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Intraday Price Change and Trading Volume Relations in the Stock and Stock Option Markets

JENS A. STEPHAN and ROBERT E. WHALEY*

ABSTRACT

This study investigates intraday relations between price changes and trading volume of options and stocks for a sample of firms whose options traded on the CBOE during the first quarter of 1986. After purging the price change series of the effects of bid/ask spreads, multivariate time-series analysis is used to estimate the lead/lag relation between the price changes in the option and stock markets. The results indicate that price changes in the stock market lead the option market by as much as fifteen minutes. The analysis of trading volume indicates that the stock market lead may be even longer.

THE INTENSE TRADING ACTIVITY in and, in fact, the very existence of organized stock option markets attest to the economic benefits that these financial contracts provide. Reduced transaction costs and increased financial leverage are two reasons why trading in the stock option market may be more attractive than trading in the market for the underlying stock. In addition, these cheaper and more flexible trading opportunities attract new and differently informed investors to the marketplace. The resulting increase in trading activity, together with the inextricable arbitrage linkage between stock and option prices, imply an increase in market efficiency.

This study investigates empirically the intraday price change and trading volume relations between stocks and options for a sample of firms whose options were actively traded on the Chicago Board Options Exchange during the first quarter of 1986. In particular, intraday call option price changes are translated into implied stock price changes using the American call option pricing model. These intraday implied stock price changes are then compared with the actual stock price changes to identify which, if either, market leads the other. In perfectly functioning capital markets, there should be complete simultaneity between the series, that is, new information disseminating into the marketplace should be reflected in the prices and the trading activity of both securities simultaneously. Institutional factors, however, may make the stock option market more attractive to information traders. This may cause price changes and trading activity due to new information to be observed in the option market first, followed by price

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changes and trading activity in the stock when arbitrageurs step in to profit from the pricing discrepancies between the two markets.

Evidence that the stock option market tends to lead the stock market has appeared in the literature. Manaster and Rendleman (1982), for example, investigate this issue by analyzing the close-to-close returns of portfolios based on the relative difference between stock prices and stock prices implied by option prices and conclude that closing option prices do, in fact, contain information that is not contained in closing stock prices. Furthermore, they claim that it takes up to one day for stock prices to adjust. The use of closing price data, however, seriously undermines the interpretation of their results. The option market closes at 3:10 PM (CST), ten minutes after the close of the stock market. Information that Manaster and Rendleman (hereafter, MR) ascribe to being in option prices and not stock prices may only be information that has disseminated into the marketplace between the times when the stock market and the option market close.

Bhattacharya (1987) uses transaction data to examine the intraday lead/lag relation between the markets. He uses observed bid/ask call prices to compute implied bid/ask stock prices, which are, in turn, compared to actual bid/ask stock prices to identify arbitrage opportunities. The stock is considered underpriced (overpriced) if the implied bid (ask) is higher (lower) than the actual ask (bid). A simulated trading strategy based on these arbitrage signals indicates that profits are insufficient to overcome transaction costs for all intraday holding periods. Bhattacharya, however, confirms the MR trading strategy results by documenting statistically significant excess returns for overnight holding periods (after the costs of transacting but before information search and exchange seat opportunity costs).[1]

A critical aspect of Bhattacharya's test design is that it will only detect whether the option market leads the stock market and not vice versa.[2] In order to test for the possibility of stock prices leading option prices he would have had to use observed bid/ask stock prices to compute implied bid/ask call prices to identify over(under)-pricing. Although he shows that option price changes have some predictive power, his results do not preclude the possibility that the stock price changes predict option price changes.

Anthony (1988) uses daily data to examine whether trading in the option market causes trading in the stock market (or vice versa).[3] He concludes that "... trading in call options leads trading in the underlying shares, with a one day lag." His results are subject to the same caveats as MR due to the nonsimultaneity of the closing times for the two markets. Moreover, the evidence is not overwhelming. He finds that (a) option volume leads stock volume for thirteen firms, (b) stock volume leads option volume for four firms, and (c) there is no unambiguous direction of causality for the remaining eight firms.

The approach used here circumvents the two major problems of the previous studies. First, transaction-by-transaction data from the stock and option markets

[1] While our research methodology clearly identifies the lead/lag structure of intraday price changes in the stock and option markets, it does not shed light on this puzzling overnight effect.

[2] Bhattacharya recognizes this problem but does not perform the simulations in the reverse way.

[3] Anthony uses the terms "cause" and "causality" in the sense of Granger (1969).

are used. Thus, the biases inherent in the nonsimultaneity of closing prices in the two markets are avoided. Second, the analysis focuses directly on the lead/lag relation between the intraday price changes in the stock and option markets rather than indirectly through simulating a trading strategy. Call price changes over five-minute intervals are transformed into implied stock price changes, and then multivariate time series regression analysis is used to estimate directly the lead/lag relations between the price changes in the stock and option markets. Unlike the previous studies, our findings indicate that the stock market leads the option market, both in terms of price changes and trading activity.

The outline of the study is as follows. In Section I, the theory underlying the price change relation between the stock and option markets is discussed. Section II contains a description of the data that are used in the analysis. All call option transactions on the Chicago Board Options Exchange (CBOE) during the first quarter of 1986 are included. Transaction prices for the underlying stocks are also used. Section III contains an examination of the univariate time series properties of the stock and option price change series. Evidence of a bid/ask price effect is apparent in both. The effect is purged from the series using a moving average process. The innovations from the MA processes are used to estimate the temporal relation of price movements in the stock and option markets in Section IV. The multiple time series results reveal that stock prices tend to lead option prices by fifteen to twenty minutes. An examination of trading activity in Section V suggests that the lead may be even longer. Section VI contains a summary of the major results and conclusions of the study.

I. Theoretical Price Change Relation

Options are redundant securities in the marketplace. A call option on a common stock, for example, is a leveraged long position in the stock, where the degree of leverage is continuously rebalanced as the stock price changes and as the option approaches expiration. Because of this redundancy, relative option valuation models can be derived.[4] In general, the value of a call (C) may be expressed as a function of the underlying stock price (S),

$$C = f(S). \tag{1}$$

Since causation is not implied in (1), the value of the stock may also be written as a function of the call price,

$$S = f^{-1}(C). \tag{2}$$

This redundancy of markets also implies a relation between the price changes of the call relative to the stock. If a call price changes in value from C_{t-1} to C_t over a small interval of time and if the equilibrium relation between the stock price and the option price remains intact,[5] the stock price change over the same

[4] The Black-Scholes (1973) call option pricing formula, for example, is a relative valuation model.

[5] Although the equilibrium relation between the call option and the stock changes through time, it is approximately constant over the five-minute price change intervals used in this study.

interval of time should be

$$f^{-1}(C_t) - f^{-1}(C_{t-1}) = \hat{S}_t - \hat{S}_{t-1} \equiv \hat{s}_t. \tag{3}$$

It is the relation between the implied stock price change $\hat{s}_t$ in (3) and the actual stock price change $S_t - S_{t-1} \equiv s_t$ that is the primary focus of this study. In efficiently functioning stock and stock option markets, the price change relation should be perfectly contemporaneous,

$$\hat{s}_t = s_t. \tag{4}$$

The theoretical price change relation (4) is the primary focus of this study. With perfectly frictionless and continuous markets, the stock price change implied by an option price movement exactly equals the stock price change. Because markets are not frictionless and because price observations from the two markets are not simultaneous, the observed relation between price changes in the two markets will be noisy. In addition, if there are economic incentives for certain traders to prefer transacting in one market vis-à-vis the other, a lead/lag relation between the price changes in the two markets is likely. A sensible empirical model to investigate is therefore

$$\hat{s}_t^0 = \alpha + \sum_{k=-K}^{K} \beta_k s_{t-k}^0 + \epsilon_t, \tag{5}$$

where s_t^0 and $\hat{s}_t^0$ are the observed actual and implied stock price changes, respectively, ϵ_t is a random disturbance, and K is the (arbitrary) number of leading and lagged regressors. Market frictions will contribute to the error variance in (5). Leading and lagged effects will be reflected through nonzero, noncontemporaneous coefficients.

II. Data

The data used in this study came from four sources. First, the Chicago Board Options Exchange (CBOE) provided stock option transaction data for the period January 2, 1986 through March 31, 1986. These data contain the time, price, and number of contracts traded for each stock option transaction. The latest stock price before the time of option transaction is also recorded in this file. Second, U.S. Treasury bill rates were collected from *Wall Street Journal* issues for each day during the first quarter of 1986. The riskless rate for each option maturity is computed using the average of the bid and ask discounts of the T-bill whose maturity most closely matched the maturity of the option. Third, the cash dividend information as well as the ex-dividend dates were drawn from the CRSP Daily Master File. The actual dividends paid are used as estimates of the anticipated dividends paid during the options' lives. Fourth, individual transaction prices and trading volumes for the stocks underlying the call options were taken from the Francis Emory Fitch data base.

A. Exclusionary Criteria

In order to estimate the implied stock price changes described in Section II, a specific option valuation equation is necessary. The valuation equation used for pricing American call options on dividend-paying stocks is an extension of the Roll (1977) American call option pricing formula and is presented in Appendix A. The model is limited to a maximum of two dividend payments on the underlying stock during the option's life so transactions on options with more than two dividends are excluded from the sample. Of the 1,080,370 call option transactions during the first quarter of 1986, 22,780 (2.1 percent) were eliminated for this reason.

In general, the American call option pricing model's parameters are easy to obtain. The exercise price and the time to expiration of the option are known values, and the stock price and the riskless rate are observable market parameters. The actual amount and timing of the dividends are used to proxy for the forecast dividends. To estimate the stock's return volatility, call option transaction prices for that stock on the previous trading day are regressed on their respective theoretical prices, where all of the parameters except σ are inputs. Because the implied volatility is estimated using the previous day's transactions, no volatility estimate is available on the first day an option is traded. In all, 8,632 (0.8 percent) of the 1,080,370 total transactions were eliminated for this reason.[6]

Prior to implementing the volatility estimation procedure, the option transactions were carefully scrutinized to identify values that violate basic rationality conditions. An American call option on a stock with two known dividends paid during the option's life has three important lower price bounds. These bounds are implied by early exercise of the call just prior to each of the two ex-dividend instants and by normal exercise at expiration. The bounds are: (a) $S - Xe^{-rt_1}$; (b) $S - D_1e^{-rt_1} - Xe^{-rt_2}$; and, (c) $S - D_1e^{-rt_1} - D_2e^{-rt_2} - Xe^{-rT}$, where S is the current stock price, and D_1 and D_2 are the dividends per share paid at the ex-dividend instants, t_1 and t_2 periods from now, respectively. Expression (a) is the lower price bound of a European call whose time to expiration equals the time to the first ex-dividend instant; expression (b) is the lower price bound of a European call whose time to expiration equals the time to the second ex-dividend instant; and expression (c) is the lower price bound of a European call option with the specific time to expiration. If the observed call option transaction price is below any one of these three values, no volatility estimate is possible. For this reason, all such option transactions were eliminated from the sample.

Deep in-the-memory and deep out-of-the-memory options also pose a problem in volatility estimation. Such options are priced at approximately their intrinsic values and contain little, if any, information about the level of the stock's volatility. To filter these option transactions from the sample, upper and lower bounds on the moneyness of the option were defined. If the moneyness of the call option fell outside the range,

$$e^{rT-.70\sqrt{T}} \leq S/X \leq e^{rT+.70\sqrt{T}}, \tag{6}$$

[6] The 8,632 deletions are in addition to the transactions lost in the first trading day of the sample period, January 2, 1986.

where X is the exercise price of the call, r is the riskless rate of interest, and T is the time to expiration of the option, the transaction was eliminated from the sample.[7]

The three lower price bounds as well as the moneyness criterion served to reduce the sample size by another 118,419 transactions (or 10.8 percent of the original sample size). Table I contains a summary of the characteristics of the 950,346 call option transactions that remain in the sample after the exclusionary criteria are applied. The first set of three columns contain a summary of those transactions by option time to expiration, and the second set of three columns contain a transaction summary by the moneyness of the option.

Short-term call options are by far the most actively traded. More than 67 percent of the total sample transactions and 71 percent of the contracts traded are for call options with less than three months to expiration. The fact that the proportion is higher for contracts traded than for number of transactions indicates that the order quantities are larger for short-term option transactions.

Similarly, slightly out-of-the-money call options have greater trading activity than the other moneyness categories. The category where stock price (S) ranges from 2.5 percent below the exercise price (X) to the exercise price accounts for 17.6 percent of the total number of transactions and 18.3 percent of the total number of contracts traded. Overall, out-of-the-money calls tend to be more active than in-the-money options, with the proportions of trading activity being approximately 57 and 43, respectively.

B. Parameter Estimation

As was noted earlier, the stock's return volatility is estimated by regressing observed call option prices (C_j's) on model prices ($\hat{C}_j$'s) across all option transactions on a particular stock in a given day (n),[8] that is,

$$C_j = \hat{C}_j(\sigma) + u_j, \qquad j = 1, \cdots, n, \tag{7}$$

where u_j is a random disturbance. Only options with a common time to expiration are used in the regression, so several maturity-specific estimates of the stock's volatility are obtained each day.

The maturity-specific estimates of volatility are then used to compute implied stock price changes on the following day. Each call option transaction price is translated into an implied stock price by inverting the option pricing formula. The assumptions imbedded in this two-step procedure (implied volatility estimation on one day followed by implied stock price estimation on the next) are that (a) the option pricing model is correctly specified, and (b) the volatility rate of the underlying stock is stationary. However, neither of these two assumptions is strictly necessary.

[7] This range of option moneyness is derived from the assumptions of the Black-Scholes model and risk-neutrality. If the current stock price equals the exercise price of the option, there is a 95 percent chance that the moneyness of the option will be within the range at the option's expiration. The value ".70" represents two times the standard deviation of return of a typical stock on the NYSE (assumed to be .35).

[8] See Whaley (1982) for details of the nonlinear regression procedure.

Table I

Summary of CBOE Call Option Trading Volume by Time to Expiration and Moneyness for Transactions during the Period from January 3, 1986 through March 31, 1986

The total number of call option transactions during the same period is 1,080,370. Of these, 98,612 (9.1 percent) violated rational boundary conditions, 22,780 (2.1 percent) had more than two dividends over the life of the option, and 8,632 (0.8 percent) did not have a volatility estimate from the previous day. The total number of transactions after the exclusions is therefore 950,346, representing 11,190,226 call option contracts traded. The moneyness of the option (m) is measured as the relative difference between the stock price (S) and the exercise price of the option (X).

Time to Expiration in Months (T)			Moneyness of Option ($m = S/X - 1$)		
Category	Proportion of Total Transactions	Proportion of Total Trading Volume	Category	Proportion of Total Transactions	Proportion of Total Trading Volume
$T < 1$	0.245	0.283	$m < -0.10$	0.073	0.077
$1 \leq T < 2$	0.252	0.255	$-0.100 \leq m < -0.050$	0.161	0.157
$2 \leq T < 3$	0.175	0.176	$-0.050 \leq m < -0.025$	0.154	0.153
$3 \leq T < 4$	0.143	0.138	$-0.025 \leq m < 0.000$	0.176	0.183
$4 \leq T < 5$	0.090	0.077	$0.000 \leq m < 0.025$	0.148	0.155
$5 \leq T < 6$	0.047	0.037	$0.025 \leq m < 0.050$	0.106	0.102
$6 \leq T < 7$	0.032	0.023	$0.050 \leq m < 0.100$	0.109	0.105
$7 \leq T < 8$	0.013	0.009	$m \geq 0.100$	0.073	0.067
$8 \leq T < 9$	0.002	0.002			

First, with respect to the correct model specification, the only assumption necessary is that the ratio of the option price to the stock price has a one-to-one mapping with the variance rate of the underlying stock. The option pricing formula is used on the first day to estimate volatility conditional on the call and stock prices and then is used on the next day to estimate the stock price conditional on the call price and the previous day's volatility estimate. As long as the same function is being applied on both days, implied stock price changes are accurate estimators of actual stock price changes.[9]

Second, the assumption that volatility is stationary is not strictly necessary either. For example, if the true volatility is not stationary on the day in which volatility is estimated, the least squares estimate represents an "average" volatility for the day. If the estimate is higher than the true volatility when the implied stock prices are computed on the following day, the implied stock price changes are smaller than the true changes; and, if the volatility estimate is lower than the true volatility, the implied stock price changes are larger than the true changes. Since the error in the volatility rate is unpredictable, the implied stock price changes $\hat{s}_t$ are unbiased but noisy estimates of the true stock price changes. This measurement error is contained in the dependent variable of the regression model (5) and causes the error variance in the regression to be higher than normal. The estimated parameters of the regression, however, remain unbiased and consistent.

Another type of error in the implied stock price is introduced if true volatility is not stationary during the day in which implied stock prices are computed. Suppose, for example, that the previous day's volatility estimate is 0.25 and that true volatility on the following morning when the market opens is exactly at that level. At the beginning of the day, the implied stock prices are accurate estimates of the actual stock prices. Now, suppose that at 10:00 AM the true volatility increases unexpectedly to a level of 0.30. Since call price is an increasing function of the volatility rate, the call option should increase in value due to the increased volatility. However, the call price is also an increasing function of the stock price, and the increased volatility will likely cause the stock price to fall. The net effect is that call price change may be positive, negative or zero. In other words, a sudden increase (decrease) in volatility during the trading day will cause a decrease (increase) in the actual stock price but will have no predictable effect on the implied stock price change. Since the error is again being captured in the dependent variable in the regression model (5), the properties of the regression parameters are unaffected.

III. Price Change Series and the Bid-Ask Spread

The prices reported on the CBOE and Fitch files are transaction prices. In order to carry out the multiple time series tests in the next section, however, price

[9] Some error is introduced as a result of Jensen's inequality. Furthermore, empirical evidence suggests that the American call option pricing formula systematically misprices CBOE call options (see, for example, Whaley (1982)), where the mispricings are related to the degree of moneyness of the option, the option's time to expiration, and the riskless rate of interest. To the extent that the stock price, the time to expiration, and the interest rate change from the day the implied volatility is estimated to the following day when the implied stock prices are estimated using the previous day's volatility, measurement error is introduced in the implied stock price changes. The net effect of these errors is probably small and is difficult to predict.

changes must be defined over time intervals of a fixed length. Choosing an appropriate interval length is an important consideration. If the interval is too short and the frequency of trading is low, many zero price changes will be recorded, thereby inducing an errors-in-the-variables problem. On the other hand, if the interval is too long, precision in identifying the length of the lead/lag structure is undermined. To eliminate options with inactive markets, all options with fewer than 144 transactions in a given day were eliminated. Then, after investigating the frequency of active option transactions, a five-minute time interval was chosen.

The active option (more than 144 transactions in a given day) sample contains 178,217 transactions, with 2,502,334 contracts traded. Forty-three firms are represented during the 60-day sample period. Some firms had more than one active option in a given day, so the final sample contains 364 firm days (a day in which a firm had at least one active option) and 726 option contract days (a day in which an option was active). Specific details of the sample of firms and their option transactions are contained in Appendix B.

The time to expiration and moneyness attributes of the active option sample are reported in Table II and are somewhat different than the attributes reported for the overall sample in Table I. For example, comparing Table II to Table I shows that the active options tend to have shorter times to expiration. Where only 24.5 percent of total call option transactions had times to expiration of less than one month, 48.9 percent of the active option transactions have times to expiration of less than one month. Along the same line, over 32 percent of the transactions of the options in the overall sample have times to expiration in excess of three months, while less than nine percent of the active option subsample has. Active options also tend to be at-the-money options. While about 33 percent of the total number of transactions in the overall sample are for at-the-money options (i.e., $-.025 \leq m < .025$, where $m = S/X - 1$), more than 53 percent of the total transactions in the active option subsample are for at-the-money options. Less than three percent of total transactions in the active option subsample are more than ten percent in- or out-of-the-money. In summary, active options are predominantly short-term and at-the-money.

The option transactions in each of the 726 "option contract days" were then used to create 726 five-minute implied stock price change series. A time grid beginning at 8:35 AM (CST) and proceeding through the trading day by five-minute increments was defined. The option transaction file was then scanned to find the last option transaction price before 8:35 AM, and it was earmarked as the 8:35 AM option price. The file was then scanned to identify the last transaction before 8:40 AM, 8:45 AM, and so on through 3:00 PM.[10] If no transaction took place during a particular five-minute interval other than at the beginning of the day, the previous period's price (i.e., the last transaction price) was used. The price series begins each day when a transaction is finally observed within a five-minute interval (e.g., if the first option transaction was at 8:36 AM, the first price recorded for the day was at 8:40 AM). In this way, some option

[10] Recall that the New York Stock Exchange closes at 3:00 PM (CST), while the CBOE stock option market remains open ten minutes later (until 3:10 PM). Since both stock and option prices are needed to estimate the temporal relation between the markets, the last ten minutes of trading in the option market is ignored.

Table II

Summary of Trading Volume of Active CBOE Call Options (More Than 144 Transactions per Day) by Time to Expiration and Moneyness during the Period from January 3, 1986 through March 31, 1986

The active CBOE call option sample contains 178,217 transactions with 2,503,334 contracts traded. The moneyness of the option (m) is measured as the relative difference between the stock price (S) and the exercise price of the option (X).

Time to Expiration in Months (T)			Moneyness of Option ($m = S/X - 1$)		
	Proportion of Total:			Proportion of Total:	
Category	Transactions	Trading Volume	Category	Transactions	Trading Volume
$T < 1$	0.489	0.530	$m < -0.10$	0.001	0.001
$1 \le T < 2$	0.318	0.295	$-0.100 \le m < -0.050$	0.090	0.091
$2 \le T < 3$	0.111	0.109	$-0.050 \le m < -0.025$	0.199	0.210
$3 \le T < 4$	0.066	0.054	$-0.025 \le m < 0.000$	0.297	0.311
$T \ge 4$	0.016	0.013	$0.000 \le m < 0.025$	0.240	0.230
			$0.025 \le m < 0.050$	0.102	0.093
			$0.050 \le m < 0.100$	0.057	0.049
			$m \ge 0.100$	0.015	0.015

contract series had fewer than the maximum number of 78 observations. In fact, the average number of price observations each option contract day is 75.20. Because the option transaction records contain the latest stock price preceding the option transaction, 726 stock price series were also obtained. These stock price series are referred to as the "CBOE stock price data."

The Fitch stock price file was, likewise, used to generate the five-minute price series for the stocks underlying the options. Only 364 stock price series ("firm days") are obtained because some firms had multiple options traded in a given day. (See Appendix B). Since the stock price fit into the time grid is not dependent on the time of the last option transaction, a firm can have only one stock price series per day. These stock price series are referred to as "Fitch stock price data."

Earlier, the active option sample was identified by eliminating options with fewer than 144 transactions on a given day. Such a constraint does not ensure that at least one transaction takes place in each five-minute interval during the trading day. The 726 option contract days produced 53,872 five-minute intervals. Of these, 80.3 percent contained at least one option transaction. The remaining 19.7 percent were intervals with no transactions. Of the five-minute intervals with no transactions, about 70.9 percent were situations where the number of consecutive intervals without a transaction was one, and about 18.8 percent were situations where the number of consecutive intervals without a transaction was two. The remaining 11.3 percent had three or more consecutive zero transaction intervals. The 364 firm days produced 27,159 five-minute intervals. Of these, more than 93.9 percent had at least one transaction. Of the intervals with no transactions, about 76.6 percent were situations where the number of consecutive zero transactions was one, about 14.1 percent were where the number was two, and about 9.1 percent were where the number was three or more. On the basis of these results, it seems fair to conclude that the active option sample includes options and stocks that trade fairly continuously throughout the day. Therefore, the errors-in-the-variables problem created by zero price changes during the non-trading intervals is small.

A. Serial Correlation in Stock Price Changes

Before examining the temporal relation between the implied and the actual stock price change series, the issue of determining the effects of the bid/ask spread in both the option and stock markets has to be addressed. Roll (1984) shows that in an informationally efficient market with at least one transaction in each interval of time successive price changes will have negative first-order serial covariance due to the random movement between bid and ask price levels.[11] The magnitude of the first-order serial covariance, he argues, is an implicit measure of the bid/ask spread. While Roll's empirical results using daily data are mixed (i.e., some firms have positive serial covariance in daily returns), his arguments are critically important here in the sense that a five-minute time

[11] Roll's assumptions are much stronger than necessary to show negative first-order serial covariance in price changes. Papers by Glosten (1987), Choi, Salandro and Shastri (1988) and Stoll (1989) develop models with weaker assumptions and find that the negative first-order serial covariance remains. For a comprehensive review of this work, see Harris (1989).

Table III

Average of Estimated Serial Correlation Coefficients of Actual and Implied Stock Price Changes (Innovations) during the Period from January 3, 1986 through March 31, 1986

The five-minute stock price change series used to compute the serial correlation coefficients from the Fitch transaction data file and the active CBOE call option data file. Using the Fitch data file, an intraday stock price change series was generated for each of the 364 firm days when option contracts traded. Using the active CBOE call option sample, an intraday implied stock price change series was generated for each of the 726 option contract days. Note that there are more option contract days than firm days because some firms had multiple active call option contracts trading on a particular day, and each option price series implies a different stock price series. The serial correlation coefficients are computed from actual (implied) stock prices and from innovations in actual (implied) stock price changes. The innovations for the actual (implied) stock price change series are the residuals from an MA(1) model fitted to the five-minute actual (implied) stock price changes during each trading day.

	Fitch Stock Price Data (n = 364)		Implied Stock Price Data (n = 726)	
Lag k	Stock Price Changes $\hat{\rho}_k$	Stock Price Innovations $\hat{\rho}_k$	Stock Price Changes $\hat{\rho}_k$	Stock Price Innovations $\hat{\rho}_k$
1	−0.091	0.008	−0.225	0.008
2	−0.018	−0.015	−0.025	−0.019
3	−0.025	−0.028	−0.008	−0.013
4	−0.016	−0.018	−0.005	−0.008
5	0.005	0.000	−0.002	−0.007
6	−0.001	−0.001	−0.008	−0.013
7	−0.010	−0.013	−0.005	−0.009
8	−0.006	−0.010	0.002	−0.005
9	−0.011	−0.014	−0.007	−0.012
10	−0.001	−0.005	0.004	−0.005
11	−0.006	−0.010	−0.009	−0.014
12	−0.011	−0.012	−0.004	−0.013

interval is used. In fact, over such a short interval of time, the bid/ask spread is likely to be the dominant part on any price movement observed.

To test for the bid/ask spread effect, serial correlations of price changes were computed for the 364 stock price change series and the 726 implied stock price change series.[12] The average serial correlations are reported in Table III. The Fitch stock price data produced an average first-order serial correlation of −0.091, with the higher order lags being not meaningfully different from zero. This is precisely the autocorrelation function implied by the models of Roll (1984),

[12] Serial correlation rather than serial covariance is used here to enable the results to be aggregated across stocks and options.

Glosten (1987), Choi, Salandro and Shastri (1988) and Stoll (1989). Likewise, the average first-order serial correlation of the implied stock price change series is −0.225, with the higher order serial correlations near zero. The higher magnitude of the first-order correlation of the implied stock price change series reflects the fact that the bid/ask spread in the option market is a higher percentage of price than in the stock market.[13]

Unpurged, the noise in the raw price change series due to the bid/ask spread will tend to reduce the degree of association between the price changes for the stock and option markets. To remove the bid/ask price effect, it is useful to note that negative first-order serial covariance implies that the observed price change series can be modeled using a moving average process of order one [i.e., MA(1)], that is,

$$s_t^0 = \mu + e_t - \theta_1 e_{t-1}, \tag{8}$$

where s_t^0 is the observed price change process under consideration, μ is the mean of the observed price changes, and e_t is a random disturbance. Such a process has an autocorrelation function of

$$\rho_k = \begin{cases} \dfrac{-\theta_1}{1 + \theta_1^2} & , \quad k = 1, \\ 0 & , \quad k > 1, \end{cases} \tag{8a}$$

exactly the behavior noted for the actual and implied stock price changes in Table III. The innovations from the MA(1) process (i.e., the ϵ_t's) should be serially uncorrelated and purged of the bid/ask effect.

An MA(1) model was fitted to each of the 364 stock price change series and to each of the 726 implied stock price change series. Because the model is fitted to *each series each day,* not only is the effect of the bid/ask spread removed but so is the effect of the differential bid/ask spreads across stocks and options. The average value of $\hat{\theta}_1$ for the stock price changes is 0.1104, and the average value for the implied stock price changes is 0.2905. The larger coefficient of the implied changes again reflects the higher bid/ask spread in the option market. The innovations (residuals) from each of the fitted MA(1) processes were recorded and then examined. As Table III shows, after the effects of the MA(1) process are removed from the price change series, practically no serial correlation remains at any lag. These results indicate that the MA(1) process implied by the bid/ask spread models discussed earlier in this section adequately describe the observed structure of five-minute price changes.[14] The conclusions about the temporal relation between the stock and option markets in the next section are based primarily on the regression results using price change innovation series.

[13] Suppose the bid/ask spread for the stock and the option are both 1/8th. While successive price changes for the stock will reflect the amount of spread, successive stock price changes implied by the option will reflect the spread of 1/8th divided by the delta value of the option.

[14] Hasbrouck and Ho (1987) posit that the intraday price changes will have both a moving average component due to transaction costs and an autoregressive component due to price adjustment delays. However, the autocorrelation functions for the raw stock price changes and for the stock price change innovations in Table III show no evidence of an autoregressive component.

B. Appropriateness of Stock Price Change Series

As was noted earlier, two stock price series are available: (a) the CBOE stock price data containing the stock price at the time of the last transaction before the option transaction and (b) the Fitch stock price data containing the stock price at the most recent transaction before the end of the grid interval. If the frequency of trading for the option is the same as the stock, source (b) is preferred. Sometimes the option transaction would be closest to the end time of the grid interval and sometimes the stock price would be. On average, because of equal frequency of trading, the option and stock transactions would be at the same time. Choosing source (a) implies that the stock price is a stale indicator of true stock value at the end of the interval and would tend to bias the results in favor of finding option price changes leading stock price changes.

Source (b), however, is not always preferred. If the stock market is more active than the option market, source (a) may be preferred if it would ensure that the time of the stock transaction is closer to, albeit before, the time of the option transaction. In the data sets used, the median time between the last transaction on Fitch and the end time of the five-minute interval is 30 seconds, while the median time for the last option transaction is 99 seconds. Thus, under source (a), the stock transaction takes place about 30 seconds before the option transaction, while under source (b) the stock transaction takes place about 69 seconds after. Clearly (a) provides greater simultaneity.

One further complication may arise in the selection of the stock price series (a) or (b). Suppose, for example, that a recording delay exists in the option market but not in the stock market, that is, a transaction takes place in the option market but does not get recorded until m minutes later. When the option transaction is finally recorded, the last transaction price of the stock is also recorded. If the delay has been significant, the stock transaction price recorded on the CBOE file may well be after the option transaction. Under this scenario, source (a) remains the preferred strategy. Choosing (b) would serve only to increase the time between the option and stock transactions.[15]

IV. Multiple Time Series Analysis of Price Changes

With the price change series purged of bid/ask price effects, multiple time series analysis was performed to deduce the temporal relation between the stock and option markets. The price change series for each day are pooled, carefully excluding overnight price changes. The multiple time series model estimated is

$$\hat{s}^0_t = \alpha + \sum_{k=-6}^{6} \beta_k s^0_{t-k} + \epsilon_t, \tag{9}$$

where s^0_t and $\hat{s}^0_t$ are the observed actual and implied stock price changes, respectively.[16] The choice of the number of lead/lag regressors was arbitrary. Six

[15] Delays in recording stock and option transactions do not appear to be significant. Stoll and Whaley (1988, p. 17) report that the time delay in recording stock transactions on the NYSE is less than two minutes. Cox and Rubinstein (1985, p. 84) report that option trades are recorded within one minute of the time of trade.

[16] The structure of this regression model is in the spirit of Sims (1972).

regressors (one-half hour of trading time) on each side of the contemporaneous price changes was thought to be generous. The inclusion of irrelevant explanatory variables with such a large sample size does not impose a significant loss in degrees of freedom. The number of observations, 45,160, reflects the total 53,872 stock price changes less then 746 × 12 observations lost each day due to the lead and lag regressors.

Four regressions are performed on the pooled data: (a) Implied stock price changes are regressed on lead, contemporaneous, and lag stock price changes created from the Fitch data file; (b) Implied stock price innovations are regressed on lead, contemporaneous, and lag stock price innovations created from the Fitch data file; (c) Implied stock price changes are regressed on lead, contemporaneous, and lag stock price changes created from the CBOE data file; and (d) Implied stock price innovations are regressed on lead, contemporaneous, and lag stock price innovations created from the CBOE data file. Both actual price changes and price change innovations are used to guage how departures from the bid/ask price effect MA(1) model may affect the results. Both Fitch and CBOE stock price data are used to deduce reporting delays. The regression results are reported in Table IV.

Many interesting phenomena are shown in Table IV, the most important of which is the pronounced leading effect of stock market price changes. In all four sets of regression results, the coefficients of the lagged stock price changes $k = 1, \cdots, 6$, are larger and more significant than the lead coefficents $k = -1, \cdots, -6$. The stock market appears to lead the option market by fifteen to twenty minutes on average, independent of which price change series is used to evaluate the relation. The regression results using the CBOE stock price innovations (the last pair of columns in Table IV), for example, show that the lagged coefficients exceed 0.05 until lag five (i.e., lags one through four have coefficient estimates of 0.3261, 0.1769, 0.1055 and 0.0645, respectively). A modest amount of feedback from the option market is also indicated by the positive, albeit small, lead one coefficient.[17]

A second observation worthy of note is that modeling the univariate time series behaviors of the implied and actual stock price changes as MA(1) processes and then investigating the time series relations between the implied and actual stock price innovations more clearly defines the temporal relation between markets. Contrast the stock price change/stock price change innovation results for the CBOE stock price data in Table IV. First, the coefficients of the lagged variables are larger and more significant. The lag one coefficient, for example, is 0.2226 using stock price changes and is 0.3261 using stock price change innovations. Second, the R^2 value is higher in the regression using price change innovations than the one using price changes. Together these results indicate that using the MA(1) model has successfully purged at least some of the bid/ask price effect from the price change series. The regression results using raw stock price changes are obviously contaminated by errors-in-the-variables introduced by random movements from bid to ask (and vice versa) prices over the five-minute inter-

[17] Based on the weak predictive power that the option market has on the stock market, it is not surprising that Bhattacharya found that a stock trading strategy based on option prices fails to generate trading profits after transaction costs.

Table IV

Parameter Estimates from Regressions of Implied Five-Minute Stock Price Changes (Innovations) on Lag, Contemporaneous, and Lead Actual Five-Minute Stock Price Changes (Innovations) during the Period from January 3, 1986 through March 31, 1986

$$\hat{s}_t^o = \alpha + \sum_{k=-6}^{6} \beta_k s_{t-k}^o + \epsilon_t$$

Implied stock price changes are changes in the stock prices implied by the prices of active CBOE call options. Call prices at the beginning and at the end of the five-minute interval are transformed to implied stock prices using the American call option pricing model. The innovations for the actual (implied) stock price change series are the residuals from an MA(1) model fitted to the five-minute actual (implied) stock price changes during each trading day. The regression model is estimated using five-minute, intraday price change series during the sixty trading day sample period. Overnight price changes are not included.

	Fitch Stock Price Data				CBOE Stock Price Data			
	Stock Price Changes		Stock Price Change Innovations		Stock Price Changes		Stock Price Change Innovations	
Parameter	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]
No. of Obs.	45,160		45,160		45,160		45,160	
R^2	0.0442		0.0831		0.0736		0.1231	
$\bar{R}^2$	0:0439		0.0829		0.0733		0.1228	
$\hat{\alpha}$	0.0000	−0.01	0.0015	1.13	−0.0009	−0.59	0.0009	0.72
$\hat{\beta}_{-6}$	−0.0059	−0.80	−0.0122	−1.89	0.0152	1.93	0.0070	1.02
$\hat{\beta}_{-5}$	0.0051	0.69	−0.0014	−0.22	−0.0235	−2.98	−0.0162	−2.35
$\hat{\beta}_{-4}$	0.0074	1.00	0.0021	0.33	0.0085	1.07	0.0000	0.01
$\hat{\beta}_{-3}$	0.0196	2.64	0.0158	2.42	0.0121	1.51	0.0028	0.40
$\hat{\beta}_{-2}$	−0.0139	−1.87	−0.0190	−2.91	0.0175	2.17	0.0080	1.13
$\hat{\beta}_{-1}$	0.0504	6.70	0.0390	5.90	0.0745	9.19	0.0567	8.01
$\hat{\beta}_0$	0.1898	25.13	0.1940	29.27	0.4324	52.79	0.4378	61.39
$\hat{\beta}_1$	0.2576	33.70	0.3012	44.89	0.2226	26.75	0.3261	45.02
$\hat{\beta}_2$	0.1203	15.64	0.1915	28.40	0.0928	11.16	0.1769	24.43
$\hat{\beta}_3$	0.0886	11.45	0.1495	22.03	0.0522	6.28	0.1055	14.58
$\hat{\beta}_4$	0.0230	2.99	0.0647	9.59	0.0287	3.47	0.0645	8.95
$\hat{\beta}_5$	0.0228	2.98	0.0504	7.52	0.0020	0.24	0.0332	4.62
$\hat{\beta}_6$	0.0066	0.86	0.0297	4.45	−0.0081	−0.98	0.0132	1.83

[a] The t-ratios for the null hypotheses that $\alpha = 0$ and $\beta_k = 0$, $k = -6, \cdots, 6$, respectively.

vals—the coefficient and the multiple correlation estimates are lower. Nonetheless, both the raw price change results and the results using the price change innovations from the MA(1) process imply that the stock market leads the option market by as much as twenty minutes.

In the last section of the paper, the appropriateness of the competing sources of stock price change information was discussed. Contrasting the regression results using the Fitch stock price data with those of the CBOE stock price data provides another way to see the effect of the greater frequency of stock transactions vis-à-vis individual option series transactions. Since the stock transaction is closer on average to the end of the five-minutes than is the option transaction, much of what should appear as a contemporaneous relation appears as a lag one relation if the Fitch stock price data is used. In the Fitch results, the lag one coefficient in the innovation results, 0.3012, is, in fact, greater than the contemporaneous coefficient, 0.1940. The CBOE stock price changes, on the other hand, are paired more closely in time, and the regression results reveal the strongest association at the contemporaneous level, 0.4378, followed by lag one, 0.3261. The innovation results using the CBOE stock price data are used as a benchmark in the stratification results to follow because they present the most conservative view of the leading effect of the stock market.[18] However, regardless of the series chosen, the coefficients for at least lags one through four are strongly positive, implying that the price changes in the stock market lead the active call option market by as much as twenty minutes.

In view of the Manaster and Rendleman and Bhattacharya studies, these results are surprising. While both of the previous studies indicate that the option market leads the stock market, the evidence reported here supports the opposite view. The lack of intraday trading profits reported in Bhattacharya's simulations are expected given the weak predictive power option price changes have on stock price changes. If Bhattacharya had reversed his strategy, positive trading profits after transaction costs may have appeared.

A. Intraday Trading Patterns

The evidence to this point clearly shows that price changes in the stock market tend to lead those in the option market. One possible explanation for this result is abnormal intraday trading patterns in the stock and option markets. To check this possibility, the proportion of total daily trading volume accounted for in each five-minute interval was computed for each stock and for each option. The proportions were then averaged across the 364 firm days for the stocks and the 726 option contract days for the options. The results are summarized in Figure 1.

In Figure 1, the solid line represents the average proportion of the total daily trading volume in each five-minute interval during the firm days, and the dashed line represents the average proportion of daily trading volume for the call options across the 726 option contract days. The trading volume patterns displayed in

[18] The stratification tests were also performed using raw price changes, and the inferences are qualitatively similar. The results are available from the authors upon request.

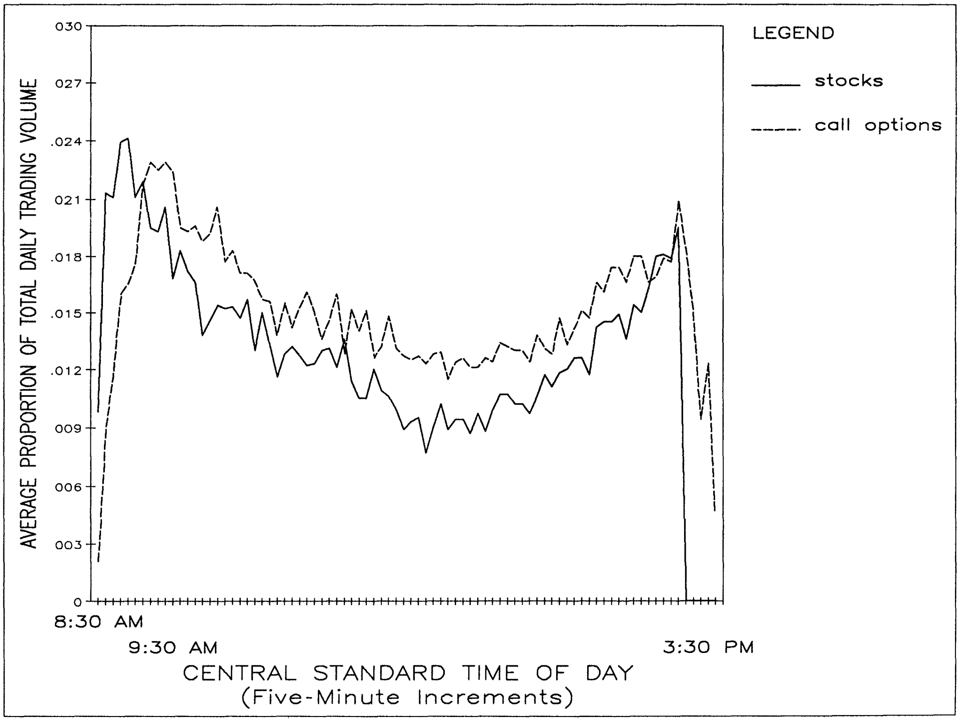

Figure 1. Average proportion of trading daily trading volume of active CBOE call options (more than 144 transactions in a day) and their underlying stocks by each five-minute interval during the trading day during the sixty trading day period from January 3, 1986 through March 31, 1986. The proportion of total daily trading volume accounted for in each five-minute interval is computed for each stock and for each option. The proportions are then averaged across the 364 firm days for the stocks and the 726 option contract days for the options.

Figure 1 are extremely interesting. Note, first, the familiar U-shape to the trading volume of the stocks. At the open, trading volume is highest. The volume then subsides through the day and increases near the close, albeit not to the level of activity that occurred at the open. The sharp decrease in volume at the end of the day is when the stock market closed at 3:00 PM (CST).

The trading volume pattern of options is distinctly different than for the underlying stocks. In general, trading volume is low at the opening and increases quickly to a peak at about 45 minutes into the trading day.[19] It then falls off, like the stock market trading volume, but not as quickly or by as much. At the close, option trading volume increases to a level almost as high as at the beginning of the day.

[19] Part of the delay in the opening trade of the stock option is procedural. First, stock options do not trade until the stock has opened. Second, when the first stock print appears at the option exchange, the stock's options go through opening rotation. In the rotation, the markets for the stock's options are opened one at a time beginning with the shortest maturity, lowest exercise price call option and proceeding upward through the range of exercise prices and chronologically through the more distant maturities. When all of the call option markets have been opened, the rotation procedure is then applied to the markets for the stock's put options.

In light of the differential intraday trading patterns, it seems sensible to reexamine the regression results. It is possible, for example, that the fifteen-to-twenty minute "average" stock market lead that is documented in Table IV is driven by the forty-five minute lead in trading activity at the beginning of the day, with the price changes in the two markets being approximately simultaneous through the remainder of the day. To test for this possibility, the regression was performed dropping the first hour of price changes (i.e., the first twelve five-minute price changes) each day. The regression results are reported in Table V.

First, note that the sample size drops to 36,448. This reflects the twelve observations that are lost in each of the 726 option contract days or a total observation loss of 8,712. Second, note that the regression results dropping the first hour of trading are virtually identical to those for the overall sample. The contemporaneous coefficient estimate for the sample excluding the first hour of trading is 0.4288 as compared with 0.4378 for the full active call option sample. The number of meaningful lag coefficients continues to be at least four, and the proportion of total variation in the implied stock price change innovations explained by the regression remains at approximately the same level. Clearly, it is not the abnormal trading volume patterns at the beginning of the day that is driving the leading effect of the stock market.

B. Information Effects

With option contracts providing traders with low-cost, highly-leveraged methods of investing in the stocks of firms and with option markets being highly liquid, it is surprising that the overall results indicate that option price changes do not lead stock price changes. One possible explanation is that option market trading is predominantly due to return/risk management motives rather than individuals acting on new information. To detect whether differential lead/lag effects exist where the motivation for the trade differs (return/risk management versus new information), the sample of 726 option contract days was divided in half according to the average daily delta value of the option. All options should have the same risk-adjusted rate of return on a before-transaction-cost basis. If information traders use options to react quickly to and profit from new information disseminating into the market, it is more likely that they use high delta value options because high delta value options have the lowest percentage transaction costs. Table VI contains the regression results for the stratified data.

Table VI shows that the temporal relations of the two groups of options are different. High delta options have stronger contemporaneous relations and weaker lagged relations between the stock and option markets than low delta value options. This indicates that high delta option price movements are more closely synchronized with stock price changes. On the other hand, the leading effect of the stock market for the high delta value subsample continues to be about twenty minutes in length (i.e., the lag four coefficient estimate is 0.0727), although no lingering effect appears at higher lags as in the low delta value results. Moreover, the lead one coefficient is only marginally greater for high delta value options than for low delta value options, 0.0641 versus 0.0499. Although there is a tighter relation between the price changes in the stock and

Table V

Parameter Estimates from Regressions of Implied Five-Minute Stock Price Change Innovations on Lag, Contemporaneous, and Lead Actual Five-Minute Stock Price Change Innovations during the Period from January 3, 1986 through March 31, 1986 Stratification: Excluding First Hour of Trading

$$\hat{s}_t^o = \alpha + \sum_{k=-6}^{6} \beta_k s_{t-k}^o + \epsilon_t$$

Implied stock price changes are changes in the stock prices implied by the prices of active CBOE call options. Call prices at the beginning and at the end of the five-minute interval are transformed to implied stock prices using the American call option pricing model. The innovations for the actual (implied) stock price change series are the residuals from an MA(1) model fitted to the five-minute actual (implied) stock price changes during each trading day. The regression model is estimated using five-minute, intraday price change series during the sixty trading day sample period. Overnight price changes are not included. The overall sample contains the price changes over five-minute intervals during all days of the sample period. The subsample excludes the first twelve five-minute price changes each day.

	Overall Sample		Excluding First Hour	
Parameter	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]
No. of Obs.	45,160		36,448	
R^2	0.1231		0.1263	
$\bar{R}^2$	0.1228		0.1260	
$\hat{\alpha}$	0.0009	0.72	0.0023	1.71
$\hat{\beta}_{-6}$	0.0070	1.02	0.0121	1.69
$\hat{\beta}_{-5}$	−0.0162	−2.35	−0.0154	−2.14
$\hat{\beta}_{-4}$	0.0000	0.01	0.0072	0.98
$\hat{\beta}_{-3}$	0.0028	0.40	−0.0027	−0.37
$\hat{\beta}_{-2}$	0.0080	1.13	−0.0009	−0.12
$\hat{\beta}_{-1}$	0.0567	8.01	0.0415	5.49
$\hat{\beta}_{-0}$	0.4378	61.39	0.4288	56.07
$\hat{\beta}_1$	0.3261	45.02	0.3276	41.97
$\hat{\beta}_2$	0.1769	24.43	0.1698	21.60
$\hat{\beta}_3$	0.1055	14.58	0.1122	14.11
$\hat{\beta}_4$	0.0645	8.95	0.0726	9.09
$\hat{\beta}_5$	0.0332	4.62	0.0326	4.05
$\hat{\beta}_6$	0.0132	1.83	0.0046	0.57

[a] The t-ratios for the null hypotheses that $\alpha = 0$ and $\beta_k = 0$, $k = -6, \cdots, 6$, respectively.

Table VI

Parameter Estimates from Regressions of Implied Five-Minute Stock Price Change Innovations on Lag, Contemporaneous, and Lead Actual Five-Minute Stock Price Change Innovations during the Period from January 3, 1986 through March 31, 1986
Stratification: Delta Value

$$\hat{s}_t^o = \alpha + \textstyle\sum_{k=-6}^{6} \beta_k s_{t-k}^o + \epsilon_t$$

Implied stock price changes are changes in the stock prices implied by the prices of active CBOE call options. Call prices at the beginning and at the end of the five-minute interval are transformed to implied stock prices using the American call option pricing model. The innovations for the actual (implied) stock price change series are the residuals from an MA(1) model fitted to the five-minute actual (implied) stock price changes during each trading day. The regression model is estimated using five-minute, intraday price change series during the sixty trading day sample period. Overnight price changes are not included. The delta value of an option is the partial derivative of the option price with respect to the stock price.

	Overall Sample		Sample Stratified by Delta Value of Option			
			Low Delta Value		High Delta Value	
Parameter	Parameter Estimate	*t*-ratio[a]	Parameter Estimate	*t*-ratio[a]	Parameter Estimate	*t*-ratio[a]
No. of Obs.	45,160		22,561		22,599	
R^2	0.1231		0.0833		0.2018	
$\bar{R}^2$	0.1228		0.0828		0.2013	
$\hat{\alpha}$	0.0009	0.72	0.0007	0.36	0.0010	0.71
$\hat{\beta}_{-6}$	0.0070	1.02	0.0310	2.79	−0.0169	−2.11
$\hat{\beta}_{-5}$	−0.0162	−2.35	−0.0392	−3.50	0.0077	0.96
$\hat{\beta}_{-4}$	0.0000	0.01	−0.0164	−1.44	0.0166	2.07
$\hat{\beta}_{-3}$	0.0028	0.40	−0.0071	−0.62	0.0118	1.46
$\hat{\beta}_{-2}$	0.0080	1.13	0.0198	1.71	−0.0056	−0.69
$\hat{\beta}_{-1}$	0.0567	8.01	0.0499	4.30	0.0641	7.86
$\hat{\beta}_{0}$	0.4378	61.39	0.3622	31.01	0.5143	62.50
$\hat{\beta}_{1}$	0.3261	45.02	0.3373	28.25	0.3186	38.36
$\hat{\beta}_{2}$	0.1769	24.43	0.2031	16.86	0.1514	18.40
$\hat{\beta}_{3}$	0.1055	14.58	0.1397	11.58	0.0759	9.23
$\hat{\beta}_{4}$	0.0645	8.95	0.0542	4.51	0.0727	8.89
$\hat{\beta}_{5}$	0.0332	4.62	0.0788	6.56	−0.0059	−0.72
$\hat{\beta}_{6}$	0.0132	1.83	0.0239	1.99	0.0036	0.44

[a] The *t*-ratios are for the null hypotheses that $\alpha = 0$ and $\beta_k = 0$, $k = -6, \cdots, 6$, respectively.

option markets for high delta value options, the length of the lead of the stock market is not noticeably shorter than it is for other options and little evidence of option price changes leading stock price changes appears.

Another proxy for information effects is the size of the rate of return of the stock during the trading day. The intraday percentage rate of return for each of the 364 firm days were computed using

$$R_S = 100 \times \frac{S_{\text{close}} - S_{\text{open}}}{S_{\text{open}}}, \tag{10}$$

where S_{open} (S_{close}) are the opening (closing) stock prices. Presumably, if unanticipated news about a particular firm reaches the market, stock prices will react differently than expected. Here, expected return is defined as being the average intraday return of the stocks across the 364 days of the sample. The distribution of these returns was centered on a mean of 0.7986 percent and a median of 0.6115 percent.[20] The bottom quartile contained intraday returns less than −0.7235 percent, and the upper quartile contained returns greater than 2.1430 percent. The regression results using intraday return as a stratification variable are contained in Table VII.

The results in Table VII show that the temporal relation between the price changes in the stock and option markets is influenced by the magnitude of the intraday stock return, albeit in an asymmetric way. Where returns are abnormally low ($R_S < -0.7235$ percent) or normal ($-0.7235 \leq R_S < 2.1430$ percent), the relations are virtually the same. However, where the stock return is abnormally high ($R_S > 2.1430$ percent), the relation shows stronger contemporaneous association (i.e., $\hat{\beta}_0$ is 0.6077 for the positive abnormal return sample versus 0.3507 and 0.3981 for the negative abnormal and normal return subsamples, respectively).

The likely reason for the asymmetric behavior is that positive abnormal returns are a by-product of "good news," where buying a call option represents an inexpensive, limited liability investment in the stock. On the other hand, if "bad news" enters the market (as characterized by our sample of negative abnormal return days), buying a put option rather than selling a call option represents the most sensible investment. Since the sample contains only call options, it is not surprising to see the temporal relation less strong for negative abnormal returns vis-à-vis positive abnormal returns.

Even though a difference in the regression structure appears, however, good news appears to have little effect either on the number of economically significant lag coefficients or on the level of lead one coefficient. The number of significant lags remains at four, with the lag four coefficient at a level of 0.0926. The lead one coefficient for the positive abnormal return subsample, 0.0776, is only slightly larger than that of the normal return subsample, 0.0562.[21]

In summary, the investigations of the price change behavior in the stock and option markets indicates that the stock market clearly leads the option market. For active call options traded on the CBOE during the first quarter of 1986, the relation between five-minute price changes in the two markets is strongest at the contemporaneous level but is also strong at lags one through four, implying that the stock market leads by as much as twenty minutes.

V. Multiple Time Series Analysis of Trading Activity

To reinforce the price change findings, trading activity regressions were performed. Option activity in each five-minute interval was regressed on stock

[20] By contrast, the rate of price appreciation on the S&P 500 stock index was 14.0 percent over the period January 2, 1986 through March 31, 1986, implying a mean daily return of 0.2333 percent.

[21] Other stratification criteria were also used but failed to produce significant differences in the results. The criteria included the option's moneyness, its time to expiration, its elasticity with respect to stock price, and its "vega" (partial derivative with respect to the standard deviation of the stock).

Table VII

Parameter Estimates from Regressions of Implied Five-Minute Stock Price Change Innovations on Lag, Contemporaneous, and Lead Actual Five-Minute Stock Price Cha Innovations during the Period from January 3, 1986 through March 31, 1986 Stratification: Intraday Stock Return

$$\hat{s}_t^o = \alpha + \sum_{k=-6}^{6} \beta_k s_{t-k}^o + \epsilon_t$$

Implied stock price changes are changes in the stock prices implied by the prices of active CBOE call options. Call prices a beginning and at the end of the five-minute interval are transformed to implied stock prices using the American call o pricing model. The innovations for the actual (implied) stock price change series are the residuals from an MA(1) model to the five-minute actual (implied) stock price changes during each trading day. The regression model is estimated using minute, intraday price change series during the sixty trading day sample period. Overnight price changes are not included intraday stock return is $R_S = 100 \times \frac{S_{close} - S_{open}}{S_{open}}$, where $S_{open}(S_{close})$ are the opening (closing) stock prices.

	Overall Sample		Sample Stratified by Intraday Stock Return (R_S)					
			$R_s < -0.7235$		$-0.7235 \leq R_S \leq 2.1430$		$R_S > 2.1430$	
Parameter	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio
No. of Obs.	45,160		11,012		25,092		9,056	
R^2	0.1231		0.0739		0.1297		0.2095	
$\bar{R}^2$	0.1228		0.0729		0.1293		0.2084	
$\hat{\alpha}$	0.0009	0.72	0.0020	0.62	0.0005	0.37	0.0002	0.06
$\hat{\beta}_{-6}$	0.0070	1.02	0.0236	1.46	−0.0036	−0.42	0.0059	0.41
$\hat{\beta}_{-5}$	−0.0162	−2.35	−0.0386	−2.37	−0.0062	−0.72	−0.0075	−0.53
$\hat{\beta}_{-4}$	0.0000	0.01	−0.0068	−0.41	0.0003	0.03	0.0081	0.57
$\hat{\beta}_{-3}$	0.0028	0.40	−0.0012	−0.07	0.0087	1.00	0.0036	0.25
$\hat{\beta}_{-2}$	0.0080	1.13	0.0179	1.04	−0.0005	−0.06	0.0144	1.0
$\hat{\beta}_{-1}$	0.0567	8.01	0.0381	2.20	0.0562	6.46	0.0776	5.39
$\hat{\beta}_0$	0.4378	61.39	0.3507	19.91	0.3981	45.68	0.6077	41.82
$\hat{\beta}_1$	0.3261	45.02	0.3323	18.13	0.3237	36.99	0.3279	22.1
$\hat{\beta}_2$	0.1769	24.43	0.2412	13.10	0.1548	17.75	0.1463	9.8
$\hat{\beta}_3$	0.1055	14.58	0.1594	8.75	0.0840	9.61	0.1027	6.92
$\hat{\beta}_4$	0.0645	8.95	0.0503	2.81	0.0580	6.65	0.0926	6.2
$\hat{\beta}_5$	0.0332	4.62	0.0674	3.83	0.0398	4.55	−0.0234	−1.5
$\hat{\beta}_6$	0.0132	1.83	−0.0235	−1.35	0.0282	3.21	0.0167	1.11

[a] The t-ratios are for the null hypotheses that $\alpha = 0$ and $\beta_k = 0$, $k = -6, \cdots, 6$, respectively.

market activity in the contemporaneous interval as well as six five-minute intervals (30 minutes) on each side of the contemporaneous period,

$$\text{Option Activity}_t = \alpha + \textstyle\sum_{k=-6}^{6} \beta_k \text{Stock Activity}_{t-k} + v_t. \tag{11}$$

Option and stock market activity in each five-minute interval is measured in two ways: (a) by the number of transactions and (b) by the number of option contracts and shares traded. Since observations from different option contracts and different firms are pooled in the regressions, it is necessary to standardize the trading volume measures. This was done at the option contract level. Raw number of transaction and trading volume figures were standardized by the mean and the standard deviation of the figures for the particular contract on a given day. (Recall that there are 726 option contract days in the sample.) The regression results using the standardized trading activity values are reported in Table VIII, both for the overall sample and for the sample excluding the first hour of trading each day.

The trading activity results reinforce the price change results. In general, the stock market tends to lead the option market, independently of whether number of transactions or number of contracts traded is used as the metric. In fact, the regression results using standardized number of transactions show that the lead may be as much as five to ten minutes longer than in the price change results. The Table VIII trading activity results are most directly comparable to the Fitch stock price change results in Table IV because the Fitch file was used to gather the stock market activity data. The innovation results for the Fitch stock price data in Table IV show that lag coefficients one through five are important using price change data. In contrast, the Table VIII results show that for the overall sample lags one through six are important. Excluding the first hour of trading each day tends to shorten the stock market lead slightly; however, there is no indication that the option market leads the stock market. The overall conclusion that the stock market leads the option market for active CBOE call options seems well-founded.

VI. Summary and Conclusions

This study documents clearly that price changes in the stock market lead price changes in the option market for active CBOE call options traded during the first quarter of 1986. After adjusting for the effects of bid/ask spreads in the stock and option markets, the lead in terms of price changes is shown to be about fifteen to twenty minutes on average. After the number of transactions and trading volume are standardized to remove scale differences, the trading activity in the stock market is shown to lead that in the option market by an even longer period of time. The evidence reported here calls into question previous work in the area. The general consensus in the literature [e.g., Manaster and Rendleman (1982), Bhattacharya (1987), and (1988)] is that the option market leads the stock market both in terms of price changes and trading activity. Our results

Table VIII

Parameter Estimates from Regressions of Standardized Option Market Trading Activity on Lag, Contemporaneous, and Lead Standardized Stock Market Trading Activity during the Period from January 3, 1986 through March 31, 1986

$$\text{Option Activity}_t = \alpha + \sum_{k=-6}^{6} \beta_k \text{ Stock Activity}_{t-k} + v_t$$

The option (stock) market activity figures are the number of transactions and the number of contracts (shares) traded in each five-minute interval during the trading day. Before performing the regressions, the five-minute trading activity figures are standardized to mean zero and standard deviation one within each trading day. The regression model is estimated using five-minute, trading activity figures during the sixty trading day sample period.

	Number of Transactions				Number of Contracts Traded			
	Overall Sample		Excluding First Hour		Overall Sample		Excluding First Hour	
Parameter	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]	Parameter Estimate	t-ratio[a]
No. of Obs.	45,160		36,448		45,160		36,448	
R^2	0.0987		0.0691		0.0519		0.0369	
$\bar{R}^2$	0.0985		0.0688		0.0517		0.0365	
$\hat{\alpha}$	0.0185	4.22	−0.0131	−2.59	0.0075	1.66	−0.0201	−3.97
$\hat{\beta}_{-6}$	0.0091	1.90	0.0065	1.28	0.0029	0.60	−0.0053	−1.04
$\hat{\beta}_{-5}$	0.0080	1.62	0.0049	0.94	0.0100	2.02	0.0088	1.65
$\hat{\beta}_{-4}$	0.0188	3.77	0.0144	2.68	0.0116	2.32	0.0128	2.38
$\hat{\beta}_{-3}$	0.0202	4.03	0.0157	2.90	0.0149	2.96	0.0128	2.34
$\hat{\beta}_{-2}$	0.0243	4.83	0.0220	4.06	0.0188	3.75	0.0134	2.47
$\hat{\beta}_{-1}$	0.0396	7.87	0.0389	7.16	0.0285	5.66	0.0259	4.74
$\hat{\beta}_0$	0.0762	15.12	0.0805	14.71	0.0644	12.78	0.0642	11.67
$\hat{\beta}_1$	0.1039	20.65	0.1011	18.44	0.0905	17.98	0.0875	15.91
$\hat{\beta}_2$	0.0883	17.61	0.0883	16.04	0.0830	16.55	0.0784	14.16
$\hat{\beta}_3$	0.0726	14.45	0.0610	10.93	0.0606	12.10	0.0551	9.87
$\hat{\beta}_4$	0.0570	11.36	0.0455	8.10	0.0455	9.14	0.0350	6.24
$\hat{\beta}_5$	0.0562	11.30	0.0483	8.65	0.0462	9.39	0.0352	6.31
$\hat{\beta}_6$	0.0526	10.94	0.0361	6.62	0.0415	8.67	0.0276	5.02

[a] The t-ratios are for the null hypotheses that $\alpha = 0$ and $\beta_k = 0$, $k = -6, \cdots, 6$, respectively.

using more refined data and a more general methodology indicate that the consensus may be wrong.

An unexpected by-product of this study is the documentation of intraday trading patterns in the CBOE call option market. Where the NYSE stocks in our sample have the familiar U-shaped pattern of trading activity by time of day, the option market begins at a relatively low level of activity, rises to a maximum activity about 45 minutes into the day, declines to a uniform level of activity above the level of activity in the stock market during the trading day, and then rises again at the close. Explaining the cause or causes of the differential trading activity between these two, essentially redundant, markets seems to be a worthwhile area for future research.

Appendix A: Valuation of American Call Options on Stocks with Two Known Dividends

This appendix contains the valuation formula for an American call option written on a stock with two known dividends. The formula is an extension of the model derived by Roll (1977).[22] The assumptions underlying the model are those of Black and Scholes (1973). The only qualification necessary is that the stock price net of the present value of the escrowed dividends paid during the option's life follows the stochastic differential equation

$$dS^x/S^x = \mu dt + \sigma dz, \tag{A1}$$

where

$$S_\tau^x = \begin{cases} S_\tau - D_1 e^{-r(t_1-\tau)} - D_2 e^{-r(t_2-\tau)} \text{ for } 0 \leq \tau < t_1, \\ S_\tau - D_2 e^{-r(t_2-\tau)} \text{ for } t_1 \leq \tau < t_2, \\ S_\tau \text{ for } t_2 \leq \tau \leq T, \end{cases}$$

and where D_1 and D_2 are the dividends per share paid at the ex-dividend instants, t_1 and t_2 periods from now, respectively, and T is the time to expiration of the option. In other words, although the stock price net of the present value of the escrowed dividends S^x follows a smooth process through time, the observed stock price S drops by the amount of the dividend at each ex-dividend instant.[23] In (A1), μ and σ are the mean and the standard deviation of the instantaneous rate of return on the stock, and z is a Wiener process.

Before proceeding with a discussion of the valuation formula, note that under certain conditions the American call option will not optimally be exercised prior to expiration. These conditions are

$$D_1 < X[1 - e^{-r(t_2-t_1)}] \tag{A2a}$$

and

$$D_2 < X[1 - e^{-r(T-t_2)}]. \tag{A2b}$$

That is, if each cash dividend is less than the present value of the interest that

[22] The single dividend version of the American call option pricing formula appears in Whaley (1981).

[23] Empirical support for this assumption may be found in Barone-Adesi and Whaley (1986).

is earned implicitly by deferring exercise, the American call will not be exercised early. If both conditions are satisfied, the price of an American call option is determined by replacing the stock price parameter in the Black-Scholes model with the stock price less the present value of the promised dividends, $S^x = S - D_1 e^{-rt_1} - D_2 e^{-rt_2}$, that is,

$$C(S, T; X) = S^x N_1(d_1) - Xe^{-rT} N_1(d_2), \tag{A3}$$

where

$$d_1 = [\ln(S^x/X) + \left(r + \frac{1}{2}\sigma^2\right)T]/\sigma\sqrt{T},\ d_2 = d_1 - \sigma\sqrt{T}.$$

The valuation problem becomes slightly more complex if one of the conditions (A2a) or (A2b) is violated. Early exercise is now a possibility, albeit just prior to one of the two ex-dividend instants. The most likely case is where (A2a) is satisfied but (A2b) is not.[24] In this case, the appropriate valuation equation is

$$\begin{aligned} C(S, T; X) = {} & S^x[1 - N_2(-a_1, -b_1; \sqrt{t_2/T})] \\ & -Xe^{-rT}[N_1(b_2)e^{r(T-t_2)} + N_2(a_2, -b_2; -\sqrt{t_2/T})] \\ & + D_2 e^{-rt_2} N_1(b_2), \end{aligned} \tag{A4}$$

where

$$a_1 = [\ln(S^x/X) + \left(r + \frac{1}{2}\sigma^2\right)T]/\sigma\sqrt{T},\ a_2 = a_1 - \sigma\sqrt{T},$$

$$b_1 = [\ln(S^x/S^*_{t_2}) + \left(r + \frac{1}{2}\sigma^2\right)t_2]/\sigma\sqrt{t_2},\ b_2 = b_1 - \sigma\sqrt{t_2},$$

and $N_2(a, b; \rho)$ is the cumulative bivariate normal density function with upper integral limits, a and b, and correlation coefficient, ρ. $S^*_{t_2}$ is that second ex-dividend stock price which satisfies

$$c(S^*_{t_2}, T - t_2; X) = S^*_{t_2} + D_2 - X. \tag{A5}$$

Call option valuation where condition (A2a) is violated but (A2b) is not takes a similar form.

If both conditions are violated, valuation becomes even more complex in the sense that there are positive probabilities of early exercise just prior to each of the two ex-dividend instants. The valuation equation for this American call option is

$$\begin{aligned} C(S, T; X) = {} & S^x[1 - N_3(-a_1, -b_1, -c_1; \sqrt{t_1/T}, \sqrt{t_2/T}, \sqrt{t_1/t_2})] \\ & -X[e^{-rt_1} N_1(c_2) + e^{-rt_2} N_2(b_2, -c_2; -\sqrt{t_1/t_2}) \\ & + e^{-rT} N_3(a_2, -b_2, -c_2; -\sqrt{t_1/T}, -\sqrt{t_2/T}, \sqrt{t_1/t_2})] \\ & + D_1 e^{-rt_1} N_1(c_2) + D_2 e^{-rt_2}[N_1(c_2) + N_2(b_2, -c_2; -\sqrt{t_1/t_2})], \end{aligned} \tag{A6}$$

[24] Quarterly dividends paid on a stock tend to be constant or slowly increasing cash amounts through time. If $D_1 = D_2$, it is obvious that condition (A2b) is more likely to be violated than condition (A2a).

where

$$a_1 = [\ln(S^x/X) + \left(r + \frac{1}{2}\sigma^2\right)T]/\sigma\sqrt{T},\ a_2 = a_1 - \sigma\sqrt{T},$$

$$b_1 = [\ln(S^x/S^*_{t_2}) + \left(r + \frac{1}{2}\sigma^2\right)t_2]/\sigma\sqrt{t_2},\ b_2 = b_1 - \sigma\sqrt{t_2},$$

$$c_1 = [\ln(S^x/S^*_{t_1}) + \left(r + \frac{1}{2}\sigma^2\right)t_1]/\sigma\sqrt{t_1},\ c_2 = c_1 - \sigma\sqrt{t_1},$$

and $N_3(a, b, c; \rho_{12}, \rho_{13}, \rho_{23})$ is the cumulative trivariate normal density function with upper integral limits, a, b, and c, and correlation coefficients, ρ_{ij}. $S^*_{t_1}$ and $S^*_{t_2}$ are the first and second ex-dividend stock prices which satisfy

$$C(S^*_{t_1}, T - t_1; X) = S^*_{t_1} + D_1 - X \tag{A7a}$$

and

$$C(S^*_{t_2}, T - t_2; X) = S^*_{t_2} + D_2 - X. \tag{A7b}$$

Appendix B: Summary of Firms with CBOE Call Options Contained in Sample during the Period from January 3, 1986 through March 31, 1986

	Firm Name	Number of Firm Days	Number of Option Days	Number of Transactions	Number of Contract Traded
1	BA	11	14	2,567	28,207
2	BAC	6	11	2,204	36,051
3	BAX	4	7	1,348	17,380
4	BMY	5	7	1,194	11,485
5	C	30	47	10,120	81,555
6	CBS	7	9	1,830	17,808
7	CCI	3	3	483	6,278
8	CI	1	1	170	2,220
9	CL	1	1	146	2,043
10	DOW	2	3	533	5,647
11	EK	33	70	15,344	212,835
12	F	8	9	1,541	18,040
13	FDX	2	2	377	3,308
14	GD	1	1	153	2,212
15	GE	6	6	975	10,841
16	GM	37	62	13,840	177,046
17	HM	5	8	1,603	26,495
18	HWP	9	9	1,557	25,088
19	IBM	60	293	91,799	1,346,648
20	ITT	14	16	2,849	47,108
21	JNJ	15	18	3,750	44,682
22	KM	12	15	2,572	42,982
23	KO	3	3	513	4,382
24	LIT	7	9	1,687	16,588
25	MOB	8	11	2,058	42,611
26	MRK	1	1	146	1,166
27	NSM	3	3	478	6,522

Appendix B—*Continued*

	Firm Name	Number of Firm Days	Number of Option Days	Number of Transactions	Number of Contract Traded
28	OXY	4	4	715	15,339
29	PRD	1	1	145	1,497
30	PWJ	1	1	211	2,521
31	PZL	9	13	2,761	33,187
32	RCA	5	6	1,387	39,341
33	RJR	8	10	2,004	29,510
34	ROK	1	1	158	1,093
35	S	15	18	3,056	46,089
36	SY	3	3	483	9,248
37	T	2	2	309	9,010
38	TDY	1	1	153	737
39	TXN	1	2	359	3,138
40	UAL	1	1	152	1,582
41	WCI	16	22	4,168	67,046
42	WMT	1	1	172	3,096
43	XON	1	1	147	2,672
Total		364	726	178,217	2,502,334

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