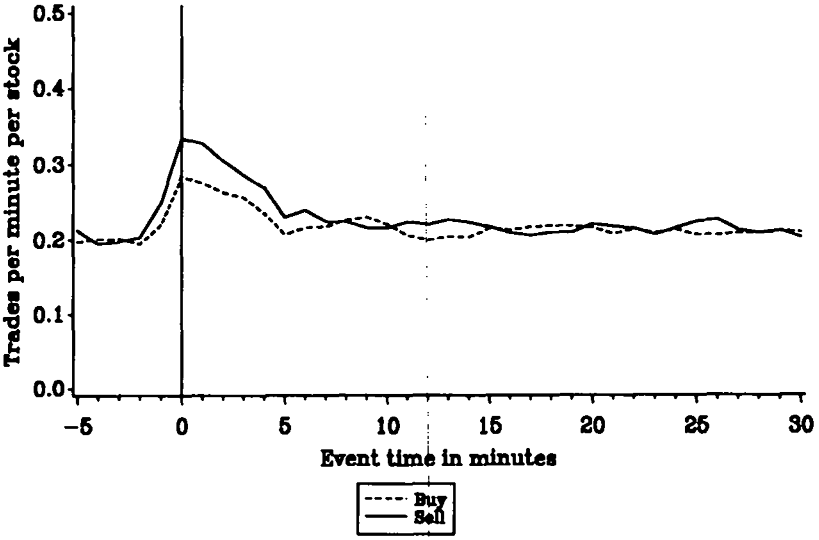


Figure 3
Event-time trades per minute per index stock surrounding index arbitrage program trades for June 1989
Estimated number of trades per minute per stock in the 457 NYSE S&P 500 stocks surrounding $10 million buy-and-sell index arbitrage program trades. The estimates plotted are regression coefficients (plus the intercept) obtained from regressions of the minute-by-minute time series of number of trades on 5 leads and 30 lags of index arbitrage buy-and-sell and nonarbitrage buy-and-sell program trades.

The magnitude of the bid-ask bounce depends both on where trade prices are located relative to their associated bid and asked quotes and also on the size of the quoted spreads. To measure the importance of the latter factor, we computed event-study averages of the index bid-ask spread surrounding the various types of program trades. The results (not presented) show that bid-ask spreads increase slightly from 1.39 index points just before to 1.40 index points just after reported program trade submission: times. The spread reverts to its preprogram trade level about five minutes after the submission. This small blip is larger for the arbitrage trades than for the nonarbitrage trades.

The event-time price staleness component is quite small. As expected, it rises to an absolute peak shortly after the submission of the program trade. The rise reflects new quotes for stocks that have not recently traded. It then declines toward zero as trades in the index stocks cause more current quotes to become “last” quotes. The price staleness component is small because the index stocks trade frequently (the value-weighted mean time since the last transaction in the NYSE S&P 500 stocks was only five minutes in June 1989) and because quotes are not updated continuously.

Figure 3 plots event-time estimates of the number of trades per minute in the S&P 500 component stocks surrounding index arbitrage program trades. Trading activity surrounding index arbitrage trades increases slightly, reaching a peak at the reported trade submission time. These results suggest that a fraction of the program trade executes almost instantaneously or more likely that some of the trade submission times are reported late. Average trading frequency remains high for about five minutes after the reported submission time. The lag reflects the time it takes to execute long trade lists. It may also be due to erroneously reported submission times. The relatively small increase in trading activity suggests that program trades did not overwhelm market capacity during the June 1989 sample period.

Examinations of the bounce and staleness components in subsamples classified by stock size (not reported) show that both components are bigger for the smallest capitalization stocks. These stocks have wider spreads on average, and they trade less frequently. Size-classified trading frequencies (also not reported) show that program trading only slightly increases the numbers of trades per minute per stock of the more actively traded large stocks. Program trades account for a smaller fraction of the total trading in these stocks.

Analogous relations for the nonarbitrage trades (not reported) are all much weaker. In particular, nonarbitrage trades have almost no effect on the mean number of trades per index stock. At least partly, this reflects the fact that nonarbitrage trades are less episodic than are arbitrage trades.

The root mean sums of squares of the predicted values from the regressions of index changes on leads and lags of the four types of program trades measure the variation in index returns that is correlated with program trading. The root mean predicted sums of squares are 6.8, 5.2, 4.1, and 3.8 hundredths of a percent, respectively, for one-minute returns to the futures, the last-trade index, the current midquote index, and the last-trade midquote index.[17] Program trade-correlated volatility is smallest for the last-trade midquote index because it is unaffected by bid-ask bounce and because it is smoothed by the nonsynchronous quoting. It is greater in the current midquote index because current quotes are less stale. The program trade-correlated volatility in the last-trade index is greater than in the last-trade midquote index because program trading causes bid-ask bounce. Finally, the program trade-correlated volatility in the futures price is greatest because it adjusts most quickly to the new information contained in (or causing) the program trading order flow.[18]

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[17] The corresponding adjusted R^2's are 6, 22, 38, and 38 percent. They do not display the same rankings because their denominators differ.

[18] The residuals for the futures return regression and for the last-trade Index return regression show

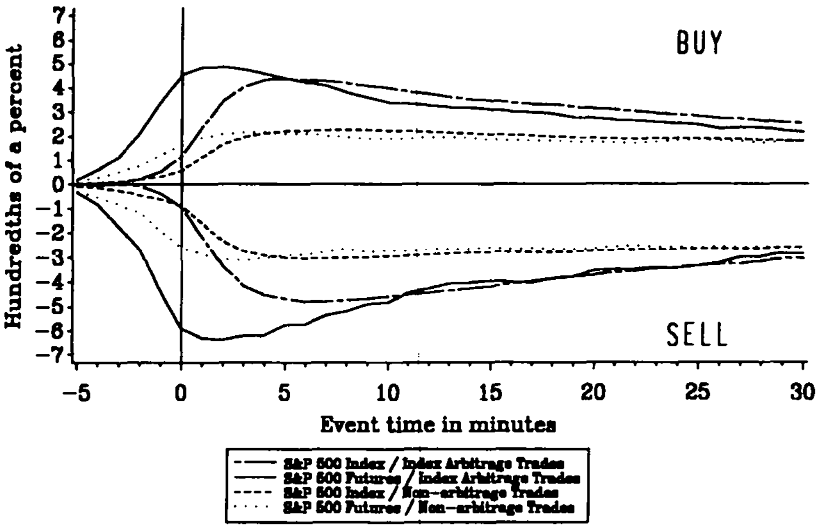

Figure 4
Event-time indices surrounding program trades for January 1989 through December 1990
Cumulated estimated S&P 500 futures and cash index returns surrounding $10 million program trades. The estimates are obtained from regressions of the intraday time series of one-minute S&P 500 futures and cash index returns on 5 leads and 30 lags of index arbitrage buy-and-sell and nonarbitrage buyand-sell program trades. The sample includes all program trades reported by member firms to the NYSE in the 505 trading days in the two-year period 1989 through 1990, except those trades occurring in the first 30 minutes and last 5 minutes of the trading day.

6. Event-Study Analysis of the Full Sample

The results in the previous section show that bid-ask bounce and nonsynchronous trading are not economically significant components of the relation between program trading and index changes. Although these results are based only on a single month of data, the small sizes of these index components suggest that they will not contribute much to our understanding of index changes surrounding program trading during other sample periods. Therefore, instead of computing quote-based indices we simply use the published cash index in a larger study of program trading. This section characterizes the relations between the four types of program trades, futures prices, the published cash index, and the basis over the two-year period starting January 1, 1989, and ending December 31, 1990.

Figure 4 plots event-time cumulatives of changes in the cash index and in the futures price surrounding sell-and-buy index arbitrage and

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little autocorrelation since the raw dependent variable series are not highly correlated. The residuals for the quote index regressions, for the basis regressions, and for the bounce regressions display positive autocorrelation. *We* did not include lagged variables or serially correlated error terms to model this serial correlation because such adjustmenta are not appropriate to the event study.

Table 6
Estimated cumulative event-time index returns surrounding $10 million program trades for January 1989 through December 1990, in hundredths of a percent

Event time interval, minutes	Program trade type: Index arbitrage Buy	Index arbitrage Sell	Nonarbitrage Buy	Nonarbitrage Sell
Cash index returns				
-5 to +30	2.52	-3.02	1.79	-2.59
	(0.055)	(0.070)	(0.065)	(0.070)
–5 to –1	0.54	-0.38	0.33	-0.62
	(0.031)	(0.037)	(0.025)	(0.032)
0 to +30	1.98	-2.65	1.46	-1.97
	(0.056)	(0.068)	(0.063)	(0.065)
Futures price returns				
-5 to +30	2.16	-2.84	1.79	-2.61
	(0.143)	(0.180)	(0.169)	(0.181)
-5 to -1	3.42	-4.39	1.20	-1.92
	(0.079)	(0.095)	(0.064)	(0.083)
0 to +30	-1.26	**1.54**	0.58	-0.68
	(0.144)	(0.176)	(0.162)	(0.166)

The estimates are obtained from regressions of intraday time series of one-minute S&P 500 futures and cash index returns on five leads and thirty lags of index arbitrage buy-and-sell and nonarbitrage buy-and-sell program trades. In parentheses are the standard errors of the estimated percent changes. The sample includes all program trades reported by member firms to the NYSE in the 505 trading days in the two-year period 1989 through 1990, except those trades occurring in the first 30 minutes and last 5 minutes of the trading day.

nonarbitrage program trades. The cash index and futures prices fall around sell and rise around buy program trades. The relations between program trades and the cash index and futures prices are stronger for index arbitrage than for nonarbitrage trades.[19]

The index cumulatives surrounding program trades must be interpreted with care. Some parts of the changes may be the immediate consequence of the program trades. Other parts, particularly those that lead the program trades, may have caused the program trades. Moreover, the lead-lag relation will be blurred by errors in submission time reports and by delays between submission and execution.

Event-time cumulatives in the futures price lead cumulatives in the cash index by three to four minutes surrounding index arbitrage trades. The timing suggests that new information first gets incorporated into futures prices and is then quickly transmitted to the cash market through index arbitrage. Around nonarbitrage program trades, the cash index starts changing at about the same time as the futures price. This timing suggests that nonarbitrage trades transmit information directly to the cash market.

Table 6 presents selected estimates and standard errors for the index and futures price changes surrounding program trades. The

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[19] The root mean predicted sums of squares are 38.2 and 33.0 hundredths of a percent for the futures and cash index regressions, respectively. The corresponding adjusted R^2's are 6 percent and 25 percent. These statistics are consistent with those from the June 1989 sample.

cumulated (net) changes in the cash index starting 5 minutes before through 30 minutes after index arbitrage buy-and-sell trades are 0.025 and –0.03 percent per $10 million, respectively. The corresponding figures for nonarbitrage buy-and-sell trades are 0.018 and –0.026 percent, respectively. All of these estimates are highly significant because, at least in part, of the large’sample size. Over the same event-time window, the cumulative futures price changes are similar to the cumulative cash index changes as they ultimately should be given cash-futures arbitrage. The small difference suggests that the event-time window is sufficiently wide.

Table 6 also shows that most of the change in the cash index occurs after the program trade orders are submitted (event-time minutes 0 through 30). In the case of the futures price, however, most of the price change occurs in the five minutes preceding order submission. In the case of buy-index arbitrage orders for example, in the five minutes before order submission the cash index changes 0.005 percent while the futures price changes 0.034 points. Again, these changes are statistically significant.

Perhaps the most notable feature/ of the event-time cash index and futures prices is the absence of large cumulative reversals in the 30 minutes after program trades. No average reversal follows the nonarbitrage trades. Only a slight reversal follows the index arbitrage trades. In the latter case, the cash index peaks five minutes after the reported order submission time, followed by a slight reversal of roughly a third of the maximum change. In the June 1989 sample, the slight reversal after index arbitrage trades is smallest for the midquote indices. This result suggests that part of the reversal is due to bid-ask bounce, but the bid-ask bounce effect is clearly not as large as in the hypothetical example in Section 1. The change in the futures price peaks one or two minutes after the order submission time and is followed by a more pronounced reversal than in the case of the cash index. Thirty minutes after the order submission time, about half the maximum change in the futures price is reversed. Assuming that there is no subsequent long-term reversal, the absence of large reversals suggests that the volatility associated with program trading is mostly fundamental volatility associated with new information and not excess volatility associated with illiquidity problems.

For all program trade types, the futures price and the cash index converge to roughly the same value within 10 to 15 minutes after the order submission time. Their convergence demonstrates that the cash and futures markets are closely integrated markets that trade essentially the same underlying risks.

Figure 5 plots event-time estimates of the basis for the four types of program trades. For index arbitrage trades, the absolute basis

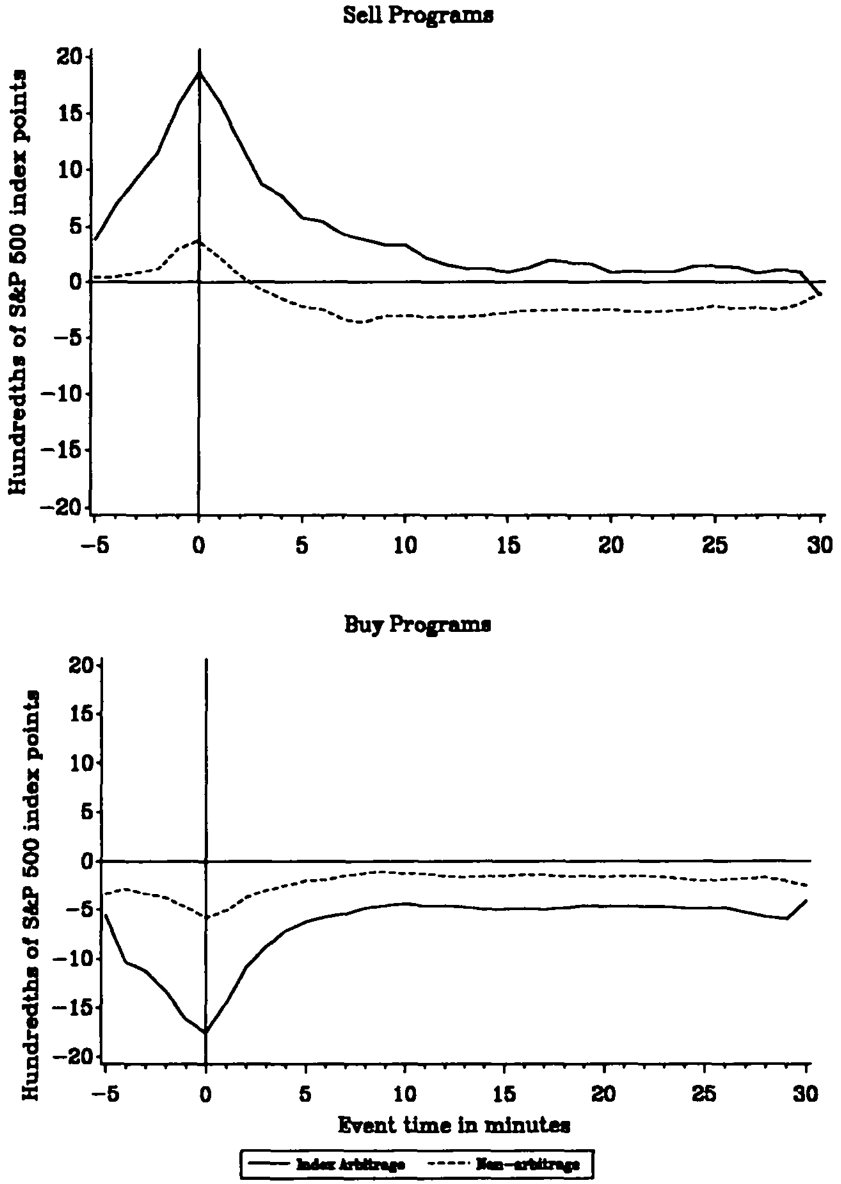

Figure 5

Event-time basis surrounding program trades for January 1989 through December 1990

Estimated basis surrounding $10 million program trades. The estimates plotted are regression coefficients (plus intercept) obtained from regressions of the minute-by-minute time series of the basis on 5 leads and 30 lags of index arbitrage buy-and-sell and nonarbitrage buy-and-sell program trades. The basis is the value of the S&P 500 index minus the price of the neatest S&P 500 futures contract plus a statistical estimate of the expected carrying cost.

increases ahead of the reported trade submission time, reaches a peak at the trade submission time, and then falls sharply.[20] Ten minutes after the reported trade submission time, the basis is back to zero. These results suggest that index arbitrage program trades take place when the basis is large and that index arbitrage quickly eliminates profitable arbitrage opportunities between the cash and futures markets. Interestingly, the basis returns to zero more quickly for buy rather than sell index-arbitrage trades. A possible explanation for this difference is that approximately 25 percent of index-arbitrage sell orders are tick sensitive. Tick-sensitive orders take longer to execute than do market orders, and a few do not get filled. As expected, the relation between nonarbitrage program trades and the basis is weak. The basis is largest at the reported submission time. This suggests that nonarbitrage traders time their trades to minimize their transaction costs. Alternatively, a few arbitrage and/or index substitution traders may fail to classify their trading activities properly.

Figure 6 plots event-time cumulatives of changes in the cash index and in the futures price surrounding index-arbitrage program trades that are separately estimated for each quarter in the two-year sample. The plots seem to be stable through time. Although some quantitative differences among the various quarters exist, the qualitative results are similar.[21] The relation between index arbitrage trades and cash and futures returns is weakest in the first three quarters of 1989 and strongest in the fourth quarter of 1990. The October 1989 minicrash is probably responsible for the relatively large reversals observed in the cash and futures markets following sell index-arbitrage orders for the fourth quarter of 1989. Analogous plots (not presented) for nonarbitrage program trades also seem; stable through time.

The relation between program trades and prices may depend on the timing of the trade within its episode. For example, the first program within an episode may have less of an effect on prices than do subsequent trades.

To identify such differences, we modified our event-study methods to measure separate event-time effects for the first program trade in an episode and for all subsequent program trades. Specifically, we regressed each analysis variable of interest on leads and lags of each of eight program trade classifications. The classifications represent all permutations of the following three categories: buy/sell, arbitrage/nonarbitrage, and first/subsequent. To control the degrees of freedom

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[20] The delay in exploiting the widening basis may partly reflect the time between the execution (and perhaps confirmation) of the futures trade and the submission of the program trade. Index arbitragers reportedly first trade the futures so that they can unwind the position quickly should something go wrong [see Holden (1990)].

[21] Formal coefficient stability tests (Chow or F -tests) reject the hypothesis that the coefficients are stable over time. The rejection is at least in part due to the large sample size.

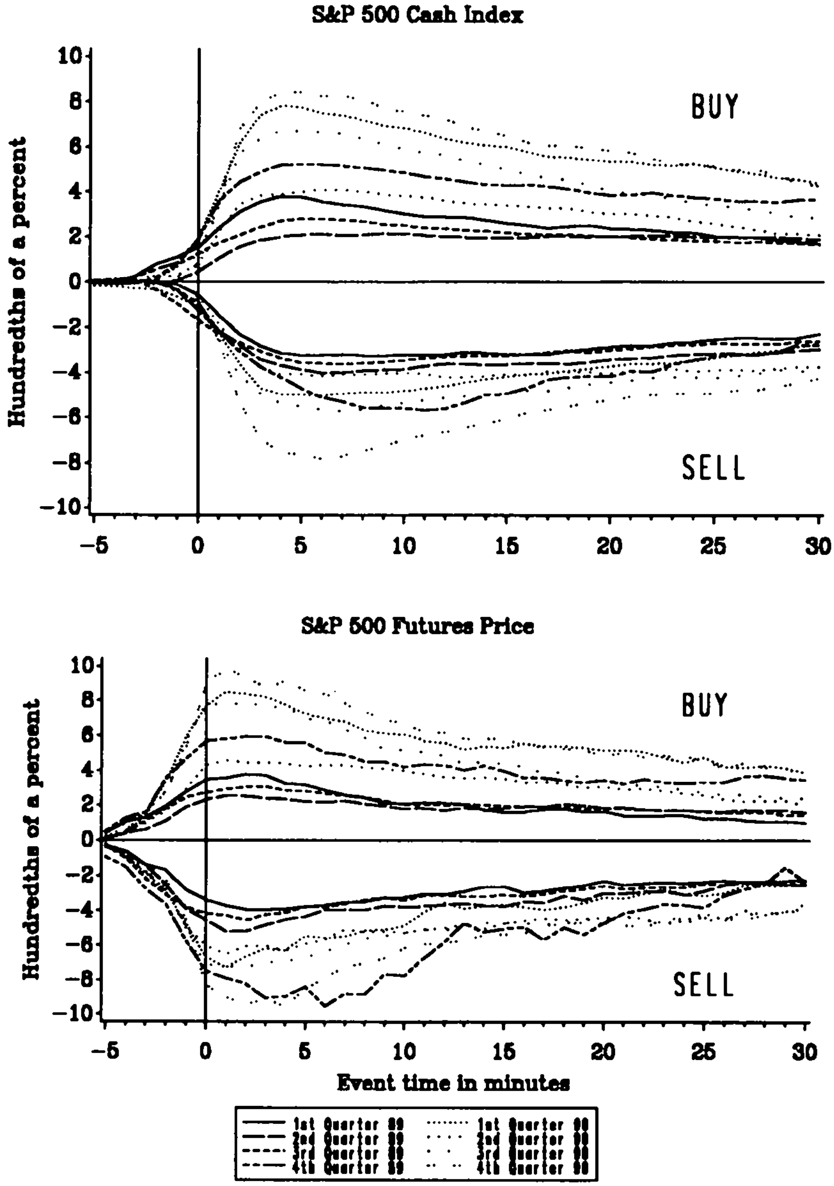

Figure 6
Event-time indices surrounding index arbitrage program trades, by quarter, for January 1989 through December 1990
The estimates are obtained from regressions of the intraday time series of one-minute returns on 5 leads and 30 lags of index arbitrage buy-and-sell and nonarbitrage buy-and-sell program trades.

in the regression, we only examined 10 one-minute lags rather than the 30 lags examined in the above regressions. Since most interesting characteristics in the above results appear within the first 10 minutes after the reported submission time, we expect that most interesting results should appear within the smaller event window. Since program trading episodes are clusters of events, the regression event-study method is essential for disentangling the effects of the first and subsequent program trades.

The event-time cumulated changes in the cash index and in the futures price surrounding index arbitrage program trades are similar for the first and subsequent program trades (Figure 7, *top).*[22] The most notable difference is that the first trade is associated with a larger change in the futures price than are subsequent trades. The difference, however, is not large. The cumulated changes for buy-and-sell trades are nearly symmetric. These results suggest that the effects of program trading on prices and on liquidity are constant within trading episodes.

The event-time cumulated changes in the cash index and in the futures price surrounding nonarbitrage program trades are substantially different for the first and subsequent program trades (Figure 7, *bottom).* The first program trades in a nonarbitrage episode are associated with a smaller cumulative change in both the index and the futures price than are the subsequent programs. The result could be due to the attempts by program traders to price discriminate by breaking their orders into smaller pieces. The first pieces will execute at better prices than will subsequent pieces if the trades exhaust market liquidity.

The event-time relation between the futures basis and index-arbitrage program trading differs substantially between the first and subsequent program trades within an arbitrage episode (Figure 8). The reported submission time of the first trade follows a large increase in the basis. The basis widens further before subsequent program trades, but the additional increase is only about half as large as the increase that precedes the first trade.[23] Not surprisingly, an index arbitrage episode seems to continue past a single trade when the first trade fails to close the basis. After both types of trades, the basis narrows.

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[22] Despite the apparent similarity of the cumulatives, F -tests reject equality of the various lagged coefficients. The rejections arc primarily due to the large sample size.

[23] When interpreting the results, it is important to remember that the regression event-study method produces results that control for the effects of adjacent trades. The smaller increase in the basis surrounding subsequent trades does not indicate that the actual basis was smaller for those trades than for the first trade. The actual average basis for the subsequent trades is a time-weighted sum of the coefficients estimated for the first trade and for the subsequent trades. The smaller increase merely reflects the smaller additional contribution of the subsequent trades to explaining the actual basis.

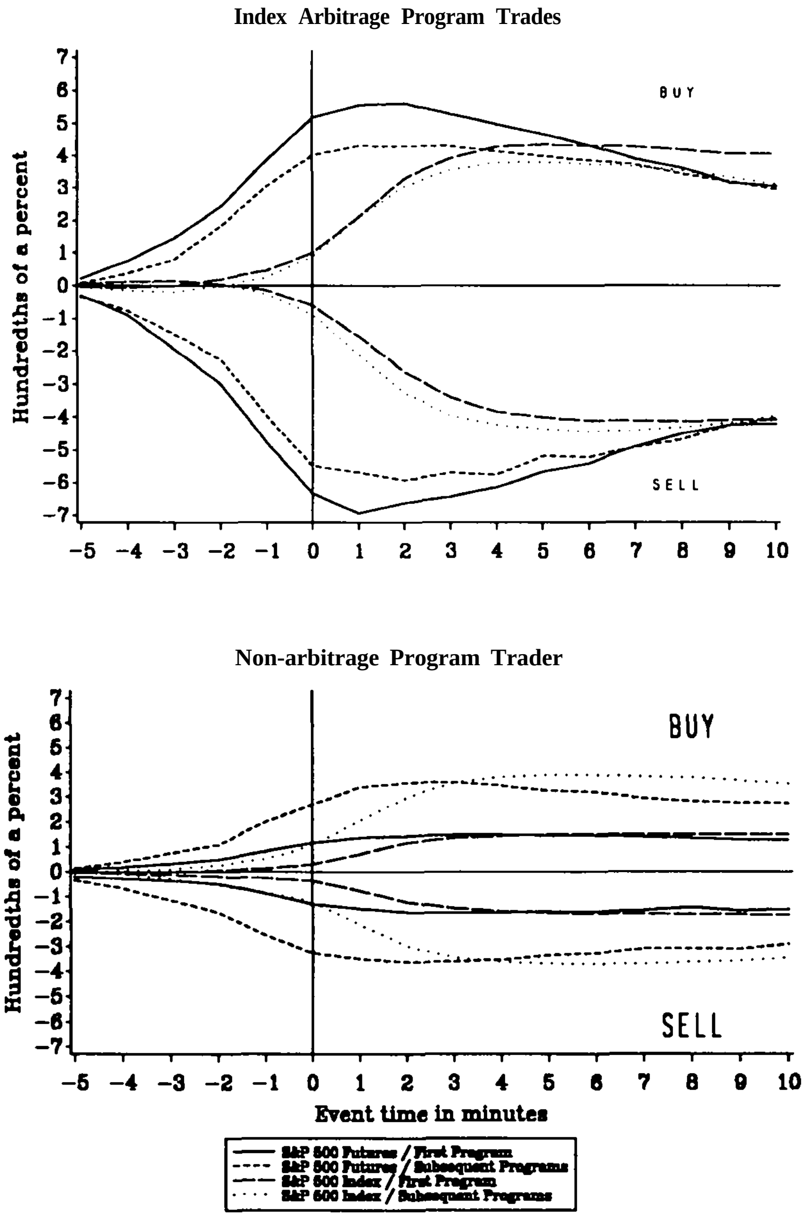

Figure 7
Event-time indices surrounding program trades, by position in an episode, for January 1989 through December 1990
Cumulated estimated S&P 500 futures and cash index returns surrounding $10 million index arbitrage program trades. The estimates arc obtained from regressions of the intraday time series of one-minute S&P 500 futures and cash index returns on 5 leads and 10 lags of index arbitrage buy-and-sell and nonarbitrage buy-and-sell program trades classified according to their position in a program trading "episode." An episode is defined as all sequences of same-type program trades

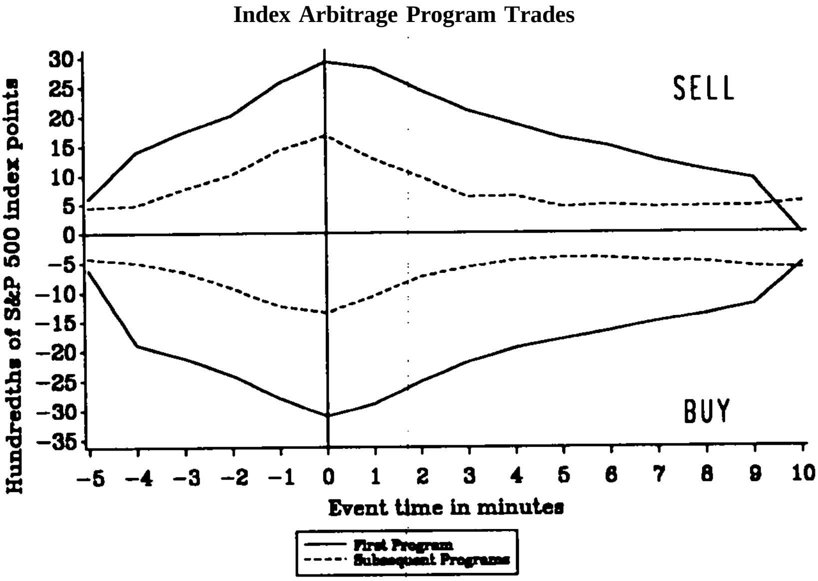

Figure 8
Event-time basis correlated with index arbitrage program trades, classified by position in an episode, for January 1989 through December 1990
Estimated basis surrounding $10 million index arbitrage program trades. The estimates plotted arc regression coefficients (plus intercept) obtained from regressions of the minute-by-minute time series of the basis on 5 leads and 10 lags of index arbitrage buy-and-sell and nonarbitrage buy-and-sell program trades classified according to their position in a program trading "episode." An episode is defined as all sequences of same-type program trades (buy index arbitrage, buy nonarbitrage, sell index arbitrage, sell nonarbitrage) that arc separated by more than five minutes of no program trading. The basis is the value of the S&P 500 minus the price of the nearest S&P 500 futures contract plus a statistical estimate of the expected carrying cost.

A similar analysis of the basis for nonarbitrage trades (not presented) shows very little difference in the effect on the basis between the first and subsequent trades in an episode.

7. Conclusion

Program trading is related to intraday changes in the S&P 500. The relation primarily seems to be due to the initiation of program trades in response to new information. To a lesser extent, the relation is also due to bid-ask bounce and the updating of stale prices caused by program trades. Since little or no average price reversal occurs in

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(buy index arbitrage, buy nonarbitrage, sell index arbitrage, sell nonarbitrage) that are separated by more than five minutes of no program trading. The sample includes all program trades reported by member firms to the NYSE in the 505 trading days in the two-year period 1989 through 1990, except those trades occurring in the first 30 minutes and last 5 minutes of the trading day.

the 30 minutes after program trades, program trades do not seem to cause excess volatility.

In the two-year period 1989-1990, the index changed by an average of 0.03 percent per $10 million of program trading. The change in the index is roughly the same for buy-and-sell index arbitrage and nonarbitrage trades. The relations between program trades and cash and futures returns are stable over the two-year period under examination.

The results in this article must be qualified in several important respects. First, they reflect only data for the two-year period 1989-1990. Although index values and program trading varied considerably during this period, no crashes or melt-ups like the October 1987 Crash occurred in this period. The minicrash of October 1989 is in the sample, however, and the plots for the fourth quarter of 1989 do exhibit slightly higher reversals than average, particularly in the futures market.

Second, the event plots and the estimates of the average price change surrounding program trades are based on *linear* regressions. The average price change per dollar of program trading surrounding a $100 million program could be much greater than for the average $7 million order observed in this sample. Moreover, the dynamic patterns may be different. Very large programs, for example, may be associated with greater reversals than is the average program.

Third, only 30 minutes following individual program trades are studied to determine whether price reversals follow program trades. The absence of a significant price reversal within 30 minutes does not necessarily imply that prices do not ultimately revert over much longer intervals.

Finally, all results presented in this article apply only to intraday program trading-program trades that took place 30 minutes after the open and 5 minutes before the close of trading. Program trades near or at the open and close—which include most expiration day trading—may also be related to index changes, possibly in different ways.

Appendix: The Program Trading Data

Since May 1988, all New York Stock Exchange member firms have been required to file with the NYSE daily trade-by-trade reports of their own transactions and their customer account transactions that meet the NYSE's definition of program trading. For the purposes of this reporting requirement, the NYSE defines *program trading* as any portfolio trading strategy involving the simultaneous or nearly simultaneous purchase or sale of 15 or more stocks with a total aggregate value of $1 million or more.[24] In addition, members must report index arbitrage trades of all sizes. This study includes only those arbitrage trades that meet the NYSE definition of program trading.

Member firms report the time that each program trade is submitted to the NYSE. Orders submitted and subsequently canceled are not reported. The time that the orders are actually executed depends on the type of order, on the line speed of the order transmission systems used by the member firms and by the NYSE, on how busy are these order transmission systems, and on how active trading is on the floor. In June 1989, an individual stock order normally took several seconds to reach the NYSE's Common Message Switch (CMS) from the member firm. About five more seconds were required to transmit the order from CMS to the appropriate specialist post, and an average of about 25 more seconds was required for the specialist to execute the order if it was a market order. Program trades take somewhat longer because they are composed of many orders that must be sequentially transmitted. In June 1989, 90 seconds would typically elapse between NYSE receipt of the first and last order in a large program trade (more than 250 stocks). Program trades that do not use simple market orders take longer to execute. Sell-short programs (10 percent of the aggregate value of program trades in June 1989) must be executed at an uptick. Buy-minus (8 percent of June 1989 program trading value) and sell-plus program trades (1 percent) also take longer to execute. Market-on-close orders, of course, are not executed until the close.

In addition to the daily program trade reports, the NYSE estimates the timing and magnitude of SuperDot submitted program trades using an artificial intelligence program called the Program Traffic Locator (PTL). PTL scans the SuperDot order flow for patterns known to be associated with program trades. PTL-identified program trades and SuperDot program trades reported by member firms generally match [see Nair (1991)].

Since human errors can affect the reporting process, it is important to understand how the data are gathered and audited. Member firms first generate a list of their program orders for a given trade day. Such lists may be generated manually, from member firm internal order-match system trading summaries, or from other sources such as the merged order log generated by the NYSE. Members then send to the NYSE a standardized report of that day's trades. Once the member firm submissions are received, the NYSE enters the trades into a database. On a weekly basis, the NYSE sends to each member firm a printout of that firm's reported trades as they appear in the database

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[24] A program trade can include both individual stock buys and sells, but such mixed programs are quite rare. For example, only three such trades were reported in June 1989.

for verification. Corrections received by the NYSE from the member firms are then made to the database.

The following adjustments to the program trading data were made for this study. Non-NYSE-executed trades and trades of less than 15 stocks or with aggregate value of less than $1 million are excluded. Seven NYSE program trades with incorrectly coded Saturday dates are dropped. Trades without valid times are excluded, with the following exceptions: all trades identified as market-on-close (with various order-entry times) or trades that report a submission time after 1600 are assigned a time of 1600; all trades that report a submission time before 0930 are assigned a time of 0930. Trades with incomplete information on the direction of the trade and on the underlying strategy are also excluded. In the pre-January 15, 1990, sample, a small number of trades identified as *splits,* where a single value is given for a set of trades submitted at different times, are dropped. Finally, a filter removes trades with unreasonable values (trades whose reported aggregate value divided by the reported number of shares is less than $10 or more than $100).

References

Biais, B., P. Hillion, and C. Spatt, 1994, "An Empirical Analysis of the Limit Order Book and the Order Flow in the Paris Bourse," working paper, Carnegie Mellon University.

Chan, K., and Y. P. Chung, 1993, "Intraday Rclationships among Index Arbitrage, Spot and Futures Price Volatility, and Spot Market Volume: A Transactions Data Test," *Journal of Banking and Finance,* 17, 663-687.

Duffee, G., P. Kupiec, and A. P. White, 1990, "A Primer on Program Trading and Stock Price Volatility: A Survey of the Issues and the Evidence," working paper, Board of Governors of the Federal Reserve System.

Feinstein, S. P., and W. N. Goetzman, 1988, "The Effect of the 'Triple Witching Hour' on Stock Market Volatility," *Federal Reserve Bank of Atlanta Economic Review,* 73, 2-15.

Feinstein, S. P., and W. N. Goetzman, 1991, "A Reassessment of the Triple Witching Effect on Stock Market Volatility, or 'Ding-Dong the Witch is Dead'," working paper, Boston University.

Froot, K. A., and A. F. Perold, 1990, "New Trading Practices and Short-Run Market Efficiency," Working Paper 3498, National Bureau of Economic Research, October.

Furbush, D., 1989, "Program Trading and Price Movements around the October 1987 Market Break," *Financial Management,* 17, 68-83.

Grossman, S. J., 1988, "Program Trading and Market Volatility: A Report on Interday Relationships," *Financial Analysts Journal,* 44, 18-28.

Harris, L., 1989a, "The October 1987 S&P 500 Stock-Futures Basis," *Journal of Finance,* 44, 77-99.

Harris, L., 1989b, "S&P 500 Cash Stock Price Volatilities," *Journal of Finance,* 44, 1155-1176.

Hasbrouck, J., G. Sofianos, and D. Sosebee, 1993. "New York Stock Exchange Systems and Trading Procedures," Working Paper 93-01. New York Stock Exchange.

Holden, C., 1990. "A Theory of Arbitrage Trading in Financial Market Equilibrium," working paper, University of California at Los Angeles.

Kleidon, A., 1992, "Arbitrage, Nontrading, and Stale Prices: October 1987," *Journal of Business,* 65, 483-508.

MacKinlay, A. C., and K. Ramaswamy, 1988, "Index-Futures Arbitrage and the Behavior of Stock Index Futures Prices," *Review of Financial Studies,* 1, 137-158.

Moser, J., 1991, "Program Trading and the Volatility of Stock Returns," working paper, Research Department, Federal Reserve Bank of Chicago.

Nair, S., 1991, "Program Traffic Locator—A Knowledge Based System," working paper, New York Stock Exchange, presented at the conference entitled "Artificial Intelligence on Wall Street," October.

Neal, R., 1992, "Program Trading on the NYSE: A Descriptive Analysis and Estimates of the Intra-Day Impact on Stock Prices," working paper, Department of Finance, University of Washington.

Neal, R., 1993, "Is Program Trading Destabilizing?" *Journal of Derivatives,* 1, 64-77.

Neal, R.. and D. Furbush, 1989. "The Intra-Day Effect of Program Trading on Stock Returns: Some Preliminary Evidence," working paper, Departmen of Finance, University of Washington.

Roll, R., 1984, "A Simple Measure of the Effective Bid/Ask Spread in an Efficient Market," *Journal of Finance,* 39, 1127- 1139.

Sofianos, G., 1993a, "Index Arbitrage Profitability," *Journal of Derivatives,* 1, 6-20.

Sofianos, G., 1993b, "Expirations and Stock Price Volatility," forthcoming in *Review of Futures Markets*

Stoll, H. R.. 1987, "Index Futures, Program Trading and Stock Market Procedures." *Journal of Futures Markets,* 8, 391-412.

Stoll, H. R., and R. E. Whaley, 1987, "Expiration Day Effects of Index Options and Futures," *Financial Analysts Journal,* 42, 16-28.

Stoll, H. R., and R. E. Whaley, 1988a, "The Dynamics of Stock Index and Stock Index Futures Prices," working paper, Owen Graduate School of Management, Vanderbilt University.

Stoll, H. R., and R. E. Whaley, 1988b, "Program Trading and Individual Stock Returns Ingredients of the Triple Witching Brew," working paper, Owen Graduate School of Management, Vanderbilt University.

Stoll, H. R., and R. E. Whaley. 1990, "Expiration Day Effects Revisited," working paper, Gwen Graduate School of Management, Vanderbilt University.