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January 1994
Revised 1997

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FORC Preprint: 94/45

The European Journal of Finance **3**, 49–72 (1997)

Option prices as predictors of stock prices: intraday adjustments to information releases

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This study tests for intraday lead/lag relationships between a given stock price and the stock value implied by the prices of call options on that stock. The results indicate that throughout the five trading days preceding earnings announcements with significant unanticipated information content, implied stock values lead their corresponding observed stock prices by about fifteen minutes. On the announcement day itself, this lead lengthens to the point that call option prices usually adjust at least one hour before the public announcement. Under most circumstances, evidence of this lead disappears immediately after the announcement and prices remain synchronous between the two markets.

Keywords: Lead/lag relationships, options, crossmarket efficiency

1. INTRODUCTION

Capital markets can be said to exhibit 'cross-market efficiency' whenever prices in all markets simultaneously reflect an identical set of information. Institutional differences, such as those that make one market more attractive to better-informed investors or that permit one market to execute trades more quickly, can generate cross-market inefficiency in the form of lead/lag relationships among prices in different markets.

Lead/lag relationships should be more evident around the time of announcements that affect market prices. If, for example, some investors possess advanced access to the contents of the announcement, or superior skill in evaluating the facts announced to the public, prices in the market that offers institutional advantages should reflect the trading activities of these better-informed investors. Arbitrage will drive prices in the other markets towards the prices in this more efficient market. Moreover, even when identical information is used in all markets, the market that offers the fastest execution will be the first to price new information.

As inherently leveraged investments, options allow better-informed investors to take full advantage of their superior information. For example, buying call options, rather than borrowing to buy stock, avoids stock market restrictions on

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margined purchases, and usually can reduce total transaction costs. Accordingly, the option market should attract the better-informed investors. Moreover, differences in floor operations may allow option trades to execute faster than stock trades. Thus, the stock market and the option market exhibit institutional differences that may lead to cross-market inefficiencies.

The purpose of this paper is to determine whether there is evidence for cross-market inefficiency, in the form of lead/lag relationships between the price of a given stock and the value implied by its call options. We focus on the time period around quarterly earnings announcements, although cross-market inefficiency could be present at the release of any information. It is not our intent to show that option prices lead stock prices most of the time or even on average. Rather, we will show that it is possible to identify events that are associated with cross-market inefficiency.

We find that throughout the five trading days preceding earnings announcements with significant unanticipated information content, implied stock values lead their corresponding observed stock prices by about 15 minutes. On the announcement day itself, this lead lengthens to the point that call option prices usually adjust at least one hour before the public announcement. Under most circumstances, evidence of this lead disappears immediately after the announcement and prices remain synchronous between the two markets. These results are consistent with the findings of Manaster and Rendleman (1982) and Bhattacharya (1987).

Our results may appear to be in contrast with the findings of Stephan and Whaley (1990) and Chan *et al.* (1993), which found evidence of the stock market leading the option market. However, these two papers tested the relationship between the two markets over a three-month time period, while our results relate to the time period around the arrival of information. Our results suggest that, even if the stock market usually leads the option market, the effect of information arrival is strong enough to reverse the direction of this lead/lag relationship. As Chan *et al.* suggest, 'trading on private information is rare'. When data from time periods when there is an opportunity to trade on private information are aggregated with data from other time periods, evidence of trading on private information 'is swamped by other types of trades' (Chan *et al.*, 1993, p. 1966).

Our results suggest that an opportunity to arbitrage the price discrepancies between markets may exist in the pre-announcement period, especially in the hour immediately preceding an announcement. In order to exploit this opportunity, one would have to identify the significant announcements before they were made. While this may be possible, for this study we rely on information that becomes available only when the announcement is made.

The remainder of the paper is organized as follows: Section 2 describes the previous research. Section 3 describes the selection of data and Section 4 explains the identification of high-information-content earnings announcements and introduces a new measure of information content. Section 5 describes a new method for the estimation of joint implied parameters. In Section 6 we show that the empirical relationship between implied stock prices and short-term excess stock returns reflects a lead/lag relationship between the markets. Section 7

presents the analysis of the return differences for 10 six-hour trading-segments, called 'pseudo-days'. Section 8 presents the analysis of the return differences for the pre-announcement and post-announcement components of the announcement day, and Section 9 that for the announcement day's individual intervals. Finally, Section 10 summarizes the results and presents the conclusions.

2. PREVIOUS RESEARCH

Most previous work on cross-market efficiency focuses on tests for a lead/lag relationship between the price of a given stock and the prices of the options on that stock.[1] Using daily closing prices, Manaster and Rendleman (1982) calculate the discrepancy between a firm's observed stock price and the stock value implied by that firm's call option prices. Averaging across all trading days and all firms, they find weak evidence to support the hypothesis that these discrepancies are related to subsequent short-term movements in observed stock prices.

Combining data from all trading days can identify a general lead/lag relationship between the two markets, but it would miss a lead/lag relationship that was limited to the period around information arrival. In addition, daily closing-price data may miss temporary intraday discrepancies between stock prices and option prices. Further, as the two markets close at different times, closing-price data may be dominated by trades that are not synchronous.

Using intraday data, Bhattacharya (1987) also finds weak evidence that option prices predict subsequent stock-price movements. However, he combines price data from high and low content announcements, thus diluting the evidence for cross-market inefficiency unique to the high-content ones. Further, Bhattacharya's data screens exclude price data from the announcement day itself, missing any lead/lag relationship that was limited to that day. Also, the screens limit the analysis to the 32 firms with the largest option volume.[2]

Biases in Bhattacharya's methodology may contribute to his weak results. His algorithm, for imputing whether the stock traded at its bid or ask price, is likely to misclassify or discard a stock price observation whenever an important disclosure makes the stock price more volatile. However, these periods of volatile stock prices are precisely when there will be large differences in the way that information is used by the two markets. In addition, he calculates implied stock prices from only two option price observations, introducing small-sample bias that may obscure an existing lead/lag relationship.

[1] To our knowledge, only three papers on cross-market efficiency do not compare the price of a stock with the prices of the options on that stock. Oellermann and Farris (1985) show that the futures price for live cattle leads the spot price. Peterson and Tucker (1988) show that the spot rates implied by currency options lead currency returns. Anthony (1988) shows that changes in call option trading volumes lead changes in stock volumes.

[2] High-volume firms, which are closely followed by investors in both markets, are unlikely to generate informational differences and, when they do generate these differences, their high liquidity could permit better-informed investors to trade without affecting the prices.

The Stephan and Whaley (1990) approach is similar to that of Manaster and Rendleman (1982) in that they test for a general lead/lag relationship between the option market and stock market over a relatively long time period, the first quarter of 1986. Using intraday transaction prices, they find that changes in observed stock prices lead changes in implied stock prices. Although, they interpret this as evidence that stock prices lead option prices, there are at least two other possible explanations for their results. First, Stephan and Whaley calculate each implied stock price from the current observed call price and an estimate of current volatility that is equal to the implied volatility from the previous trading day. If volatilities are not constant from day to day, this use of stale data (the previous trading day's implied volatility) may introduce a spurious lag into the implied stock-price time series. Since Stephan and Whaley do not verify the stability of stock-price volatility in their sample period, their results could be attributed to this spurious lag. Also, Chan *et al.* (1993) show that the lead found by Stephan and Whaley disappears when their transaction prices are replaced by the midpoint of the bid/ask spread. Thus, the Stephan and Whaley result is probably an artifact of using transaction prices rather than the midpoint of the bid/ask spread and can be attributed to 'spurious lead introduced by infrequent trading of options' (Chan *et al.*, 1993, p. 1957). Most importantly, the Stephan and Whaley paper is not intended to examine the effects of information arrival on the lead/lag relationship.

Like Stephan and Whaley (1990), Chan *et al.* (1993) test for a general lead/lag relationship between the option market and stock market over the first quarter of 1986. Their method does not rely on implied stock prices and does not seem to require volatility estimates. When they use the option transaction prices used by Stephan and Whaley, they find evidence of the stock market leading the option market. When they replace these transaction prices with the midpoint of the bid/ask spread for options, they find that the two markets are synchronous. Thus, they show that the evidence for the stock market leading the option market can be attributed to less frequent trading in the option market. They find no evidence that trading on private information causes the option market to lead the stock market. However, like Manaster and Rendleman, they use a procedure that is biased against finding such evidence. If trading on private information is limited to the period around the arrival of significant information, then evidence of this trading would be swamped when combined with data from normal periods when the two markets are synchronous.

In order to examine more effectively the relationship between the price of a given stock and the value implied by its call options, specifically at the time of the release of information, we introduce innovations into the fields of information content measurement and implied parameter estimation.

3. DATA REQUIREMENTS

Options on individual stocks grew in importance from their introduction in 1973 until the end of 1979. Until October 1979, financial derivative markets offered

few alternatives to investing in options on individual stocks. Although interest-rate futures began trading in 1975, they generated little volume until the Federal Reserve switched from controlling interest rates to controlling the money supply. The relative importance of options on individual stock was eroded further by the introduction of stock-index futures in 1982 and the introduction of stock-index options in 1983.

Since 1977, trading by institutional investors has driven explosive growth in the equity markets. In 1977, the average daily volume on the NYSE was 22 million shares per day, with an average of 215 block trades per day. By 1990, the average daily volume on the NYSE had grown to 157 million shares per day, with an average of 3332 block trades per day (CBOT, 1991, p. 99). Institutional investors often hedge these positions by simultaneously taking positions in the derivatives markets. This institutional trading is not information-driven and would tend to mask any information-driven lead/lag relationship between derivatives and their underlying assets.

Thus, the early months of 1979 represent a time when the market for trading options on individual stocks was well developed and institutional trading did not yet dominate the financial markets. In that interval, institutional trading was unlikely to mask any information-driven lead/lag relationship between derivatives and their underlying assets. For that reason, we selected data from the first four months of 1979.

Our analysis requires both intraday price data and the exact time of each earnings announcement. The resorted format of the Berkeley Option Data Base is the source of our intraday price data. The data consist of prices of Chicago Board Options Exchange (CBOE) options and the New York Stock Exchange (NYSE) prices for their underlying stocks.[3] The Dow Jones News/Retrieval Service (DJNR) provided the hour and minute of each earnings announcement.[4] Firms with CBOE traded options made 145 earnings announcements during the first four months of 1979. We were able to identify the exact time of 135 of these announcements.

We conjecture that the lead/lag relationship between the option market and the stock market may change over time in response to changes in the markets. Our results represent an early phase in the development of option markets and can be regarded as a 'baseline' for assessing subsequent changes in the financial markets. In today's financial markets, trading on index options is more important than trading on individual options, circuit breakers constrain trading in all markets, and hedging activity by institutional investors dominates the trading activity in individual options. If current data produce evidence of

[3] Each option record reports either the bid and asked price for an option quote or the transaction price and volume for an option trade. Each option record also posts the price of the underlying stock as of its last trade on the NYSE.

[4] We use only actual earnings announcements, not earnings forecasts. Where there are multiple reports of the same announcement, we use the time of the earliest report.

increased or decreased cross-market efficiency or a reversal of the lead/lag relationship, these changes can be attributed to changes in the financial markets.

4. HIGH INFORMATION CONTENT EARNINGS ANNOUNCEMENTS

We choose to use quarterly earnings announcements for four reasons. First, earnings announcements have a well-documented relationship with stock[5] and option price movements.[6] Second, an earnings announcement happens at a specific time. Third, well-established measures of information content[7] allow a researcher to discriminate between 'low-content' announcements, which deliver little unanticipated information to investors, and 'high-content' announcements, which deliver significant unanticipated information. Finally, when compared with economic events such as oil-price shocks, firm-specific events such as earnings announcements are more likely to generate an informational advantage for some investors.

Selecting earnings announcements that actually deliver significant information requires a measure of their information content. When an announcement delivers significant unanticipated information, there should be a significant reaction in the price of the firm's securities, i.e. 'a price impact'. The Standardized Announcement Return (SAR) provides a price-impact-based approach to measuring information content.[8] The SAR for an arbitrary announcement, j, SAR_j, is defined as follows:

$$SAR_j = (EDR_{j,0} + EDR_{j,-1})/ESE \tag{1}$$

Where $EDR_{j,0}$ is the excess return on the announcement day, $EDR_{j,-1}$ is the excess return on the previous day, and ESE is the estimated standard error of the two-day return.

Using CRSP daily returns, we calculate SAR_j for each of the 135 available announcements and rank the announcements by this measure. We define a 'high positive content' announcement as one that ranks in the top 30 and a 'high

[5] See Jones and Litzenberger (1970), Joy *et al.* (1977), Latané and Jones (1977, 1979), Rendleman *et al.* (1982), and Watts (1978).
[6] See Whaley and Cheung (1982).
[7] See Latané and Jones (1977) and Foster *et al.* (1984).
[8] SAR is an example of an earnings expectation model based on security returns. Foster *et al.* (1984) compare security-returns-based earnings expectations models, very similar to SAR, with the more traditional earnings expectation models based on a time series of earnings. They state that security-returns-based models are less likely to be contaminated by unmeasured risk factors. Using daily returns, they show that stock portfolios that are constructed on the basis of performance at the time of announcement, and held without revision for 60 days, will generate abnormal returns only if the performance measurement is based on a time series of earnings. When the performance measurement is based on security returns, these portfolios generate no significant abnormal returns.

negative content' announcement as one that ranks in the bottom 30.[9] Thus, we identify a total of 60 high content announcements, the 'SAR announcements'.[10]

5. ESTIMATION OF THE JOINT IMPLIED PARAMETERS

Implied stock prices may be estimated either independently, or jointly with the implied stock-price volatility. Estimating the implied stock price independently requires a proxy for the average stock-price volatility over the remaining life of the option. If the volatility proxy is based on stale data, then the implied stock price also will be based on stale data. Thus, the use of a volatility proxy that is based on stale data could introduce a spurious lag into the implied stock price time series. For example, we would expect that implied stock prices based on historical sample standard deviations would lag implied stock prices on the true average stock-price volatility over the remaining life of the option.

While the previous day's implied volatility may be an adequate volatility proxy in many applications, its use may introduce biases that are unacceptable when examining lead/lag relationships. When the volatility proxy is the previous day's implied volatility, each implied stock price is a nonlinear transformation of the current observed call price, the previous trading day's observed call prices and the previous trading day's observed stock prices. Although the problem is less severe than when historical sample standard deviations are used, stale data still could introduce a spurious lead/lag relationship. This problem would be exacerbated when the impending arrival of information causes instability in the stock-price volatility. Also, in the presence of lead/lag relationships between the option market and the stock market, independently estimated implied volatilities are biased (Boyle and Park, 1994). Using this volatility proxy would result in an off-setting bias in the independently estimated implied stock price. Jointly estimated implied stock prices and implied volatilities would not be subject to such biases.

In order to avoid introducing a spurious lag into the implied stock price time series, we chose to estimate the implied stock price jointly with the implied volatility. The estimation of a pair of implied parameters requires the 'simultaneous observation of the prices of at least two options. Because true simultaneous observation of prices is impossible, researchers usually approximate simultaneity by taking the last option prices for a given interval. In studies using daily data, the natural interval is the trading day. In research using intraday data researchers must specify the length of the interval. The length of

[9] Choosing 30 provides a set that is large enough for reliable statistical analysis and, in terms of the information content measure, is approximately one standard deviation away from the mean of the population.

[10] In order to verify that our results are consistent with results obtained using a more traditional measure of information content, we repeated the analysis using an earnings expectation model based on a time series of earnings. We used Standardized Unexpected Earnings (SUE), which was developed in Jones and Litzenberger (1970), to represent an earnings expectation model based on a time series of earnings. SUE is very similar to one of the time-series models tested in Foster *et al.* (1984).

The results for the SUE announcements are very similar to those for the SAR announcements. Tables presenting the SUE results are available from the authors.

the interval is a tradeoff between a short one containing too few option price observations, which could lead to small-sample bias, and a long one containing option prices that reflect different market conditions.

We partition the six hours of each trading day[11] into 24 fifteen-minute intervals.[12] For each firm and interval, we select the last available quoted price for every call option series[13] and for the underlying stock.[14] We assume that these prices occur at the end of the interval, just as final daily prices are assumed to occur at the end of the day in studies using daily data.

This study contributes two innovations to the joint implied parameter literature. First, for the data in our sample, the differences among the implied volatilities for individual intervals within a particular trading day are not statistically significant.[15] Consequently, we assume that the stock-price volatility remains constant throughout the trading day, except for a possible shift during the announcement interval.[16] The second innovation is the use of the three-dividend form of the American call option pricing model.[17] These innovations reduce the number of unknown parameters to be estimated and increase the number of observations available. Thus, the analysis can include firms with thinly traded options, whose option prices are quite likely to lead their stock

[11] In order to control for the effects of trading that is not synchronous between the two markets, we limit the data to the six hours of each trading day in which both the CBOE and the NYSE are open.

[12] The choice of a 15-minute interval length is common in this stream of research (Bhattacharya, 1987).

[13] When the type of record is a trade, the transaction price is used as the option price. When the type of record is a quote, the midpoint of the bid/ask spread is used as the option price. If there is more than one record for a given option within a single 15-minute interval, only the option price associated with the final record is used.

We do not use option prices generated by options which violate arbitrage bounds. We also excluded option price data from options that are about to expire, deep-in-the-money options and deep-out-of-the-money options because such options are associated with severe mispricing biases (Geske, 1979). Finally, we do not use option price data from options priced less than $0.50. They are eliminated because the CBOE restricts the trading of such options (Phillips and Smith, 1980, p. 197). After all of these restrictions, on average, slightly more than five different options remain for each firm in each interval, both before and after the announcement.

[14] We use the stock price that is associated with the last option record of the interval, which may be one of the records that we exclude in selecting option price data. Within a given interval, on average, the option trades or quotes that generate the option price data occur three minutes earlier than this final option record of the interval. Furthermore, the stock price associated with a given option record is the last traded stock price as of the time the option trade or quote is reported, but this report may be as much as five minutes late when the options transaction volume is heavy. Since the stock price that is used is for a given 15-minute interval, is the stock price associated with the interval's last option record, this stock price is the last traded stock price as of three to eight minutes after the average option trade or quote. Accordingly, even though the stock price that is used for a given interval is associated with a stock trade that must occur before the final option trade or quote is reported, there is little chance of systematically using stock prices that occur earlier than the option prices that are used.

[15] Snelling (1987).

[16] Our assumption of constant stock-price volatility is somewhat different from that made by Stephan and Whaley in that we assume that the volatility is constant for one day or less, not two days. Also, we did test the stability of stock-price volatility in our sample period.

[17] Selby and Hodges (1987).

prices.[18] Moreover, the resulting implied stock prices are less likely to be biased by small sample sizes.

The joint implied parameters are determined by minimization of the following objective function denoted by Q:

$$\underset{S_x, V}{\text{Min}}\, Q \equiv \sum_{x=F}^{L} \sum_{i=1}^{M_x} [C_{i,x} - SH_{i,x}(S_x, V)]^2 \tag{2}$$

where

$C_{i,x}$	is the observed price of the ith call option in interval X
F	is the first of the N intervals
L	is the last of the N intervals
M_x	is the number of available call options on the specified stock in interval X
N	is the number of fifteen-minute intervals in the relevant trading period
S_x	is the implied stock price in interval X
$SH_{i,x}(S_x, V)$	is the corresponding Selby–Hodges price for the American call
V	is the implied variance for the relevant trading period.

When there is no announcement within a given trading day, expression (2) is solved with $F = 1$, the first interval of the trading day, and $L = 24$, the last interval of the trading day, producing 24 implied stock prices and one implied volatility. For trading days with an announcement in interval Y, expression (2) is solved in two parts. First, we put $F = 1$ and $L = Y - 1$, the interval immediately preceding the announcement interval. Second, we put $F = Y + 1$, the interval immediately following the announcement interval, and $L = 24$. Thus, the announcement-day solution produces twenty-three implied stock prices and two implied volatilities. No implied stock price is calculated for the announcement interval itself.[19]

For announcements made while the markets are closed, we solve expression (2) separately for each of the five trading days preceding the announcement and each of the five trading days that follow the announcement, generating 10 implied volatilities and 240 implied stock prices. For announcements that are made while the markets are open, we solve expression (2) for the announcement day itself, each of the five trading days that precedes the announcement day, and each of the five trading days that follows the announcement day. These

[18] Such firms are likely to generate informational differences and, because of their lack of liquidity, their prices are likely to reveal the trading activities of better-informed investors. Of course, a better-informed investor would prefer to trade when there is sufficient liquidity to prevent their transactions from affecting prices. If they are able to do this, then we would find little evidence of the option market leading the stock market in either liquid or illiquid markets.

[19] Because there is an inflection in the relationship between option prices and volatility, one should avoid gradient-based algorithms in determining implied volatilities. We solved equation (2) using the Levenberg–Marquadt algorithm.

solutions generate 12 implied volatilities and 263 implied stock prices.[20] For each announcement[21] j, we retain the implied stock price, $S^*_{j,t}$, for each event-time interval from $t=-120$ to $t=-1$ and from $t=+1$ to $t=+120$.[22]

6. PROPORTIONAL ERRORS AND HOLDING PERIOD EXCESS RETURNS

The stock, its associated options, and the market return over the holding period, all may provide information about subsequent stock prices. A direct comparison of the implied stock price and the subsequent observed stock price should combine these three sources of information. We define the proportional error, $PE_{j,t}$, for each announcement from $j=1$ to $j=60$, and for each event-time interval from $t=-120$ to $t=+120$ (excluding $t=0$) as:

$$PE_{j,t} = (S^*_{j,t} - S_{j,t})/S_{j,t} \tag{3}$$

where $S_{j,t}$ is the observed stock price, and $S^*_{j,t}$ is the corresponding implied stock price. Note the similarity between equation (3) and the expression for the corresponding stock return, $SR_{j,t+L}$:

$$SR_{j,t+L} = (S_{j,t+L} - S_{j,t})/S_{j,t}$$

where $S_{j,t}$ is the stock price observed at the end of interval t and L is the length of the holding period. If the implied stock price at time t perfectly predicted the stock price at time $t+A$, and the holding period, L, exactly equalled the adjustment time, A, then the proportional error, $PE_{j,t}$, would provide a perfect prediction of the stock return, $SR_{j,t+L}$. In fact, this prediction is biased and noisy because of biases in the option pricing model, unpredicted factors affecting the stock price, and differences between the length of the holding period and the length of the adjustment time. However, if the stock price at least partially adjusts towards the implied stock price within the interval $(t, t+L)$ and the biases and noise are small relative to the size of the proportional error, then there should be evidence of a positive association between the stock return, $SR_{j,t+L}$, and the proportional error, $PE_{j,t}$. By combining an analysis of the associations between a given proportional error and stock returns for various holding periods with an analysis of the relative size of these stock returns, one can infer the pattern of the lead/lag relationship between the option market and

[20] There are potentially two types of missing data problems in solving equation (2). First, within a given trading day, a firm may have an interval in which there are no eligible option trades or quotes. In this case, the firm and the day remain in the data set and the implied stock price for that interval is treated as missing data. Second, there may be days in which a firm has fewer than two eligible option trades or quotes or for which the system of equations fails to converge to a solution. For these days, all of the firm's implied stock prices are treated as missing data. Fortunately, missing data are not a severe problem and at least event day data are available for every announcement.

[21] Since the information content measure (SAR) identifies 60 high information content announcements, the earnings announcement number, j, can take values from 1 to 60.

[22] For earnings announcements made while the markets are open, the announcement interval is designated by the event-time index, $t=0$, and no implied stock price is calculated for this interval. For earnings announcements made while the markets are closed, no interval is designated $t=0$. The first interval of the following trading day is designated by the event-time index, $t=1$, and the last interval of the previous trading day is designated by the event-time index, $t=-1$.

the stock market.[23]

Following accepted practice in this line of research,[24] this analysis compares the proportional error with the short-term excess returns in order to isolate the information that is unique to the contemporaneous option prices. The first step in calculating the short-term excess returns is to calculate a 'one-interval,' i.e. 15-minute stock return, $R_{f,s}$, for every firm, f, and every calendar interval, s, in the CBOE data set.

$$R_{f,s} = (S_{f,s+1} - S_{f,s})/S_{f,s} \tag{4}$$

where $S_{f,s}$ is the stock price assumed to occur the end of interval s.[25] The corresponding excess return, $ER_{f,s}$, is defined by

$$ER_{f,s} = R_{f,s} - RM_s \tag{5}$$

where RM_s is the 'market index' for interval s, constructed as an equally weighted average of the one-interval stock returns.[26]

For the event-time interval t, the stock of the firm that makes earnings announcement j has a one-interval excess return defined by

$$ER_{j,t} = R_{j,t} - RM_t \tag{5'}$$

The holding period return between the end of event-time interval t and the end of interval $t+L$, $HPR_{L,j,t}$ (where t may take values from -120 to $+120$, including

[23] For example, suppose there is a positive association between the proportional error, $PE_{j,t}$, and the stock return, $SR_{j,t+L1}$, and also a positive association between the proportional error, $PE_{j,t}$, and the stock return for a longer interval, $SR_{j,t+L2}$. If the two returns are equal in size, then the stock price completely adjusts to the implied stock price within the interval $(t, t+L1)$. If $SR_{j,t+L2}$ is larger than $SR_{j,t+L1}$, then the stock-price adjustment occurs partially within the interval $(t, t+L1)$ and partially within the interval $(t+L1, t+L2)$. If $SR_{j,t+L2}$ is smaller than $SR_{j,t+L1}$, then the stock-price adjustment within the interval $(t, t+L1)$ is partially reversed within the interval $(t+L1, t+L2)$. If there is a positive association between the proportional error and $(SR_{j,t+L2})$ but no association between the proportional error and $(SR_{j,t+L1})$, then the stock-price adjustment occurs completely within the interval $(t+L1, t+L2)$.

[24] See, for example, Manaster and Rendleman (1982), Bhattacharya (1987), and Stephan and Whaley (1990).

[25] Note that if s is the last interval of a trading day, then $R_{f,s}$ will contain the return over the period when the market is closed.

Because of the structure of the Berkeley database, if there is no option trade or quote for a given firm within a given 15-minute interval, then there is no stock price observation for that firm in that interval. For a given firm on a given trading day, the 15-minute stock return for an interval is treated as missing data if the interval occurs before the firm's first option record of the day. However, if an interval with no option records occurs after the firm's first option record of the day, we assume that the reason for no option activity is that no information reached either market within the interval. Hence, the corresponding 15-minute return is defined to be zero.

Also, when a number of successive option records are associated with identical stock prices, there is no way to distinguish between the case of a stock that did not trade and the case of a stock that traded several times without a change in the stock price. Both cases generate a 15-minute stock return equal to zero.

[26] We choose an equally weighted index to reflect better the performance of the average CBOE firm. A value weighted index would cause our analysis to be dominated by the larger firms.

$t = 0$, and L may equal 1, 2, 3, 4, 8, or 24),[27] is expressed by the following equation:

$$1 + HPR_{L,j,t} = \prod_{\tau=t}^{t+L-1} (1 + ER_{j,\tau}) \tag{6}$$

The analysis of the relationship between the proportional errors, $PE_{j,t}$, and the excess returns, $HPR_{L,j,t}$, is in three parts. In the following section, we examine the 240 trading intervals centred on each announcement, partitioning them into ten 'pseudo-days' of 24 intervals each. Then, we focus on the announcement day itself, examining the pre-announcement and post-announcement components in Section 8 and the individual intervals in Section 9.

In each part, we partition the available stocks into five equal-sized portfolios, based on the rank of their proportional errors. For clarity and brevity, the results presented below examine only the differences between returns to the highest ranked portfolio and the returns to the lowest ranked portfolio. However, an analysis of the differences among all five average portfolio returns is available from the authors. These results provide additional evidence of the option market leading the stock market.

Our experimental design tests the hypothesis that the option market leads the stock market against the alternative that the option market does not lead the stock market. This alternative would include both the case that the option markets lags the stock market and the case that the two markets are synchronous. We do not believe that conflicting prior evidence mandates testing for evidence of the stock market leading the option market.[28] We report one-tailed *t*-statistics[29] for positive return differences.[30]

7. THE PSEUDO-DAY ANALYSIS

If information arrival causes the option market to lead the stock market, then a positive association between announcement proportional errors and short-run stock returns should be evident near the announcement times. Therefore, if we form stock portfolios on the basis of proportional error ranks, we should expect portfolios based on high (low) proportional error announcements to exhibit high (low) subsequent average portfolio returns.

[27] For holding periods of fewer than 24 intervals, we do not use returns that include data from two successive trading days. For example, we would delete a 30-minute return that included the last 15 minutes of the day s and the first 15 minutes of the day $s + 1$. Such returns are not comparable to the majority of returns that contain only data from one trading day.

[28] While Stephan and Whaley (1990) found evidence of a leading stock market, Chan *et al.* (1993) showed that this result probably is an artifact of using transaction prices rather than the midpoint of the bid/ask spread.

[29] Obviously, some of the *t*-statistics reported below are not independent.

[30] A negative return difference is not evidence that stock prices lead option prices. Rather, a negative return difference implies that the stock price moves opposite to the direction predicted by the proportional error. Since there is no reason to believe that this is true, the one-tailed test is appropriate.

We expect evidence of a lead/lag relationship to be stronger near the announcement time. Accordingly, for each announcement, we partition 240 fifteen-minute intervals (the 120 intervals immediately preceding the announcement interval plus the 120 intervals following the announcement interval) into 10 six-hour segments. We chose six-hour segments to match the length of the trading day. For an announcement made while the markets are closed, each six-hour segment will represent a calendar six-hour trading day. On the other hand, for an announcement made while the markets are open, each six-hour segment will include data from two sequential trading days. To recognize that these six-hour segments represent the same length of trading time as a trading day, but do not necessarily correspond to a calendar trading day, we call them 'pseudo-days'. We denote each pseudo-day by the symbol d, which takes integer values from -5 to $+5$, excluding zero.[31]

In order to calculate the relevant average portfolio returns, we first rank the 60 stocks by their $PE_{j,t}$ in each interval. Without loss of generality, we re-label, putting j equal to 1, for the highest ranked stock, through j equal to 60, for the lowest ranked stock. Then, we partition the 60 stocks into five equal-sized portfolios. We assign the twelve highest ranked stocks to portfolio $p = 1$, and so forth. For each portfolio, p, we average the returns for the stocks within the portfolio in order to define the portfolio return with holding period of length L, in interval t, $PR_{L,p,t}$, as follows:

$$PR_{L,p,t} = (1/12) \sum_{k=12p-11}^{12p} HPR_{L,k,t} \qquad p = 1,.,5 \tag{7}$$

Similarly, we now average the returns for the intervals within a pseudo-day in order to define the average portfolio return of length L, for portfolio p, and pseudo-day d, $APR_{L,p,d}$, to be:

$$APR_{L,p,d} = (L/24) \sum_{k=0}^{k'} PR_{L,p,d'+kL} \tag{8}$$

where $k' = (24/L) - 1$ and d' is the first interval within pseudo-day d.[32]

When the option market leads the stock market, returns on the portfolio of stocks with the highest proportional errors should be higher than returns on that with the lowest proportional errors. Further, options are particularly

[31] In general, a given pseudo-day, d, contains data from intervals numbered $t = 24d\text{-}u$ to $t = 24d\text{-}u + 23$, with $u = 23$ when $d > 0$ and $u = 0$ when $d < 0$. For example, for an announcement at 12:05 p.m. on Friday, the thirteenth, the pseudo-day $d = -1$ corresponds to the 24 trading intervals between noon on Thursday, the twelfth, and noon on that Friday, while the pseudo-day $d = -5$ corresponds to the trading intervals between noon on Friday, the sixth, and noon on Monday, the ninth. Similarly, the pseudo-day $d = 1$ corresponds to the trading intervals between 12:15 p.m. on Friday, the thirteenth, and 12:15 p.m. on Monday, the sixteenth, while the pseudo-day $d = 5$ corresponds to the trading intervals between 12:15 p.m. on Thursday, the nineteenth, and 12:15 p.m. on Monday, the twentieth.

[32] We define $d' = 24d\text{-}23$ when $d < 0$ and $d' = 24d$ when $d > 0$. Also, the averaging process omits overlapping data. Thus, when $L = 24$, there can be no averaging and $APR_{24,p,d} = PR_{24,p,d'}$.

Table 1. Differences in average portfolio returns by pseudo-day for all SAR announcements[a]

	Number of 15-minute intervals in holding period					
Pseudo-day	*1*	*2*	*3*	*4*	*8*	*24*
−5	8.7**	3.7	10.6	13.5	−13.4	35.3
	(1.75,46)	(0.44,22)	(0.74,14)	(0.71,10)	(−0.32,4)	(0.28,13)
−4	11.5***	14.3**	13.1	31.8***	29.0	−18.8
	(3.10,46)	(2.14,22)	(1.00,14)	(2.93,10)	(1.35,4)	(−0.41,14)
−3	14.1***	17.4**	17.6	44.1**	55.9	103.2
	(3.93,46)	(2.22,22)	(1.19,14)	(2.19,10)	(1.21,4)	(0.69,14)
−2	18.6***	14.6*	38.9**	32.2**	−99.0	165.6*
	(3.56,46)	(1.37,22)	(2.63,14)	(2.14,10)	(−0.93,4)	(1.65,15)
−1	27.0***	27.4***	51.1**	52.9*	125.0*	330.0*
	(3.16,46)	(2.77,22)	(2.10,14)	(1.76,10)	(1.62,4)	(1.44,11)
1	2.4	12.3	6.3	38.5*	23.5	−82.8
	(0.45,46)	(1.11,22)	(0.33,14)	(1.72,10)	(0.38,4)	(−0.57,13)
2	6.2	6.5	−4.5	20.3	−11.3	−11.2
	(1.24,46)	(0.61,22)	(−0.41,14)	(0.89,10)	(−0.38,4)	(−0.13,16)
3	2.6	4.9	4.0	−13.0	−18.5	9.6
	(0.60,46)	(0.70,22)	(0.39,14)	(−0.93,10)	(−0.70,4)	(0.11,16)
4	2.1	17.9**	2.3	8.0	33.0*	67.3
	(0.72,46)	(2.47,22)	(0.14,14)	(0.62,10)	(1.58,4)	(0.83,13)
5	5.7	19.8***	27.7**	15.3	17.3	−46.6
	(1.27,46)	(2.73,22)	(1.80,14)	(0.77,10)	(0.84,4)	(−0.80,16)

[a] All returns are multiplied by 10 000.

*** Significant at the 1% level for one-tailed test.

** Significant at the 5% level for one-tailed test.

* Significant at the 10% level for one-tailed test.

Each main entry is the difference between the average return on the portfolio with the highest proportional errors and that for the portfolio with the lowest proportional errors. The *t*-statistics and the degrees of freedom are in parentheses. For holding periods of fewer than 24 intervals, the degrees of freedom are based on the number of nonoverlapping holding periods within the pseudo-day. For the 24-hour interval holding period, the degrees of freedom are based on the number of stocks in the two portfolios.

attractive when investors wish to establish short-positions.[33] Thus, one might expect evidence of a lead/lag relationship to be stronger when the content of the announcement is negative. On the other hand, investors who wish to establish short-positions may prefer to trade puts, rather than calls. In that case, one might expect these call option data to provide weaker evidence of a lead/lag relationship when the content of the announcement is negative.

Accordingly, we examine $APR_{L,1,d} - APR_{L,5,d}$, the difference between the returns on the two portfolios, splitting the total SAR announcements (Table 1) between

[33] For example, on the New York Stock Exchange, an investor can short-sell a stock only when the stock price is increasing (the uptick rule), but may establish a short position at anytime by writing a call or buying a put. Also, less capital may be required to establish a short position through the option market.

Table 2. Differences in average portfolio returns by pseudo-day for positive SAR announcements[a]

	Number of 15-minute intervals in holding period					
Pseudo-day	*1*	*2*	*3*	*4*	*8*	*24*
−5	10.1**	12.0*	27.9**	12.9	−6.2	−52.2
	(1.83,46)	(1.37,22)	(2.07,14)	(0.90,10)	(0.16,4)	(0.51,5)
−4	8.7*	5.1	5.3	17.5	−22.3	−4.7
	(1.37,46)	(0.39,22)	(0.31,14)	(0.88,10)	(0.74,4)	(0.12,5)
−3	16.4***	23.5***	29.5*	56.0**	37.1	232.7
	(3.75,46)	(3.03,22)	(1.66,14)	(2.65,10)	(1.11,4)	(1.34,8)
−2	8.6**	0.6	31.6*	20.9	−98.1	252.6
	(1.71,46)	(0.04,22)	(1.59,14)	(0.61,10)	(−0.90,4)	(1.20,5)
−1	25.0**	39.3**	68.5**	83.0**	189.4*	549.1
	(2.38,46)	(2.28,22)	(1.79,14)	(2.53,10)	(2.10,4)	(1.47,3)
1	4.4	10.9	−9.8	2.0	19.1	−123.4
	(0.64,46)	(1.04,22)	(−0.39,14)	(0.09,10)	(0.29,4)	(1.44,3)
2	3.5	−3.5	−8.2	10.0	−38.4	144.7
	(0.53,46)	(0.22,22)	(−0.41,14)	(0.36,10)	(−0.88,4)	(1.08,7)
3	−4.6	−8.7	−14.7	−22.8	−60.2	−79.6
	(−0.87,46)	(−0.85,22)	(−0.87,14)	(−2.33,10)	(−1.65,4)	(−0.47,7)
4	−0.3	6.5	−6.7	16.3	27.3	60.1
	(−0.08,46)	(0.65,22)	(−0.43,14)	(0.92,10)	(0.74,4)	(0.75,6)
5	−0.9	14.0*	5.2	6.0	4.9	−59.7
	(−0.16,46)	(1.43,22)	(0.27,14)	(0.25,10)	(0.19,4)	(−1.30,8)

[a] All returns are multiplied by 10 000.

*** Significant at the 1% level for one-tailed test.

** Significant at the 5% level for one-tailed test.

* Significant at the 10% level for one-tailed test.

Each main entry is the difference between the average return on the portfolio with the highest proportional errors and that for the portfolio with the lowest proportional errors. The *t*-statistics and the degrees of freedom are in parentheses. For holding periods of fewer than 24 intervals, the degrees of freedom are based on the number of nonoverlapping holding periods within the pseudo-day. For the 24-hour interval holding period, the degrees of freedom are based on the number of stocks in the two portfolios.

those that deliver positive information (Table 2) and those that deliver negative information (Table 3).

Table 1 presents the pseudo-day analysis for all SAR announcements. Prior to the announcement, pseudo-days −4 through −1 suggest strongly that option prices lead stock prices by one hour. There is also some evidence of a 24-hour lead in pseudo-days −2 and −1. After the announcement, there is evidence of a lead of 30 to 45 minutes in pseudo-days 4 and 5.

Both the positive and negative SAR announcements (Tables 2 and 3) show evidence of leads of up to one hour in the pseudo-days that precede the announcement. For the positive SAR announcements, there is little evidence of longer leads or of leads in the pseudo-days that follow the announcement. In contrast, for the negative SAR announcements, there is evidence of 24-hour

Table 3. Differences in average portfolio returns by pseudo-day for negative SAR announcements[a]

	Number of 15-minute intervals in holding period					
Pseudo-day	*1*	*2*	*3*	*4*	*8*	*24*
−5	5.6	−8.0	9.2	2.9	−59.1	128.6
	(0.69,46)	(−0.46,22)	(0.38,14)	(0.07,10)	(−0.71,4)	(0.57,6)
−4	11.9**	16.8*	15.6	26.2*	80.3	−45.0
	(1.90,46)	(1.62,22)	(0.74,14)	(1.74,10)	(1.60,3)	(−0.52,7)
−3	10.4**	7.4	−7.2	11.8	−0.3	−187.7
	(1.89,46)	(0.70,22)	(−0.44,14)	(0.48,10)	(−0.00,4)	(−1.21,6)
−2	24.3***	17.6*	47.9**	40.3*	25.6	161.1**
	(2.58,46)	(1.51,22)	(2.01,14)	(1.80,10)	(0.45,3)	(1.86,8)
−1	25.8**	12.4	35.6*	6.6	−71.3	228.2**
	(2.35,46)	(0.95,22)	(1.63,14)	(0.28,10)	(−1.33,3)	(2.13,7)
1	4.0	14.8	8.6	55.9**	7.2	51.7
	(0.58,46)	(0.93,22)	(0.39,14)	(1.86,10)	(0.09,4)	(0.29,8)
2	6.2	4.4	−14.0	−17.4	8.4	−120.5
	(0.79,46)	(0.39,22)	(−0.76,14)	(−0.59,9)	(0.27,3)	(−1.05,7)
3	9.8**	28.1***	17.9	1.7	38.8	112.9
	(1.79,46)	(3.41,22)	(1.30,14)	(0.06,10)	(1.04,4)	(1.67,7)
4	6.6*	27.1**	20.2	3.2	64.6	−51.9
	(1.46,46)	(1.99,22)	(0.76,14)	(0.13,10)	(1.47,3)	(0.38,6)
5	9.2*	29.0**	37.7*	33.8*	−6.0	−50.8
	(1.31,46)	(2.13,22)	(1.68,14)	(1.46,10)	(−0.12,4)	(−0.45,6)

[a] All returns are multiplied by 10 000.

*** Significant at the 1% level for one-tailed test.

** Significant at the 5% level for one-tailed test.

* Significant at the 10% level for one-tailed test.

Each main entry is the difference between the average return on the portfolio with the highest proportional errors and that for the portfolio with the lowest proportional errors. The *t*-statistics and the degrees of freedom are in parentheses. For holding periods of fewer than 24 intervals, the degrees of freedom are based on the number of nonoverlapping holding periods within the pseudo-day. For the 24-hour interval holding period, the degrees of freedom are based on the number of stocks in the two portfolios.

leads in pseudo-days −2 and −1.[34] Further, there are leads as long as one hour among the post-announcement pseudo-days.

The preponderance of significant positive *t*-statistics in Tables 1–3 strongly suggests that option prices lead the price of their underlying stock by at least 15 minutes over the entire pre-announcement period. Evidence of this lead holds irrespectively of the information content measure or the sign of the announcement.

[34] It may be that with a 24-hour lead, traders are reluctant to act on positive information by opening a position that must remain open overnight, but they are willing to act on negative information by closing a position.

8. ANALYSIS OF ANNOUNCEMENT-DAY COMPONENTS

If the option market and the stock market are synchronous throughout the pre-announcement and post-announcement components of the trading day, then the corresponding average return differences should not be significantly different from zero. In this section, we analyse the individual components of the announcement day, employing the same procedures as in the pseudo-day analysis, with two modifications.

First, we use only data from trading days on which an announcement is made while both markets are open. Depending on the time of the announcement, the interval numbers for a given announcement day will take on 23 consecutive values in the range from $t=-23$ to $t=+23$.[35]

Second, for every portfolio and holding period, we construct an 'announcement-day average portfolio return' for each of the two components of the announcement day by averaging the portfolio returns for the intervals within the component of the announcement day. The announcement-day average portfolio return, for a given component of the announcement day, $ADAPR_{L,p,q}$ ($q=0$, for the pre-announcement component and $q=1$ for the post-announcement component), is defined as:

$$ADAPR_{L,p,q} = (L/24) \sum_{k=0}^{k'} PR_{L,p,q1+kL} \tag{9}$$

where $k'=22$ if $L=1$ and $k'=(24/L)-1$ otherwise. Further, we set $q1=-23$ for the pre-announcement component and $q1=1$ for the post-announcement component.[36]

As in the pseudo-day analysis, we examine the differences between the returns on the two portfolios, $ADAPR_{L,1,q}, -ADAPR_{L,5,q}$, splitting the total SAR announcements (Table 4, Panel A) between those that deliver positive information (Table 4, Panel B) and those that deliver negative information (Table 4, Panel C).

In Table 4, Panel A, there is a clear progression in the significant positive return differences in the pre-announcement component. This is strong evidence to suggest that the option market is 'front-running' the stock market by at least one hour. However, after the announcement, there are no significant return differences. Therefore, the two markets become synchronous within fifteen minutes of the announcement.

This pattern is repeated for the positive SAR announcements in Table 4, Panel B, but the negative SAR announcements in Table 4, Panel C show no significant return differences, either before or after the announcement. This suggests that this front-running with call options may be a phenomenon of the positive announcements.

[35] For example, for announcements made in the last interval of the trading day, we use intervals from $t=-23$ to $t=-1$, and for announcements made in the first interval of the trading day, we use intervals from $t=+1$ to $t=+23$. There are no announcement-day returns for the 24-interval holding period because they cannot be calculated using only announcement-day prices.

[36] Note that, as in equation (8), the averaging process omits overlapping holding periods.

Table 4. Differences in average portfolio returns by component of the announcement day[a]

Panel A: All SAR announcements					
	Number of 15-min intervals in holding period				
	One	*Two*	*Three*	*Four*	*Eight*
Component of announcement day					
Pre-announcement	37.0**	51.6**	88.5**	109.6*	223.7
	(1.87,36)	(1.87,16)	(1.87,10)	(1.74,6)	(1.69,2)
Post-announcement	7.0	16.2	6.7	29.8	−24.5
	(0.78,38)	(0.97,18)	(0.42,10)	(0.85,7)	(−0.42,2)
Panel B: Positive SAR announcements					
	Number of 15-min intervals in holding period				
	One	*Two*	*Three*	*Four*	*Eight*
Component of announcement day					
Pre-announcement	30.1*	35.1	131.0*	116.8**	218.5
	(1.30,34)	(1.24,16)	(1.69,10)	(2.01,6)	(1.66,2)
Post-announcement	7.8	11.0	2.8	26.5	−13.6
	(0.50,29)	(0.53,12)	(0.07,8)	(0.59,5)	(−0.13,1)
Panel C: Negative SAR announcements					
	Number of 15-min intervals in holding period				
	One	*Two*	*Three*	*Four*	*Eight*
Component of announcement day					
Pre-announcement	31.7	56.9	58.9	−7.6	2.9
	(1.12,34)	(0.92,16)	(0.62,10)	(−0.29,6)	(0.07,2)
Post-announcement	8.9	−9.7	31.5	−3.0	−28.5
	(0.53,34)	(−0.59,16)	(0.54,9)	(−0.06,7)	(−0.27,2)

[a] All returns are multiplied by 10 000.

*** Significant at the 1% level for one-tailed test.

** Significant at the 5% level for one-tailed test.

* Significant at the 10% level for one-tailed test.

Each main entry is the difference between the average return for the portfolio with highest proportional errors and that for the portfolio with lowest proportional errors. Parentheses contain the *t*-statistics and the degrees of freedom, which are based on the number of nonoverlapping holding periods within the component of the announcement day. Intervals without return reduce the degrees of freedom.

We interpret the above analysis as strong evidence that, when significant positive news is about to be released, the option market leads the stock market by up to one hour.

9. ANALYSIS OF INDIVIDUAL INTERVALS

Averaging across time may obscure extremely short-lived lead/lag relationships between markets. Accordingly, in this section we test for such relationships by examining portfolio returns for individual intervals, $PR_{L,p,t}$. Only intervals within

Table 5. Differences in portfolio returns for individual announcement-day intervals for all SAR announcements[a]

Portfolio information interval	*Number of 15-min intervals in holding period*				
	One	*Two*	*Three*	*Four*	*Eight*
−4	−24.8	4.0	17.9	233.6*	55.7
	(−0.79,8)	(0.07,8)	(0.22,8)	(1.62,8)	(0.31,5)
−3	27.8	64.4	209.0**	59.2	69.4
	(0.72,8)	(1.22,8)	(2.27,8)	(1.10,6)	(0.69,5)
−2	26.8	135.3*	144.9**	168.5**	192.6*
	(0.37,8)	(1.47,8)	(2.20,7)	(2.18,8)	(1.60,6)
−1	236.6**	268.3***	278.7***	274.0***	197.0*
	(2.62,10)	(2.98,9)	(3.30,9)	(3.27,9)	(1.65,9)
1	−12.8	35.5	−47.7	13.6	−78.6
	(−0.47,10)	(1.22,10)	(−0.57,10)	(0.28,9)	(−1.15,7)
2	−3.7	−283.4	−20.3	−22.8	37.3
	(−0.18,10)	(−0.59,10)	(−0.42,10)	(−0.36,9)	(−0.45,8)
3	−92.3	−18.4	−13.0	−4.8	−50.7
	(−1.29,10)	(−0.48,9)	(−0.24,8)	(−0.08,7)	(−0.41,5)
4	12.7	33.7	6.4	25.2	62.2
	(0.19,9)	(0.48,9)	(0.08,7)	(0.40,7)	(0.37,4)

[a] All returns are multiplied by 10 000.

*** Significant at the 1% level for one-tailed test.

** Significant at the 5% level for one-tailed test.

* Significant at the 10% level for one-tailed test.

Each main entry is the difference between the average return for the portfolio with highest proportional errors and that for the portfolio with lowest proportional errors. Parentheses contain the *t*-statistics and the degrees of freedom, which are based on the number of stocks in each portfolio.

one hour of the announcement, i.e. intervals −4 to −1 and 1 to 4, provide sufficient data for individual analyses.

For each of the eight intervals and each holding period, Tables 5, 6 and 7 present, $PR_{L,1,t} - PR_{L,5,t}$, the difference between the return on the portfolio with the highest proportional errors and that on the portfolio with the lowest ones.

Table 5 shows that for portfolios formed at the end of interval −1, immediately preceding the announcement, the return differences are significantly positive, regardless of the length of the holding period. This strongly suggests that, for all SAR announcements, option prices adjust to the earnings announcement at least 15 minutes before the stock price adjusts.

The approximate equality of these return differences suggests that the observed stock prices complete their movement towards the implied ones within 15 minutes, and that the return within the first 15 minutes is strong enough to dominate holding periods of up to two hours.[37] This movement is consistent with the stock price fully adjusting to the announcement within the

[37] The first 15 minutes of each of these holding periods is the announcement interval itself.

Table 6. Differences in portfolio returns for individual announcement-day intervals for positive SAR announcements[a]

Portfolio information interval	*Number of 15-min intervals in holding period*				
	One	*Two*	*Three*	*Four*	*Eight*
−4	−17.1	−22.6	−26.9	205.7*	107.5
	(−0.33,4)	(−0.38,4)	(−0.44,4)	(1.80,4)	(0.97,3)
−3	29.7	77.5	298.2**	187.6**	214.6
	(0.50,4)	(0.86,4)	(2.33,4)	(3.01,2)	(1.11,2)
−2	−5.7	164.5	116.9	144.0	157.7
	(−0.11,4)	(1.23,4)	(1.38,3)	(1.22,3)	(0.76,2)
−1	237.2**	271.3***	315.5***	308.8***	285.3*
	(2.20,4)	(5.01,3)	(4.67,3)	(4.62,3)	(2.26,3)
1	39.4	45.1	−124.0	−7.8	−43.7
	(1.42,4)	(1.51,3)	(−0.78,4)	(−0.09,3)	(−0.38,3)
2	14.8	−33.2	21.5	60.5	23.6
	(0.74,4)	(−0.31,4)	(0.35,4)	(0.71,4)	(0.24,4)
3	−156.6	−20.7	−15.5	−18.5	−152.5
	(−1.07,4)	(−0.32,3)	(−0.19,3)	(−0.21,3)	(−2.23,1)
4	62.4	51.3	92.0	67.5	9.4
	(0.43,3)	(0.32,3)	(0.69,3)	(0.61,3)	(0.02,1)

[a] All returns are multiplied by 10 000.

*** Significant at the 1% level for one-tailed test.

** Significant at the 5% level for one-tailed test.

* Significant at the 10% level for one-tailed test.

Each main entry is the difference between the average return for the portfolio with highest proportional errors and that for the portfolio with lowest proportional errors. Parentheses contain the *t*-statistics and the degrees of freedom, which are based on the number of stocks in each portfolio.

interval in which it is made. This immediate and full adjustment is in agreement with the semi-strong form of the efficient market hypothesis.

When considered in conjunction with the evidence from interval −1, the significant *t*-statistics for intervals −2 to −4 suggest that part of the option-price adjustment occurs as much as one hour earlier. After the announcement, there are no significant return differences, which is consistent with the hypothesis that cross-market efficiency is restored.

The positive SAR announcements (Table 6) display a pattern of significant return differences that is similar to that for all SAR announcements. However, for the negative SAR announcements (Table 7), there are significantly positive return differences for portfolios formed in interval −2 and none for interval −1. This suggests that stock prices adjust to these negative earnings announcements 15 minutes before the information appears on the Dow Jones News Wire.

The above analysis leads us to conclude that significant negative information may be leaked before the announcement. Moreover, this leaked information is acted upon through the option market. The two markets, however, become synchronous very soon after the announcement.

Table 7. Differences in portfolio returns for individual announcement-day intervals for negative SAR announcements[a]

Portfolio information interval	*Number of 15-min intervals in holding period*				
	One	*Two*	*Three*	*Four*	*Eight*
−4	24.8	−35.2	14.4	32.9	−34.8
	(0.50,2)	(−0.47,2)	(0.31,2)	(0.55,2)	(−0.00,1)
−3	−79.4	−75.9	30.6	−230.1	−94.1
	(−1.23,2)	(−1.00,2)	(0.38,2)	(−0.96,1)	(−0.59,1)
−2	335.9**	404.4**	385.0**	380.4**	206.7
	(6.40,2)	(3.27,2)	(3.23,2)	(3.14,2)	(1.70,2)
−1	−39.1	33.0	65.8	72.7	−127.8
	(−0.72,4)	(0.57,4)	(0.82,4)	(1.53,4)	(−0.90,1)
1	−21.1	−11.6	−20.8	−41.0	−115.1
	(−0.53,4)	(−0.37,4)	(−0.32,4)	(−0.62,3)	(−1.16,2)
2	−33.1	63.8**	37.9	−28.2	−67.4
	(−1.49,2)	(3.65,2)	(1.45,2)	(−0.79,1)	(−3.39,1)
3	−73.3	−28.3	−115.3	−72.4	−63.7
	(−1.76,4)	(−0.51,4)	(−5.01,2)	(−2.66,2)	(−0.79,1)
4	34.8	−36.9	−41.0	−14.2	−38.6
	(0.57,3)	(−0.65,3)	(−0.85,2)	(−0.29,1)	(−1.57,1)

[a] All returns are multiplied by 10 000.

*** Significant at the 1% level for one-tailed test.

** Significant at the 5% level for one-tailed test.

* Significant at the 10% level for one-tailed test.

Each main entry is the difference between the average return for the portfolio with highest proportional errors and that for the portfolio with lowest proportional errors. Parentheses contain the *t*-statistics and the degrees of freedom, which are based on the number of stocks in each portfolio.

10. SUMMARY AND CONCLUSIONS

Regardless of the information content measure used and its sign, the results presented in this paper strongly support the hypothesis that a firm's option prices can lead its stock price. We find that before significant unanticipated information is announced, the option market leads the stock market by at least 15 minutes and, possibly, by as much as one hour. There is also evidence that the option market may lead the stock market, in the post-announcement period, under certain circumstances.

By far the most intriguing results of this study relate to the announcement-day analysis. The SAR announcements show strong evidence of option prices leading their underlying stock. On average, for the component preceding the SAR announcements, the option market leads the stock market by about one hour. Separating the positive and negative SAR announcements indicates strongly that the leaking of positive information is the source of this effect. The results cannot be attributed to investors hedging their stock positions before an anticipated information release. The appropriate call option hedge for a long position in the stock is call writing. Since most stock positions are long, the

postulated hedging activity would tend to depress the price of calls before an anticipated information release. Thus, the hedging explanation would lead us to expect evidence of the option market leading the stock market before negative announcements, not before positive announcements.

Our test procedure has some potential biases. For example, the 15-minute interval length may be too long to insure that the option trades are synchronous. On the other hand, stock returns calculated for this short interval may be affected by the negative serial correlation induced by the bid/ask spread[38] and not accounting for the bid/ask bounce may affect the results.[39] Moreover, the assumption that volatility remains constant throughout the trading may distort the implied stock prices. Likewise, the assumption of a common volatility for options of various maturities ignores the effects of the term structure of volatility. However, the significant results are concentrated before the announcement. It is difficult to attribute this pattern of results to biases, because any such effect should be equally present both before and after the announcement.

We do not believe that these results can be attributed to missing data problems. Missing data were not a severe problem either before or after the announcement. In particular, there were no missing data in the announcement-day analysis, which produced the most striking results.

It may be useful to distinguish between leads of 15 minutes and leads longer than 15 minutes. Faster execution of option trades can account for the option market leading the stock market by 15 minutes, even when there is no evidence that private information is available to option traders. Longer leads can be attributed to the option market attracting investors with superior skill in evaluating public information.

The evidence from the individual 15-minute intervals that precede the announcements, however, suggests that the observed stock price clearly reacts during the presumed announcement interval, while the option prices lead this adjustment by about one hour. From this, we conjecture that, during the four months of 1979 covered by this study, investors were trading options on private information approximately one hour before the public announcement. The alternative explanation, that the actual public announcement consistently precedes the presumed announcement interval by one hour, seems unlikely.

The general phenomenon of the option market leading the stock market, over the entire five days before the announcement, shows that price discrepancies may persist for a substantial time period. This cross-market inefficiency could

[38] Ideally, we would use a stock price that was equal to the midpoint of the stock's bid and asked prices. Unfortunately, only transaction stock prices were available. The alternative of using a moving average process to purge the effects of the bid asked spread is inappropriate in this analysis because the timing of the prices is extremely important.

As an anonymous referee pointed out, the correlation between the proportional error and subsequent returns could be induced by a combination of both higher than normal spreads in the stock prices in the portfolio formation interval and the use of stale stock prices. Lacking bid/ask data for the stock prices, we can neither confirm no refute the referee's belief that the stocks in the data set have higher spreads preceding earnings announcements. However, as explained above, we are very sure that we are not using stale stock prices.

[39] See Vijh (1988) for a detailed discussion.

invalidate empirical research and undermine trading strategies based upon implied parameters. Moreover, these leading option prices cannot reflect the contemporaneously observed stock price. Rather, they must reflect the option market's own assessment of stock value.

Finally, in general, our information content measures cannot be used to develop profitable trading strategies. SAR cannot be calculated until the announcement is made. Therefore, only in the case of negative SAR announcements, where the lead/lag relationship extends beyond the announcement, could a potentially profitable trading strategy be based on these measures. However, we believe that it would be possible to exploit these pre-announcement arbitrage opportunities by developing other measures that rely only on pre-announcement data.

ACKNOWLEDGEMENTS

This paper is adapted from Paula L. Varson's PhD dissertation, which was submitted to the University of North Carolina at Chapel Hill under the name Paula Varson Snelling. She wishes to thank the members of her committee, Steve Allen, Bob Conroy, Richard McEnally, Dick Rendleman, Fritz Russ, and Bob Whaley. Also, we are indebted to James Day for providing information about the institutional details of option market and stock market trading. Particular thanks are also due to Richard Brealey, Greg Connor, Julian Franks, and Stewart Hodges for their valuable comments. Very special thanks are due to Ben Steil for insightful discussions on the development of institutional influences on financial markets.

An earlier version of this paper was awarded an 'Inquire 1993' prize.

REFERENCES

Anthony, J.H. (1988), The interrelation of stock and options market trading-volume data, *J. Finance*, **43**, 949–964.

Bhattacharya, M. (1987), Price changes of related securities: the case of call options and stocks, *J. Financial and Quantitative Analysis*, **22**, 1–15.

Boyle, P.P., and Park, H.Y. (1994), Implied volatility in option prices and the lead–lag relation between stock and option prices. OFOR Paper Number 94–01, Office for Futures and Options Research, University of Illinois at Urbana-Champaign.

Chan, K., Chung, Y.P. and Johnson, H. (1993), Why option prices lag stock prices: a trading-based explanation, *J. Finance*, **48**, 1957–1967.

Chicago Board of Trade (1991), *CBOT Financial Instruments Guide*, Chicago, Il: Chicago Board of Trade.

Foster, G., Olsen, C. and Shevlin, T. (1984), Earnings releases, anomalies, and the behavior of security returns, *Accounting Review*, **59**, 574–603.

Geske, R. (1979), A note on an analytical valuation formula for unprotected American call options on stock with known dividends, *J. Financial Economics*, **7**, 375–380.

Jones, C.P., and Litzerberger, R.H. (1970), Quarterly earnings-reports and intermediate stock price trends, *J. Finance*, **25**, 143–148.

Joy, O.M., Litzenberger, R.H. and McEnally, R. (1977), The adjustment of stock prices to announcement of unanticipated changes in quarterly earnings, *J. Accounting Research*, **15**, 207–225.

Latané, H.A. and Jones, C.P. (1977), Standardized unexpected earnings – a progress report, *J. Finance*, **32**, 1457–1465.

Latané, H.A. and Jones, C.P. (1979), Standardized unexpected earnings – 1971–1977, *J. Finance*, **31**, 717–724.

Manastér, S., and Rendleman, R.J., Jr. (1982), Option prices as predictors of equilibrium stock prices, *J Finance*, **37**, 1043–1057.

Oellermann, C.M. and Farris, P.L. (1985), Futures or cash: which market leads live beef cattle prices? *J. Futures Markets*, **5**, 529–538.

Peterson, D.R. and Tucker, A.L. (1988), Implied spot rates as predictors of currency returns: a note, *J. Finance*, **43**, 247–258.

Phillips, S.M. and Smith, C.W., Jr. (1980), Trading costs for listed options: the implications for market efficiency, *J. Financial Economics*, **8**, 179–201.

Rendleman, R.J., Jr., Jones, C.P. and Latané, H.A. (1982), Empirical anomalies based on unexpected earnings and the importance of risk adjustment, *J. Financial Economics*, **10**, 269–287.

Selby, M.J.P. and Hodges, S.D. (1987), On the evaluation of compound options, *Management Science*, **33**, 347–355.

Snelling, P.V. (1987), Earnings surprises and the information content of option prices, Unpublished PhD dissertation, University of North Carolina at Chapel Hill.

Stephan, J.A., and Whaley, R.E. (1990), Intraday price changes and trading volume relations in the stock and stock option markets, *J. Finance*, **45**, 191–220.

Vijh, A.M. (1988), Potential biases from using only trade prices of related securities on different exchanges: a comment, *J. Finance*, **43**, 1049–1055.

Watts, R.L. (1978), Systematic 'abnormal' returns after quarterly earnings announcements, *J. Financial Economics*, **6**, 127–150.

Whaley, R.E. and Cheung, J.K. (1982), Anticipation of quarterly earnings announcements: a test of market efficiency, *J. Accounting and Economics*, **4**, 57–83.