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Stock price clustering on option expiration dates

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Abstract

This paper presents striking evidence that option trading changes the prices of underlying stocks. In particular, we show that on expiration dates the closing prices of stocks with listed options cluster at option strike prices. On each expiration date, the returns of optionable stocks are altered by an average of at least 16.5 basis points, which translates into aggregate market capitalization shifts on the order of $9 billion. We provide evidence that hedge rebalancing by option market makers and stock price manipulation by firm proprietary traders contribute to the clustering.

JEL classification: *G12; G13; G24*

Keywords: Stock price clustering; Option expiration; Hedging; Manipulation

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1. Introduction

Exchanged-based trading of options commenced in the United States in 1973 when the Securities and Exchange Commission (SEC) authorized the Chicago Board Options Exchange (CBOE) to undertake a pilot program to trade calls on 16 underlying common stocks (Securities and Exchange Commission, 1978, pp. 1–2.) In June 1977 the SEC first permitted the listing of puts, but only on an experimental basis (Whaley, 2003, p. 1134). Later in 1977, however, the SEC proposed a moratorium on new option introductions while it investigated exchange-listed option trading.[1] An important factor in the SEC's initial caution in allowing exchange-based trading of calls and puts and its subsequent moratorium on new option listings was a concern that underlying stock prices would be perturbed. Despite this longstanding concern, little evidence has emerged that option trading has much impact on underlying stock prices.

One set of studies examines option introductions to see whether option trading influences underlying stock prices.[2] Some of the earlier papers (Skinner, 1989; Conrad, 1989; Bansal, Pruitt, and Wei, 1989) indicate option introductions produce a decrease in the price volatility of underlying stocks. However, Lamoureux and Panikkath (1994), Freund, McCann, and Webb (1994), and Bollen (1998) provide evidence that this effect is likely due to market-wide volatility changes, as similar changes occur in samples of matched control firms. Conrad (1989) and Detemple and Jorion (1990) investigate whether option introductions change the price levels of underlying stocks and find positive effects. Recent evidence, however, suggests that this result is not robust. Sorescu (2000) finds a positive price impact during Conrad's data period (i.e., prior to 1980), but a decrease in stock prices after 1980. Ho and Liu (1997) obtain similar results. Mayhew and Mihov (2004) find that, like the volatility effects, the apparent price level effects largely vanish when a comparison is made against an appropriate set of control firms.[3]

[1] By 1977 options were trading at several U.S. exchanges. These exchanges voluntarily complied with the proposed moratorium until the SEC signaled its approval to resume option introductions in 1980.
[2] There is also a large theoretical literature on how the introduction of derivatives might impact stock prices. The results of this literature are ambiguous in that different models, and sometimes the same model with different parameter values, imply different impacts. Mayhew (2000) provides a recent survey of this literature.
[3] Some of the option introduction studies also examine the impact on the trading volume or microstructure level characteristics of the underlying stock. Kumar, Sarin, and Shastri (1998) is an example of this type of research.

A smaller number of studies investigate stock price behavior around expiration dates.[4] An early CBOE (1976) report finds no evidence of abnormal price behavior in the two-week period leading up to option expirations. Klemkosky (1978) examines 14 option expiration dates in 1975 and 1976 and finds an average abnormal return of –1% in the week leading up to option expiration and +0.4% in the week following option expiration. The finding for the week leading up to expiration is more reliable.[5] Cinar and Vu (1987) also study the impact of impending option expiration on six underlying stocks over a longer six and one-half year period from January 1979 to June 1985. They find that the return from the Thursday to Friday of expiration week when compared to nonexpiration weeks is significantly positive for one stock, significantly negative for one stock, and insignificant for the other four stocks. Although a joint test of the returns for the six stocks is not performed, it would not be surprising if such a test failed to show a significant expiration week difference. None of the six stocks had volatilities from Thursday to Friday on expiration weeks that were significantly different from other Thursday-to-Friday time periods.

All in all, the literature relating to option introductions and expirations has not shown that equity option trading significantly impacts the prices of underlying stocks. The present paper, in contrast, provides striking evidence that option trading alters the distribution of underlying stock prices and returns. In particular, we show that over the 1996 to 2002 period, optionable stocks (i.e., stocks with listed options) cluster at option strike prices on expiration dates. There is no corresponding expiration date change in the distribution of the closing prices of nonoptionable stocks. Nor are optionable stocks more likely to close near a strike price on the Fridays before or

[4] There is a larger body of research on expiration effects for stock index options or futures (e.g., Stoll and Whaley, 1986, 1987, 1991, 1997; Edwards, 1988; Feinstein and Goetzmann, 1988; Herbst and Maberly, 1990; Hancock, 1991; Chen and Williams, 1994; Karolyi, 1996; Diz and Finucane, 1998; Bollen and Whaley, 1999; Alkebäck and Hagelin, 2002; Chow, Yung, and Zhang, 2003). Mayhew (2000; p. 32) surveys much of this literature, and concludes that "there is little evidence of a strong, systematic price effect around expiration." It may be the case that expiration effects for index derivatives have been more widely studied because (unlike stock options) they are cash-settled. Whaley (2003, Section 7.2) argues that cash-settled derivatives are more likely to have expiration effects in the prices of their underlying assets.

[5] The negative return in the week leading up to expiration is significant at the 5% level for seven of the fourteen expiration dates. The positive return in the week following option expiration is significant at the 5% level for only three of the fourteen expiration dates. Klemkosky (1978) does not examine volatility changes in the underlying stock around expirations. In a non-U.S. study, Pope and Yadav (1992) find similar, though smaller, return effects in the U.K.

after expiration Fridays. Hence, it appears that the increased likelihood that the stock prices close near option strike prices is indeed attributable to the expiration of the options written on them.[6]

Not surprisingly, the changes in expiration-Friday closing stock prices are associated with return differences on expiration relative to nonexpiration Fridays. On expiration Fridays, optionable stocks are more likely to experience returns that are small in absolute value and less likely to experience returns that are large in absolute value. This difference suggests that the expiration date clustering is produced primarily by cases in which Thursday stock prices that are close to option strike prices remain in the neighborhood of the strike rather than by cases in which Thursday stock prices that are distant from the strike price move to the neighborhood of the strike.

We derive an expression that provides a lower bound on the expiration date return deviations. Using this expression, we estimate that optionable stocks have their returns altered on average by at least 16.5 basis points (bps) per expiration date. In addition, we are able to determine that on a typical expiration date, at least 2% of optionable stocks have their returns altered. Since at any point during our data period there are roughly 2,500 optionable stocks, the 16.5 bps lower bound on average return impact implies that if all 2,500 optionable stocks are impacted the average deviation in returns is 16.5 bps, if half or 1,250 are impacted the average deviation is 16.5/0.5 = 33 bps, if 5% or 125 are impacted the average deviation is 16.5/0.05 = 330 bps, and if 2% or 50 are impacted the average deviation is 16.5/0.02 = 825 bps. Regardless of the percentage of optionable stocks that are impacted, our estimates imply that on average the return deviations shift market capitalizations of optionable stocks by at least $9.1 billion per expiration date.

The expiration day stock price deviations lead to wealth transfers in both the option and the stock markets. For example, there are wealth transfers in the option market insofar as investors who have purchased expiring options make exercise decisions based on expiration-Friday closing stock prices. The changed exercise decisions have welfare implications for both the option purchasers and the option writers whose probability of getting assigned varies with the exercise decisions.[7] There

[6] Krishnan and Nelken (2001) provide a related piece of evidence. They show that shares of Microsoft (which is an optionable stock) close near integer multiples of $5 more frequently on expiration Fridays than on other trade dates.
[7] It is possible, of course, that all option purchasers are aware of the clustering phenomenon and successfully account for it when making exercise decisions at option expiration. This possibility seems remote.

are also wealth transfers when nonexpiring options trade near expiration, because option prices vary with the prices of underlying stocks. In addition, transfers occur among stock market investors who do not participate in the option market but who happen to be trading optionable stocks near expiration.

Our results naturally raise the question of what produces the strike price clustering on option expiration dates. We investigate four potential explanations. Here we indicate their general nature, deferring to the body of the paper a more detailed discussion of the mechanism by which each might cause the clustering. The first is proposed by Avellaneda and Lipkin (2003), who develop a model in which stock trading undertaken to maintain delta hedges on existing net purchased option positions pushes stock prices toward strike prices as expiration approaches. The second is that the clustering is induced by delta hedging (with the underlying stock) particular types of changes in option positions on the day of expiration. The third potential explanation is that the clustering results from investors unwinding certain combined stock and option positions on expiration dates. A final possible explanation is that investors with written options intentionally manipulate the underlying stock price at expiration so that the options finish at-the-money (ATM) or just out-of-the-money (OTM) and consequently are not exercised.[8]

We investigate these potential explanations in several ways. First, we reexamine the strike price clustering around option expiration dates for subsamples of underlying stocks for which likely delta hedgers have net purchased or net written option positions. We find that when the likely delta hedgers have net purchased option positions, the clustering increases in the days leading up to expiration and spikes on the expiration date. On the other hand, when likely delta hedgers have net written option positions, the clustering decreases in the days leading up to option expiration, but still increases on the expiration date. These findings suggest that the clustering is produced by hedge

[8] A fifth potential explanation is that since strike prices are usually round numbers such as integer multiples of $5.00 or $2.50, our findings may be just another manifestation of the asset price clustering that is known to pervade financial markets (e.g., Harris, 1991). An earlier version of this paper includes an in-depth empirical investigation of this possibility and finds no evidence that it contributes to the expiration date clustering. Since it seems somewhat implausible that the explanation plays an important role—because it would require that investors switch to a coarser grid of transaction prices on expiration Friday and then switch back the following Monday—we omit the analysis of this explanation from the paper.

rebalancing combined with one or more of the other mechanisms, because hedge rebalancing predicts increasing (decreasing) clustering leading up to the expiration date when delta hedgers have net purchased (written) option positions, while the other mechanisms predict in both cases an increase in clustering on the expiration date. Second, we perform logistic regressions to determine which of the explanations' predictions about the increased likelihood of stock prices closing near strike prices on expiration dates are realized in the data. We find that the clustering is significantly elevated when the delta-hedge rebalancing and stock price manipulation explanations predict that it should be greater, but that the clustering does not increase as predicted by the delta hedging of new option positions or the unwinding of combined stock and option position explanations. Third, we examine the option writing in the week leading up to expiration of a group of investors who are natural candidates for manipulating stock prices. In accordance with the hypothesis that these investors manipulate stock prices, we find that the written option positions turn out to be quite profitable and that when calls (puts) are written, there is an elevated probability that on the expiration date the underlying stock price crosses below (above) the strike price so that the options finish OTM.

In summary, our investigation of these four explanations provides evidence that the hedge rebalancing described by Avellaneda and Lipkin (2003) and stock price manipulation by option writers both contribute to the clustering, while suggesting that the two other potential factors do not play an important role. These findings are interesting not only because they provide insight into the clustering phenomenon, but also because they indicate more generally that hedging and manipulation each impact underlying stock prices.

The remainder of this paper is organized as follows. The next section describes the data. Section 3 documents underlying stock price clustering at strike prices on option expiration dates. The fourth section presents four potential explanations for the clustering. Section 5 provides empirical evidence on these explanations. The sixth section concludes, and an appendix contains the proof of a technical result.

2. Data

The primary data used in this paper are the Ivy DB data from OptionMetrics LLC. This data set includes end-of-day bid and ask quotes, open interest, and daily trading volume on every call and put option on individual stocks traded at any U.S. exchange from January 4, 1996 through September 13, 2002. It also provides daily price, return, dividend, and split data on all stocks that trade on U.S. exchanges. For the paper's main tests we use the Ivy DB data to determine on each trade date the universes of optionable and nonoptionable stocks. We also use this data set to obtain daily closing stock prices, stock returns, and stock trading volumes.

The second data set that we use is obtained from the CBOE. These data include daily open interest and trading volume for each option that trades at the CBOE from the beginning of 1996 through the end of 2001. When a CBOE option also trades at other exchanges, the open interest data reflect outstanding contracts from all exchanges at which the option trades. The volume data, on the other hand, are only for transactions that actually occur at the CBOE. The open interest data are broken down into four categories defined by purchased and written open interest and two types of investors,[9] while the trading volume data are broken down into eight categories defined by four types of volume and two types of investors. The four volume types are volume from buy orders that open new purchased positions (open buy volume), volume from sell orders that open new written positions (open sell volume), volume from buy orders that close existing written positions (close buy volume), and volume from sell orders that close existing purchased positions (close sell volume).

The two investor types are public customers and firm proprietary traders. The Option Clearing Corporation (OCC) assigns one of three origin codes to each option transaction: *C* for public customers, *F* for firm proprietary traders, and *M* for market makers. The CBOE data include all non-market-maker open interest and volume broken down into public customer and firm proprietary trader categories according to the OCC classification.[10] Investors trading through Merrill

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[9] While aggregate purchased open interest must equal aggregate written open interest, this generally will not be true for each type of investor.

[10] The CBOE further subdivides the public customer category into customers of discount brokers, customers of full-service brokers, and other public customers. This further subdivision of the public customer category is not employed in any of the results reported in this paper, but is used in some untabulated robustness checks.

Lynch or E*trade are examples of public customers while an option trader at Goldman Sachs who trades for the bank's own account is an example of a firm proprietary trader.

Exchange-listed options expire at 10:59 pm Central Standard Time on the Saturday immediately following the third Friday of each month. The options do not trade between the close of the markets on Friday and the expiration on Saturday night, and we treat the third Friday of each month as the option expiration date. There are 80 option expiration dates during our data period that extends over the 80 months from January 1996 through August 2002. On a given trade date, a stock is considered optionable if it has at least one option listed on it and a strictly positive closing price in the Ivy DB database. From January 1996 through August 2002, there are 4,395 stocks that are optionable on at least one trade date, and there are a total of 184,449 optionable stock-expiration date pairs across the 80 option expiration dates. On a given trade date, a stock is considered nonoptionable if it has a strictly positive closing price but no options listed on it. There are 12,001 stocks that are nonoptionable on at least one expiration date during our data period from January 1996 through August 2002. Across the 80 expiration dates, there are a total of 417,007 nonoptionable stock-expiration date pairs.

Daily stock closing prices and numbers of shares outstanding from the Center for Research in Security Prices (CRSP) are used to compute market capitalizations of optionable stocks. CRSP daily stock returns are also used for a robustness check reported in a footnote.

3. Stock price clustering on option expiration dates

This section of the paper investigates stock price clustering on option expiration dates. In the first subsection, we show that optionable stocks are more likely to close at or near strike prices on expiration dates. The second subsection provides two pieces of evidence that the clustering is actually related to option expiration. First, we show that there is no expiration date clustering for the universe of nonoptionable stocks. Second, we show that the expiration date clustering appears when nonoptionable stocks become optionable and disappears when optionable stocks become nonoptionable. In the third subsection, we compare the closing price and return distributions of optionable stocks on expiration and nonexpiration Fridays. The final subsection estimates a lower bound on the magnitude of the expiration-Friday changes in the returns of optionable stocks.

3.1. Closing prices of optionable stocks

We begin our investigation by examining the probability that optionable stocks close near a strike price as a function of the number of trade dates before or after expiration. Panel A of Fig. 1 displays the percentage of optionable stocks that have a daily closing price within \$0.25 of a strike price (of one of its own options) for each of the 21 trade dates from ten trade dates before to ten trade dates after an option expiration Friday.[11] In the figure, trade date –10 is ten trade dates before the option expiration date (i.e., typically two Fridays before option expiration), trade date 0 is the option expiration Friday, and trade date 10 is ten trade dates after the option expiration Friday (i.e., typically two Fridays after option expiration.) Panel A shows that more than 19% of optionable stocks close within \$0.25 of a strike price on option expiration Fridays while less than 18% do so on the Fridays before and after expiration (i.e., on trade dates –5 and +5). It is clear from the plot that the percentage on trade date zero is well outside of the range of the percentages on the other (i.e., nonexpiration) trade dates. We test formally for a difference on trade date zero by computing a z-statistic for the null hypothesis that the percentage on the expiration Friday is drawn from the same population as the percentage on the nonexpiration dates. We estimate the mean and the standard deviation of this population by the sample mean and standard deviation from the 20 nonexpiration dates. The resulting z-statistic is a highly significant 8.15.[12] It is also worth noting that the percentages appear to be increasing in the week leading up to expiration (i.e., on trade dates –5 through –1). We return to this observation when we consider various explanations for the expiration date clustering.

[11] Here and for the remainder of the paper *within* \$*x* of a strike price means *less than or equal to* \$*x* from a strike price.

[12] A large part of the variability on the nonexpiration dates is attributable to the few days immediately prior to expiration. As discussed below, clustering on these dates appears to be due to one of the phenomena that explain clustering on the expiration date. Thus, this z-statistic (and the others reported below) understate the statistical significance of the results.

Panels B and C of Fig. 1 are constructed like Panel A except that they depict the percentage of optionable stocks that close, respectively, within \$0.125 of a strike price or exactly on a strike price. As expected, the percentages are lower in Panel B than Panel A and lower still in Panel C. The overall shapes of the three plots, however, are very similar. In all three cases, the percentages seem to be increasing in the week leading up to expiration and there is a pronounced spike on the expiration date. The percentage on trade date zero is different than the other dates with high significance in both Panels B and C. In particular, the *z*-statistics for Panels B and C are, respectively, close to nine and seven. For brevity, in the rest of the paper we focus on the case of stock prices closing within \$0.125 of a strike price. None of the conclusions are sensitive to this choice.

3.2. Is the clustering related to option expiration?

If the clustering that we document above is indeed related to the presence of expiring options, then it should not be observed for nonoptionable stocks. In addition, the clustering should materialize when stocks become optionable and vanish when they become nonoptionable. We next investigate these implications of the clustering being related to option expiration.

Obviously, nonoptionable stocks do not have associated strike prices.[13] As a result, in order to compare clustering of optionable and nonoptionable stocks, we investigate the extent to which these two universes of stocks congregate around integer multiples of \$5. We do this because exchanges introduce equity options in such a way that there are usually options with exercise prices at integer multiples of \$5 that lie near the current price of an underlying stock.[14] Consequently, if the closing price of an optionable stock is near an integer multiple of \$5, it is most likely near a strike

[13] Strictly speaking, nonoptionable stocks also do not have option expiration dates. We use the expiration date the stock would have if it were optionable—all U.S. exchange-traded equity options expire on the Saturday following the third Friday of the month.

[14] Exercise prices below \$20 include odd integer multiples of \$2.50. Occasionally exercise prices that are not integer multiples of \$2.50 also occur, typically when options are adjusted for stock splits or stock dividends. (The practice of regularly listing options with strike prices that are integer multiples of \$1 began after the end of our data period.) Not every integer multiple of \$5 is an option strike price because even though new option series are typically added when the underlying stock trades through the highest or lowest strike price available, this is generally not done when there would be only a short time remaining until expiration. Also, option strike prices greater than \$200 are at \$10 intervals.

price. Panel A of Fig. 2 displays percentages of optionable stocks that have a daily closing price within $0.125 of an integer multiple of $5, while Panel B displays these percentages for nonoptionable stocks. The plot for the optionable stocks has a conspicuous spike at the option expiration date while there is no expiration date increase for the nonoptionable stocks. Indeed, for the optionable stocks, the *z*-statistic for the expiration date percentage being different than the nonexpiration date percentages has a highly significant value of about nine, while for the nonoptionable stocks the expiration date percentage is right in the middle of the percentages from the nonexpiration dates. It is also interesting that while the main features of optionable stock clustering around integer multiples of $5 (i.e., Panel A of Fig. 2) are similar to those for clustering around strike prices (i.e., Panel B of Fig. 1), the clustering around integer multiples of $5 is somewhat less distinct. That is, the size of the expiration date spike is a bit smaller and the increase in clustering through the expiration week is not as clear. We attribute this to integer multiples of $5 being a somewhat noisy proxy for the prices about which optionable stocks actually are clustering, namely, option strike prices.

We next investigate whether there are changes in clustering when stocks become optionable or nonoptionable. In our sample, there are 2,628 stocks that first become optionable between February 1996 and August 2002. These stocks yield 47,134 observations on option expiration dates before they become optionable, and 81,170 observations on option expiration dates while they are optionable. Panel A of Fig. 3 reports the percentages of their prices that close within $0.125 of an integer multiple of $2.50 before the stocks become optionable.[15] The average percentage is around 11.0%, and there is not much variation as a function of the number of trade dates from the option expiration date. In particular, the percentage on the option expiration date is typical of all of the percentages that are observed. Panel B of Fig. 3 reports the percentage of closing stock prices within $0.125 of an integer multiple of $2.50 after the stocks become optionable. Once the stocks are optionable, the average percentage on nonexpiration dates increases from 11.0% to 11.5% and the

[15] We use integer multiples of $2.50 for Figs. 3 and 4 instead of the integer multiples of $5 used earlier, because the stocks that become nonoptionable during the sample period tend to have lower prices. Option strike prices below $20 are typically integer multiples of $2.50.

percentage on the expiration date jumps to 12.3%. The *z*-statistic for the difference between the expiration and nonexpiration dates is close to six.

In our sample, there are 1,079 optionable stocks that subsequently became nonoptionable. These stocks have 30,149 expiration date observations during the time they are optionable and 20,412 expiration date observations when they no longer have listed options. Panel A of Fig. 4 shows the percentages of these stocks that have closing prices within \$0.125 of an integer multiple of \$2.50 during the time period when they are optionable, while Panel B shows the percentages that have closing prices within \$0.125 of an integer multiple of \$2.50 after their options have been delisted. Because of the smaller sample size, these graphs display more variability than the previous ones. It is still the case, however, that when the stocks were optionable the percentage on the expiration date is greater than on any other trade date, with a *z*-statistic slightly above four. After the stocks were no longer optionable, the percentage on the option expiration date is well within the range of the percentages from the other trade dates.

3.3. Price and return distribution differences between expiration and nonexpiration Fridays

We have established that on expiration Fridays, optionable stocks are more likely to close near strike prices than on other dates.[16] The expiration-Friday change in the distribution of optionable stock prices farther away from the strike prices is also of interest. In order to abstract from any potential day-of-the-week effects, we compare the distribution of closing prices for optionable stocks on expiration Fridays to the distribution on the Fridays before and after expiration. The comparison is made by computing for optionable stocks the absolute difference (*AD*) between closing prices and nearest strike prices and sorting these absolute differences into 20 nonoverlapping adjacent intervals: $AD \leq \$0.125$, $\$0.125 < AD \leq \$0.25$, $\$0.25 < AD \leq \$0.375$, …, $\$2.375 < AD \leq \$10.00$.[17] We then compute the percentage of optionable stocks that close in each of the twenty intervals on expiration Fridays and the percentage of optionable stocks that close in each of the

[16] We also compute the percentage of closing stock prices near strike prices for each year from 1996 to 2002 and for each month from January to December. Optionable stocks are more likely to close near strike prices on option expiration dates in every year and every month.
[17] The small number of observations with $AD > \$10.00$ are omitted.

twenty intervals on the Fridays before and after expiration. Panel A of Fig. 5 plots for each of the twenty intervals the percentage from the expiration Fridays minus the percentage from the Fridays before and after expiration.

The plot has a large positive bar of about 1.3% in the first (i.e., $AD \leq \$0.125$) interval. This bar indicates that optionable stocks are about 1.3% more likely to close near a strike price on expiration Fridays than on the Fridays before or after expiration. Although this is already known from the previous figures, this bar underscores that the effect is not related to the fact that expirations occur on Fridays. By construction, the bars in the panel must sum to zero. It is interesting, however, that the large positive bar in the first interval is not offset by negative bars evenly distributed across the other nineteen intervals. Instead, the negative bars are concentrated around an absolute difference of about \$0.50 to \$1.00. Consequently, on expiration Fridays, more optionable stock prices close near a strike price and fewer close from \$0.50 to \$1.00 away from the nearest strike price. This fact is consistent with optionable stocks that would have otherwise closed between \$0.50 and \$1.00 from the nearest strike price on nonexpiration Fridays instead closing within \$0.125 of a strike price on expiration Fridays. However, this need not be the case. For example, the plot is equally consistent with some optionable stocks that would have closed between \$0.50 and \$1.00 from the nearest strike price instead closing about \$0.25 from the nearest strike price and an equal number that would have closed about \$0.25 from the nearest strike price instead closing within \$0.125 of a strike price.

We next examine the difference in returns of optionable stocks on expiration Fridays and the Fridays before and after expiration. We proceed by considering the twenty absolute return intervals, $0 \text{ bps} \leq |r| < 50 \text{ bps},\ 50 \text{ bps} \leq |r| < 100 \text{ bps}, \ldots,\ 950 \text{ bps} \leq |r| < 1{,}000 \text{ bps},$ and compute the percentage of optionable stocks with positive option volume that have absolute returns in each interval on expiration Fridays and on the Fridays before and after expiration. For each interval, Panel B of Fig. 5 plots the percentage of returns from the expiration Fridays minus the percentage from the Fridays before and after expiration.[18] All of the bars from 0 bps to 300 bps are positive while all of

[18] For both Panels in Fig. 5, the plots are similar if the nonexpiration Fridays are limited to only the Fridays before or only the Fridays after expiration.

those from 300 bps to 1,000 bps are negative.[19] This pattern indicates that on expiration Fridays optionable stocks are more likely to experience returns that are small in absolute value and less likely to experience returns that are large in absolute value, and suggests that the clustering is due more often than not to cases in which Thursday stock prices close to the strike are prevented from leaving the neighborhood of the strike rather than cases in which Thursday stock prices distant from the strike are pushed to the strike.[20] The 0 bps to 50 bps interval shows the greatest increase and the 350 bps to 500 bps intervals show the greatest decrease (although there is also a noticeable increase in the 50 bps to 100 bps interval and a noticeable decrease over the entire 300 bps to 750 bps range.) The plot is consistent with optionable stocks that would have had returns with absolute values of 350 bps to 500 bps on nonexpiration Fridays instead having returns with absolute values of less than 50 bps on expiration Fridays. As with Panel A, however, the plot in Panel B does not force this conclusion. It is also consistent, for example, with some optionable stocks that would have had absolute returns of 350 bps to 500 bps instead having returns of about 200 bps and an equal number of optionable stocks that would have had returns of about 200 bps instead having returns of fewer than 50 bps. It should also be noted that the figure does not entail that the effect arises solely from absolute returns shifting toward zero; all that is required is that the frequency with which absolute returns are decreased exceeds the frequency with which they are increased.

3.4. Implications of differences in expiration day returns

In order to understand more fully the expiration day alteration in the movement of optionable stock prices, we next develop an expression that provides a lower bound on the average deviation in the absolute returns of optionable stocks on expiration dates. Let $\hat{r}_i$ denote the return on the stock in the *i*-th optionable stock-expiration date pair on expiration Friday, and let r_i denote what the return would have been in the absence of the expiration day effect, i.e., let r_i denote the unaltered stock return. We are interested in the quantity $E\left|\hat{r}_i - r_i\right|$, which measures the average effect on returns. The following proposition, derived in the appendix, provides a lower bound for $E\,|\,\hat{r}_i - r_i\,|$.

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[19] As in the previous panel, the bars must sum to zero by construction.
[20] It should be borne in mind that if expiration Friday returns are altered by phenomena other than clustering, these alterations will also be reflected in the return distribution difference as well.

Proposition 1. *Define* $\hat{a}_i \equiv |\hat{r}_i|$ *and* $a_i \equiv |r_i|$. *Then*

$$E|\hat{r}_i - r_i| \geq |E(\hat{a}_i) - E(a_i)|. \tag{1}$$

The quantities $E(\hat{a}_i)$ and $E(a_i)$ can be interpreted as the average distances of $\hat{r}_i$ and r_i from zero, so the right-hand side of Eq. (1) can be interpreted as the change in the average distance. Interpreting the right-hand side this way, the proposition says that if the average distance from zero changes, then on average returns are shifted by at least the same amount. The right-hand side of Eq. (1) provides a lower bound on the average shift in returns rather than an estimate of it due to the existence of shifts in returns that do not affect the average distance from zero. For example, consider three returns $0 \leq x < y < z$. If one stock has its return shifted from *y* up to *z* and another stock has its return shifted from *z* down to *x*, the bound $|E(\hat{a}_i) - E(a_i)|$ only includes the net effect of a single shift from *y* down to *x*, and thus understates the alteration of returns on option expiration dates. The bound also underestimates $E|\hat{r}_i - r_i|$, because it does not account for cases in which a return *x* is shifted to *y* and another return *y* is shifted to *x* and for the greater change in return when a stock with return *y* ($\geq x > 0$) has its return shifted to $-x$ rather than to *x*. The bound provided by the right-hand side of Eq. (1) can be crudely estimated from Panel B of Fig. 5, and estimated accurately from a version of the figure that uses a smaller bin size. To see this, note that Panel B of Fig. 5 shows the differences in the probabilities of each of the bins. If one multiplies the differences in the probabilities by the midpoints of the bins and sums the products, the result is an estimate of the differences in average distances $E(\hat{a}_i) - E(a_i)$, but with an error stemming from the relatively large bin sizes. In order to develop a more accurate estimate, let $\hat{f}(\bullet)$ and $f(\bullet)$ be the density functions of, respectively, $\hat{a}_i$ and a_i. We can then rewrite the right-hand side of Eq. (1) as

$$|E(\hat{a}_i) - E(a_i)| = \left| \int_0^\infty \left[\hat{f}(u) - f(u) \right] u \, du \right| \tag{2}$$

and approximate it as

$$\left|E\left(\hat{a}_i\right)-E\left(a_i\right)\right| \approx \left|\sum_{b=1}^{B}\left[\hat{p}\left(b\right)-p\left(b\right)\right]a\left(b\right)\right|, \tag{3}$$

where $b=1,...,B$ indexes B absolute return intervals, $a\left(b\right)$ is the absolute return of interval *b*, and $\hat{p}\left(b\right)-p\left(b\right)$ is the difference in the probability that an optionable stock's absolute return will fall in interval *b* on expiration and nonexpiration Fridays.[21] The *B* absolute return intervals should be nonoverlapping and cover the range of absolute returns for which there is a nontrivial difference in the expiration and nonexpiration densities. In order to illustrate the components of the right-hand side of approximation (3), consider Panel B of Fig. 5. In this panel B is 20, $a\left(b\right)\in \left[(b-1)\times 50 \text{ bps}, b\times 50 \text{ bps}\right)$, and $\hat{p}\left(b\right)-p\left(b\right)$ is equal to the value of the *b*th bar. The quality of the approximation in expression (3) is governed by the width of the absolute return interval. In the limit, where the width of the intervals goes to zero, the approximation becomes exact (provided that the *B* intervals cover the range of absolute returns for which the expiration and nonexpiration densities are not identical.)

We estimate a lower bound for $E\left|\hat{r}_i-r_i\right|$ by computing the right-hand side of approximation (3) from optionable stocks with positive option volume. We set $B=1{,}000{,}000$ and use 0.01 bps absolute return intervals to cover the range from 0 bps up to 10,000 bps (i.e., up to 100%). For each of the 1,000,000 intervals, we set $a\left(b\right)$ to the average of the absolute returns that fall within the interval. The resulting lower bound for $E\left|\hat{r}_i-r_i\right|$ is 16.57 bps. This estimate is not sensitive to the choices we make when computing it. For example, if the bin width is changed from 0.01 bps to 1 bp, the lower bound is still 16.57 bps (i.e., there is no change to two-decimal-place accuracy.) If we keep the bin width at 0.01 bps but limit the absolute return intervals to the range 0 bps to 5,000 bps, then the lower bound decreases only from 16.57 bps to 15.88 bps.[22]

The 16.57 bps lower bound on $E\left|\hat{r}_i-r_i\right|$ implies that across optionable stocks the average expiration date alteration in absolute return is at least 16.57 bps. This lower bound suggests that the total impact is consequential regardless of the percentage of optionable stocks that are influenced on

[21] We estimate the probabilities $p(b)$ from the returns on optionable stocks on the Fridays before and after expiration.
[22] We also perform the lower bound calculations using CRSP rather than OptionMetrics returns. The results are very similar.

a typical expiration date. For example, if 10% of the optionable stocks (or about 250) have their returns altered, the average absolute return deviation of the impacted stocks is at least 165.7 bps. Return deviations of this magnitude are large, especially in light of the fact that option expirations occur twelve times per year.[23] Since the positive bars in Panel B of Fig. 5 sum to about 2%, we know that at least 2% of optionable stocks are influenced on a typical expiration date. We doubt that only 2% are impacted, because that would imply there are no cases in which a large absolute return is shifted to an intermediate absolute return and an intermediate absolute return is shifted to a small absolute return. If it nonetheless turns out that only 2% of optionable stocks (or about 50) have their returns altered, then the lower bound on the average absolute return deviation of the impacted stock is an enormous 828.5 bps. Although it also seems unlikely, it is possible that nearly all optionable stocks (or about 2,500) are impacted on each expiration date. In this case, the lower bound on the average absolute return deviation is 16.57 bps. This is still an impressive number, because during our data period optionable stocks comprised the great majority of U.S. stock market capitalization.

As is common with many financial market phenomena, the lower bound on the average absolute return effect varies with market capitalization. We document this variation by grouping the optionable stocks on each expiration date into deciles based on their market capitalizations, and then computing the lower bound for each decile separately. The estimates of the lower bounds ranged from 24.30 bps and 28.52 bps, respectively, for deciles one and two (the deciles with the smallest market capitalization stocks), to 13.63 bps and 6.70 bps for deciles nine and ten (the deciles with the largest market capitalization stocks). Note that this sort into size deciles is based on only the optionable stocks, and the market capitalizations of optionable stocks tend to be larger than those of nonoptionable stocks. For example, the median stocks in deciles one and two fall into the second and third deciles of NYSE market capitalizations, and the 13.63 bps and 6.70 bps lower bounds apply to some of the largest market capitalization stocks traded in the U.S.

We can also use the lower bounds on $E\left|\hat{r}_i - r_i\right|$ for the deciles to estimate the average expiration day impact on the market capitalization of optionable stocks. We do so by multiplying the

[23] That is, if 10% of optionable stocks are impacted on each expiration date, in expectation each optionable stock will be impacted every year.

lower bound and average market capitalization for each decile and then summing these products across the deciles. This procedure yields a lower bound on the impact on the market capitalization of optionable stocks of $9.1 billion per expiration date. Hence, it appears that each month at expiration there are large shifts in market capitalization associated with the changes in the returns of optionable stocks. Note that the $9.1 billion approximation for the lower bound is invariant to the percentage of optionable stocks that typically have their returns altered on expiration dates.

4. Potential sources of the clustering

This section of the paper describes four potential explanations for the expiration date strike price clustering of optionable stocks documented above. The next section provides empirical evidence on these explanations. The explanations are not mutually exclusive, so more than one may contribute to the clustering.

4.1. Rebalancing of delta hedges on existing option positions

Avellaneda and Lipkin (2003) propose a model in which expiration date stock price clustering at strike prices is produced by the delta-hedging activity of option market participants with existing net purchased option holdings. A delta-hedging option investor attempts to maintain a stock position that is opposite to the delta of his net option position. Consequently, as the deltas of his existing portfolio of options change, he trades in the underlying stock in order to keep his overall option and stock position close to delta neutral. Specifically, when the delta of his net option position increases (decreases), a delta hedger sells (buys) stock in order to remain delta neutral. If the elasticity of the underlying stock price with respect to selling and buying volume is nonzero (which Avellaneda and Lipkin assume), then the rebalancing of delta hedges will affect stock prices.

In order to understand how rebalancing by investors with net purchased option positions pushes stock prices toward strike prices as expiration approaches, recall that the Black-Scholes delta of a call option on a nondividend-paying stock is $N(d_1)$, where $N(\bullet)$ is the standard normal distribution function,

$$d_1 \equiv \frac{\ln(S/K) + (r + s^2/2)(T-t)}{s\sqrt{T-t}}, \tag{4}$$

S is the stock price, K is the strike price, r is the risk-free rate, s is the volatility of the underlying stock, T is the expiration date, and t is the current date. A straightforward application of put-call parity shows that the corresponding put delta is $N(d_1) - 1$. These formulas imply that the time derivatives of the call and put deltas are the same:

$$\frac{\partial N(d_1)}{\partial t} = \frac{\partial\left(N(d_1)-1\right)}{\partial t} = N'(d_1)\frac{1}{2s\,(T-t)^{3/2}}\left[\ln(S/K) - (r + s^2/2)(T-t)\right], \tag{5}$$

where $N'(\bullet)$ is the standard normal density function.

If we disregard the term $\left(r + s^2/2\right)(T-t)$, which is small relative to $\ln(S/K)$ as $t \to T$ provided $S \neq K$, the remaining component of the time derivative is greater than or less than zero depending on whether S is greater than or less than K. That is, denoting the time derivative of the option delta by $\partial\Delta/\partial t$, for both a put and a call as $t \to T$

$$\frac{\partial\Delta}{\partial t} \approx \frac{N'(d_1)}{2s\,(T-t)^{3/2}}\ln(S/K) > 0 \quad \text{if } S > K, \tag{6}$$

$$\frac{\partial\Delta}{\partial t} \approx \frac{N'(d_1)}{2s\,(T-t)^{3/2}}\ln(S/K) < 0 \quad \text{if } S < K. \tag{7}$$

This time derivative of the option Δ plays a key role in the analysis of Avellaneda and Lipkin (2003).

In particular, consider an agent who has purchased options on n shares of stock, and thus has a position with a delta of $n\Delta$. If the agent continuously rehedges the option position, then at each instant of time the stock position is $-n\Delta$ shares. The previous analysis implies that if $S > K$ as expiration approaches, then the time derivative $\partial\Delta/\partial t > 0$. The positive time derivative of Δ, in turn, implies that $\partial\left(-n\Delta\right)/\partial t < 0$, or, that as time passes the agent sells stock driving S down toward K.

On the other hand, if $S < K$, then $\partial(-n\Delta)/\partial t > 0$, which implies that as time passes the agent buys stock driving S up toward K. That is, the hedge rebalancing of an agent who has net purchased option positions tends to push the stock price toward the option strike price. A directly analogous argument, however, shows that a delta-hedging agent with a net written option position trades in the opposite direction, and thereby tends to push the stock prices away from a strike price. Thus, the Avellaneda and Lipkin (2003) model implies that stock prices should tend to cluster at option strike prices when delta-hedging option market participants have net purchased option positions and to decluster when they have net written option positions.

Avellaneda and Lipkin (2003) suppose that market makers are the heaviest delta hedgers in the option market and that they sometimes have net purchased option positions. Below we establish that although it is not unusual for market makers to have net written option positions, they most often have net purchased positions. Hence, the Avellaneda and Lipkin (2003) model of hedge rebalancing is capable of explaining stock price clustering at option strike prices. In our empirical analysis below, we also make use of the fact that the model predicts declustering at strike prices when likely delta hedgers have net written option positions.

4.2. Delta hedging of changes in option positions

Investors who delta hedge their net option positions will buy and sell the underlying stock not only to rebalance when the deltas of their existing options change as discussed above, but also to establish or remove hedges when they open or close option positions. This fact may lead to clustering through the following mechanism suggested in Anders (1982). Suppose that some nontrivial portion of non-delta-hedging (e.g., public) option investors do not like to exercise and take delivery of shares if their purchased call options expire in-the-money (ITM). These customers will then sell their ITM purchased calls in the days leading up to expiration. However, for those calls close to the money, it is not clear until expiration Friday whether they will expire ITM. For these calls, the non-delta-hedging investors wait until expiration Friday and sell if the stock price is above the strike price. When the non-delta-hedging option customers sell their calls, they are typically purchased by market makers who delta hedge the increase in their call position by selling stock. The stock sale tends to push the stock price down toward the strike price. Analogously, if non-delta-hedging investors do not like to deliver shares, then on expiration Fridays they will sell their purchased slightly ITM puts to market makers who will delta hedge the increase in their put position by buying stock. The stock buying will push the stock price upward toward the strike price.

In addition to the specific mechanism just described, there may be other option market practices that result in likely delta hedgers buying calls (or selling puts) when the stock price is slightly above the strike price on expiration Fridays or buying puts (or selling calls) when the stock price is slightly below the strike price on expiration Fridays. Consequently, below we test for a relation between clustering and these changes in the option positions of likely delta hedgers.

4.3. Stock trading by non-delta-hedging option investors

Investors who do not delta hedge still sometimes enter into stock positions in combination with option positions. If these investors unwind their combined positions on expiration Fridays, then their transactions in the underlying stock may contribute to the clustering.[24] Two common positions are covered calls, which are written call positions combined with long stock positions, and protective puts, which are purchased put positions combined with long stock positions. Investors may be more likely to unwind OTM covered calls or protective puts. The reason is that when the options finish ITM the stock can just be delivered to the counterparty upon assignment (in the case of a covered call) or exercised (in the case of a protective put.) If the options finish OTM, on the other hand, then the investor is left with a naked stock position over the weekend if he does not sell his long stock position on expiration Friday. Since the unwinding of covered calls and protective puts by non-delta hedgers both involve selling stock, it has the potential to push the stock price downward and thereby contribute to clustering when close to expiration the stock price is above the strike price. Consequently, in the empirical tests below, we check whether the clustering is positively related to the purchased OTM put and written OTM call open interest of investors who are relatively less likely

[24] Unwinding these positions also involves buying or selling options to market makers who will generally transact in the underlying stock to delta hedge the changes in their option positions. This delta hedging by the market makers will be accounted for in the empirical work via the changes in the option positions of likely delta hedgers (which is discussed in the previous subsection.)

to be delta hedging their option positions when shortly before expiration the stock price is greater than the nearest strike price.

4.4. Option investor manipulation of underlying stock prices

If the option market is populated by sophisticated and unsophisticated investors, then stock price manipulation by a subset of the sophisticated investors is another possible explanation for the greater propensity of optionable stocks to close on or near strike prices at expiration dates. Suppose that sophisticated traders have the resources to manipulate underlying stock prices and that at expiration unsophisticated investors follow the simple rule of exercising their purchased options when the closing stock price on expiration Friday indicates that the option is ITM. In this case, sophisticated option writers have an incentive to manipulate underlying stock prices so that unsophisticated option buyers do not exercise their options. In particular, sophisticated option writers have an incentive to manipulate underlying stock prices so that ITM options become OTM and OTM options are prevented from becoming ITM. When a sophisticated option writer prevents exercise through such manipulation, he avoids a liability equal to the (absolute) difference between the unmanipulated underlying stock price and the strike price.

Of course, some option buyers will be drawn from the pool of sophisticated option market participants. They might recognize that other sophisticated option market participants with written options sometimes manipulate the underlying stock price and may exercise their positions even if they are not ITM according to the closing price of the underlying stock. Although this would lessen the incentive to manipulate, it would not eliminate it provided that some option buyers are unsophisticated.[25] Further, even if sophisticated option buyers are aware that underlying stock prices are sometimes manipulated, they will not know with certainty whether manipulation occurred in particular cases, so they will still sometimes fail to exercise options when manipulation has actually occurred.[26]

[25] Some option writers will be drawn from the pool of unsophisticated investors. They will not manipulate underlying stock prices, and their existence does not alter the incentive that sophisticated option writers have to manipulate.

[26] It should also be noted that if nonmanipulating sophisticated investors could identify manipulation with a high degree of accuracy, they might choose to bet against it directly in the stock market. However, given the difficulty

Finally, since artificially moving or constraining stock prices is costly, sophisticated option writers have no further incentive to manipulate once an initially ITM option becomes OTM or when an OTM option is not just about to become ITM. Thus, stock price manipulation by option traders with written positions will tend to increase the frequency with which optionable stock prices close on or near strike prices on expiration dates.

While it might seem that traders with purchased option positions would have similar incentives to manipulate the prices of underlying stocks leading up to expiration, they do not. Suppose a sophisticated trader who has purchased a call manipulates the stock price upward so that exercise seems optimal. If he then exercises the call on the expiration date, he will receive shares of overpriced stock. These shares may well be difficult to sell at their inflated value, reducing or eliminating the apparent profit. Likewise, if a sophisticated trader who has purchased a put manipulates the stock price downward and then exercises the put, he will deliver shares of undervalued stock. The fact that the delivered shares are undervalued will also reduce or eliminate the apparent profit.[27] Written and purchased option positions do not provide symmetric incentives to manipulate the underlying stock price, because the sophisticated option writer gains when an unsophisticated purchaser is "tricked" into making an exercise decision based upon the manipulated price; an option purchaser cannot profit by tricking himself into making an incorrect exercise decision.[28]

It is also worth noting that the argument above implies that any stock position held by option traders, for example a delta hedge, will not affect the incentives to manipulate created by the existence of written option positions. Any apparent gain or loss on the stock position from the manipulation will reverse when the stock price reverts to its nonmanipulated level.

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that nonmanipulating investors would face in identifying manipulation with confidence, it would not be surprising if such betting does not occur.

[27] This argument that a trader who has purchased options cannot benefit from manipulating the price of the underlying asset does not apply to cash-settled index options. Of course, manipulating a stock index is likely to be more difficult than manipulating the price of an individual stock.

[28] Even if investors with purchased option positions do engage in manipulation, they would have no reason to stop manipulating the stock price once the option becomes ITM. Consequently, their manipulation would not produce strike price clustering. Manipulators with written option positions, on the other hand, will stop manipulating once the option is more than slightly OTM, because manipulating is costly and they receive no additional benefits as the option goes further OTM.

Of course, the fact that option market participants have incentives to manipulate the prices of the underlying stocks does not imply that they do so. There are also costs to manipulating, including the cost of artificially moving or constraining the stock price and the possibility of penalties if the manipulation is detected. A trader contemplating manipulation must assess whether the benefit is likely to exceed the cost. The benefit will be increasing in the size of the short option position, while the cost of the manipulation is not directly related to the size of the option holdings. This fact suggests that traders who undertake larger option positions are more likely candidates for manipulating the underlying stock price at expiration.

Evidence that investors manipulate prices in two other contexts lends plausibility to the notion that investors in exchange-traded options may manipulate underlying stock prices at expiration dates. First, Carhart, Kaniel, Musto, and Reed (2002) provide evidence that mutual fund managers manipulate the prices of the stocks in their portfolios on the last days of quarters and years in order to obtain top rankings and benefit from the resulting inflow of investments. It seems at least as likely that option traders or option trading desks would manipulate stock prices, because stock price manipulation produces immediate profits for option investors. The benefits to mutual fund management companies, in contrast, are delayed until after future increased investment flows into funds. In addition, the benefit to mutual fund managers is attenuated by the fact that increasing returns in one period through stock price manipulation comes at the cost of reducing returns in the next period. Second, in late November 1994, a hedge fund operated by well-known fund manager Michael Steinhardt bought from Merrill Lynch $500 million of “knock-in” put options on Venezuelan Brady bonds that expired in early January. By early December there was open warfare between the hedge fund that was trying to drive the price of the underlying bonds up to the knock-in level and Merrill Lynch, which was trying to keep the price of the bonds below the knock-in level. On December 9, as much as $1.5 billion of the $6.5 billion of face value outstanding changed hands. The head of emerging market debt trading at a big European bank remarked “nobody could have imagined the amount of money” that each side would spend to muscle the market in its favor. (Sesit and Jereski, 1995). Although the market for listed equity options is clearly different along a number of dimensions than the over-the-counter market for barrier options on Brady bonds, this incident lends credence to the idea that traders of exchange-listed options may engage in stock price manipulation.

5. Evidence on potential explanations for clustering

In order to provide an empirical assessment of the potential explanations, we need to separate cases in which there is more delta hedging of options on an underlying stock by investors with purchased options from those in which there is more delta hedging by investors with written options. Although the numbers of purchased and written option positions on an underlying stock are necessarily identical, certain types of investors are more likely than others to delta hedge. Avellaneda and Lipkin (2003) maintain that the clustering in their model would be produced by option market makers with net purchased option positions. Cox and Rubinstein (1985) likewise contend that market makers are the option market participants who are most likely to delta hedge their net option positions on underlying stocks. They write:

> … many Market Makers attempt to adhere quite strictly to a delta-neutral strategy. However, a delta-neutral strategy usually requires relatively frequent trading. As a result, it is not advisable as a consistent practice for investors with significant transaction costs. While public investors fall into this category, Market Makers do not. (p. 308)

Hull (2000, pp. 307, 319) similarly maintains that market makers and firm proprietary traders but not public customers are likely to delta hedge their net option positions. He explains that delta hedging is relatively more attractive to investors who hold large portfolios of options on an underlying stock. These investors can delta hedge their entire portfolios with a single transaction in the underlying stock and thereby offset the hedging cost with the profits from many option trades. Delta hedging by investors who hold only a small number of options on an underlying asset, on the other hand, is extremely expensive. McDonald (2003) devotes an entire chapter of his textbook to "Market-Making and Delta-Hedging." Based on the widely held view that nonpublic investors are the predominant delta hedgers in the option market, we assume either that delta hedging is concentrated in the market makers or that it is concentrated in the market makers plus firm proprietary traders. The results of the test conducted below are quite similar regardless of which assumption is made.

Consequently, for brevity, we report results only for tests that assume delta hedging is concentrated in the market makers.

5.1. Clustering and net purchased or written positions of likely delta hedgers

The implications of hedge rebalancing for expiration date clustering at strike prices depend crucially upon the net option position of market participants who delta hedge with the underlying stock. When delta hedgers have net purchased positions in the expiring options of an underlying stock with a particular strike price, hedge rebalancing will push the stock price toward the strike price and thereby tend to produce clustering. When delta hedgers have net written option positions, on the other hand, hedge rebalancing will push the stock price away from the strike price and thereby tend to produce declustering (i.e., lower probabilities of closing near the strike price.)

Based on the assumption that market makers are the predominant delta hedgers in the option market, Fig. 6 uses the CBOE open interest data to investigate the extent to which clustering depends on the net option position of market makers from January 1996 to December 2001. The CBOE data contain the total purchased and written open interest for all non-market makers on every CBOE traded option on every trade date.[29] We obtain market maker net open interest for an underlying stock-trade date from these data in the following way. First, we compute non-market maker net open interest as non-market maker purchased open interest in the closest to expiration call and put with strike price nearest to the trade date's closing stock price minus non-market maker written open interest in these options. We then set the market maker net open interest to the negative of the non-market maker net open interest. When this quantity is positive on a trade date for an underlying stock, the stock-trade date is classified as one on which market makers have net purchased open interest. When the quantity is negative, the stock-trade date is classified as one on which market makers have net written open interest. Market makers have net purchased open interest on 62% of the stock-trade date pairs and net written open interest on 38% of the stock-trade date pairs.

[29] The public customer and firm proprietary traders together constitute all non-market makers. Recall that when CBOE-listed options also trade at other markets, the open interest data reflect the positions across all markets.

Panel A of Fig. 6 shows the percentage of optionable stocks closing within $0.125 of a strike price as a function of the number of trade dates before or after option expiration when market makers have a net purchased position in the closest-to-expiration options on an underlying stock with the strike price nearest to the closing stock price. This plot has two important features. First, the spike at trade date zero is very pronounced. It is nearly 2% higher than on the nonexpiration dates, which is about double the size of the spike when there is no conditioning on whether the market makers have net written or purchased option positions (i.e., Panel B of Fig. 1.) Second, the percentages before expiration are larger than those after expiration.[30] That is, there is elevated clustering leading up to the expiration date. Consequently, the evidence in Panel A of Fig. 6 is consistent with the hedge rebalancing explanation which predicts that when delta hedgers have net purchased option positions, clustering will be elevated leading up to expiration and will peak at expiration. It should be noted, however, that since some of the other explanations considered in the previous section predict increased clustering right at expiration, the evidence is also consistent with hedge rebalancing plus one or more of the other mechanisms producing the expiration date clustering.

Panel B of Fig. 6 is like Panel A except that it is constructed from stock-trade date pairs for which option market makers have a net written (rather than a net purchased) position in the closest-to-expiration options on an underlying stock with strike price nearest to the closing stock price. This plot also has two important features. First, although there is still a spike on the expiration date, it is now less pronounced than when there is no conditioning on the market maker net option position (i.e., Panel B of Fig. 1). Second, the percentages before expiration are now lower than those after expiration.[31] That is, there is declustering leading up to the expiration date. Neither hedge rebalancing nor any of the other explanations in isolation can account for both of the features of this plot. The hedge rebalancing explanation predicts the declustering leading up to the expiration date but cannot explain the positive spike at expiration. Indeed, the hedge rebalancing explanation

[30] A binomial test shows that the difference in percentages between the three trade dates before expiration (i.e., dates –3 to –1) and the three trade dates after expiration (i.e., dates +1 to +3) is highly significant with a *p*-value of less than 0.000001.

[31] Once again, a binomial test shows that the difference in percentages between the three trade dates before expiration (i.e., dates –3 to –1) and three trade dates after expiration (i.e., dates +1 to +3) is highly significant with a *p*-value of less than 0.000001.

predicts that declustering should be most conspicuous at expiration. The other explanations can account for the spike at expiration, but do not predict declustering leading up to expiration. It seems that the expiration date clustering is produced by hedge rebalancing combined with at least one of the other potential explanations.[32]

5.2. Logistic regressions

We now perform logistic regressions to investigate further the contributions of the potential explanations to the expiration date clustering. We use a fixed-effects logistic regression model with a dependent variable that is set to one when the underlying stock price closes within $0.125 of an option strike price, and zero otherwise.[33] The unit of observation in the regressions is a stock-expiration Friday pair, e.g., Microsoft on Friday, September 21, 2001. Observations that meet the following conditions are included: (1) the stock has strictly positive closing prices on both the expiration Friday and the preceding Thursday;[34] (2) the distance between the Thursday closing stock price and the strike price nearest the Friday closing stock price is less than $10; and, (3) the CBOE data include written open interest (which may be zero) for both the firm proprietary traders and the public customers. There are observations on 2,585 different stocks and 75,690 stock-expiration Friday pairs in the period from January 1996 through December 2001 that satisfy these conditions.

The first independent variable measures clustering pressure from the hedge rebalancing activities of likely delta hedgers. We again assume that market makers are the primary delta hedgers in the option market, and set the first independent variable to the *market maker net purchased open interest*. This variable is computed from the open interest data at the close of trading on Thursday in

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[32] We believe that the main features of Fig. 6 do not result from error in our measure of delta-hedgers' net option positions, because we obtain a similar figure if we assume that market makers plus firm proprietary traders (rather than market makers alone) are the predominant delta hedgers in the option market. Hedge funds are another group of investors who may tend to delta hedge their net option positions. Our data do not allow us to separate out the purchased and written option positions of hedge funds. Nonetheless, given our results are robust to using either market makers alone or market makers combined with firm proprietary traders as the assumed delta hedgers, we doubt that including hedge funds as well would make much of a difference. Even if there is nontrivial noise in our proxy for the delta hedgers, it is difficult to see how one could account for the evidence in the figure without appealing to both hedge rebalancing and at least one other explanation.

[33] We also perform the logistic analysis with pooling and with random effects. The results are similar to those reported below.

[34] Here and throughout the discussion of the logistic regressions, "Thursday" and "Friday" always refer to the Thursday and Friday of expiration week.

the expiring put and call whose strike prices are nearest to the Thursday closing stock price.[35] As in the previous subsection, we compute the market maker net purchased open interest by using the fact that it is equal to the negative of the non-market maker net purchased open interest. The hedge rebalancing explanation predicts a positive coefficient on this variable.

The next variable measures clustering pressure from the delta hedging of changes in option positions (as opposed to delta hedging that results from the changing deltas of existing option positions). That is, it measures delta hedging of changes in market maker option positions which requires selling stock on Friday when the stock price is greater than the strike price or buying stock on Friday when the stock price is less than the strike price:

$$Newdelta\ hedging \equiv sign\left(S_{Thur} - K\right) \times (DeltaAdjChgOI_{Call}^{MM} + DeltaAdjChgOI_{Put}^{MM})\ . \tag{8}$$

In this expression, $sign\left(S_{Thur} - K\right)$ takes the values +1, 0, and -1 when the Thursday closing stock price is, respectively, greater than, equal to, or less than the nearest strike price, $DeltaAdjChgOI_{Call}^{MM}$ is the delta-adjusted Thursday-to-Friday change in net market maker open interest aggregated across all calls on the underlying stock, and $DeltaAdjChgOI_{Put}^{MM}$ is a similar variable for the puts on the underlying stock. In order to understand how this variable measures clustering pressure from delta hedging of new option positions, consider the situation in which the Thursday closing stock price is greater than the nearest strike price. In this case, $sign\left(S_{Thur} - K\right)$ is equal to +1. Since increases (decreases) in net long call positions are delta hedged by selling (buying) stock, increases (decreases) will lead to hedging which pushes the stock price toward (away from) the strike price. For this reason, the changes in call net open interest enter positively. Analogous considerations for puts

[35] If there is a large stock price change on Friday, the option strike price nearest the Thursday closing stock price may no longer be the strike price nearest the intraday stock price on Friday, and net purchased open interest at the strike price nearest the Thursday closing stock price may not be the best measure of the potential effect of hedge rebalancing. A separate issue is that when $S_{\text{Thurs}} = K$, clustering pressure from delta hedging changes in option positions may be negative, but the expression in Eq. (8) below treats it as zero. We address these issues by reestimating the regressions including only those observations for which the option strike price closest to the stock's closing prices is the same on both Thursday and Friday and the Thursday closing stock price is not equal to a strike price. There are observations on 2,236 different stocks and 62,121 stock-expiration Friday pairs in the period from January 1996 through December 2001 that satisfy these conditions in addition to conditions (1)–(3) above. Reestimating the logistic regressions with this smaller sample results in coefficient estimates that are similar in magnitude and significance to those reported below.

indicate that the $DeltaAdjChgOI_{Put}^{MM}$ variable should also enter the expression with a positive sign. A positive coefficient on the *new delta hedging* variable indicates that delta hedging of changes in option positions contributes to the clustering.

The third independent variable measures the unwinding by non-delta hedgers of positions that combine options and the underlying stock. As discussed in Subsection 4.3, non-delta-hedger unwinding of OTM covered calls and OTM protective puts will tend to push the stock price toward the strike price when the stock price is greater than the strike price. For this reason we define a covered call and protective put unwinding variable by

$$\begin{aligned} Covered\ call\ and\ protective\ put\ unwinding \equiv I\left(S_{Thur}-K\right)\times\Big[&OTMPurchasedOI_{Put}^{Firm+Public} \\ &+OTMWrittenOI_{Call}^{Firm+Public}\Big], \end{aligned} \tag{9}$$

where $I\left(S_{Thur}-K\right)=1$ if the Thursday closing stock price is greater than the strike price nearest the Thursday closing stock price, and $I\left(S_{Thur}-K\right)=0$ otherwise. The variable $OTMPurchasedOI_{Put}^{Firm+Public}$ is the purchased open interest of expiring OTM puts at the close on Thursday by firm proprietary traders and public customers, while $OTMWrittenOI_{Call}^{Firm+Public}$ is the written open interest of expiring OTM calls at the close on Thursday by firm proprietary traders and public customers. Although it is possible that stock activity related to non-delta hedgers unwinding combined option positions other than covered calls or protective puts could be in the right direction to induce clustering, we doubt that it would have a meaningful impact on the results if unwinding related to covered calls and protective puts is not important.[36]

Two sets of independent variables are included to provide evidence on whether the clustering is related to attempts by either the firm proprietary traders or the public customers to manipulate underlying stock prices on expiration Friday so that their written option positions finish OTM. First, we include the option volume that opens new written positions on the Tuesday through Thursday

[36] In results that are not reported, we include a measure of total open interest to control for unwinding of other combined stock and option positions by non-delta hedgers. The coefficient on the control variable is insignificant and its inclusion has little impact on the magnitudes or significance of the coefficient estimates on any of the other variables.

leading up to expiration for both firm proprietary traders and public customers. As we explain below, we do not include expiration Friday volume, because doing so would introduce an endogeneity problem. The second set of independent variables consists of the written open interest for firm proprietary traders and public customers at the close of trading on Thursday. Both of these sets of variables are constructed only from the currently expiring call and put with a strike price nearest to the Thursday closing stock price. These variables provide measures of either the possible intention or the incentive of the different investor types to engage in stock price manipulation. That is, investors who intend to manipulate stock prices at expiration would be inclined to write options in the days leading up to expiration, while investors with larger written option open interest have a larger incentive to manipulate the stock price at expiration regardless of the original motivations for entering into those positions. If stock price manipulation contributes to the stock price clustering, then we would expect a positive relation between the clustering and the option writing volume or open interest of investors who have the resources and knowledge necessary to manipulate stock prices. Firm proprietary traders are the most likely candidates for manipulating stock prices, because they have both the ability to enter into sizeable written option positions for which the benefit to manipulation is large and the wherewithal to manipulate the prices of the underlying stocks. Although market makers have the resources and knowledge to manipulate stock prices, they are unlikely to do so because their trading in underlying stocks is carefully monitored.[37]

The final independent variable measures the (absolute) distance between the Thursday closing stock price and the strike price nearest the Friday closing stock price. It is included to control for the fact that the stock price is more likely to close on or near an option strike price on an expiration Friday if it closed near that strike price on the preceding trade date. It is crucial to include this control, because option market activity in short-term options may be higher when the stock price is close to the option strike price. Consider the open written volume variables that are included to measure stock price manipulation. It is plausible that trading volume in expiring options is higher on Friday when the stock price is closer to the option strike price (and thus trading volume is likely to be

[37] Cox and Rubinstein (1985, p. 89) argue that market makers are unlikely to manipulate stock prices at expiration in order to make options expire OTM, because their trading in underlying stocks is monitored by exchange officials on a daily basis.

positively correlated with the probability that the stock price closes on or near an option strike price) even if no traders are manipulating the stock price. Because the control variable consists of the distance between the Thursday closing stock price and the option strike price closest to the Friday closing stock price, it will not control for the fact that Friday's volume in the currently expiring option may be higher when the intraday stock price is closer to the option strike price. For this reason, we do not include volume from the expiration Friday in our variables that measure option trading volume from transactions that open new written option positions. This is also the reason that the market-maker net purchased open interest, the covered call and protective put unwinding, and the written open interest variables are all constructed from open interest at the close of trading on Thursday.

Table 1 reports summary statistics for the independent variables. The first column of numbers in Table 2 reports the logistic regression results under the assumption that market makers are the predominant delta hedgers in the option market. Standard errors are included in parentheses below the point estimates.

Three variables have coefficient estimates that are significant at the 1% level. (And no other variable is significantly different from zero at even the 5% level.) First, as expected, the variable which measures the absolute distance between the Thursday closing stock price and the strike price nearest the expiration-Friday closing stock price is significantly negative. The negative sign indicates that it is more likely that the stock price closes on or near an option strike price on the expiration Friday when the distance between the Thursday closing stock price and the strike price is smaller. Second, consistent with the hedge rebalancing explanation (and Fig. 6) the coefficient on market-maker net purchased open interest is positive and significant. Third, the coefficient on the firm proprietary trader option volume that opens new written option positions on Tuesday through Thursday of expiration week is significantly positive. This positive and significant coefficient estimate is consistent with the firm proprietary traders opening written option positions with less than one week to expiration and then manipulating the underlying stock price to ensure that the options expire OTM.

It is not surprising that we find evidence of stock price manipulation in the firm proprietary trader open written volume but not in their written open interest. After all, it is not obvious what other than the manipulative strategy would motivate the firm proprietary traders to write very many new options during expiration week.[38] Consequently, the signal about manipulation from firm proprietary traders establishing new written option positions during expiration week has the potential to be relatively strong. Firm proprietary trader written open interest on the Thursday of expiration week, on the other hand, is more reflective of the full range of reasons that firm proprietary traders write options. Consequently, it is likely to provide a relatively weaker signal about manipulation. Put differently, if only a subset of firm proprietary traders engage in the manipulation, then we would expect their share of new written option volume during expiration week to be larger than their share of written open interest. In the next subsection of the paper, we present further evidence that firm proprietary traders who write new option positions during expiration week subsequently manipulate the underlying stock price so that the options finish OTM.

Turning to the remaining variables, there is no evidence that delta hedging of changes in option positions or unwinding of combined stock and option positions by non-delta hedgers contributes to the clustering. The fact that neither the open written volume nor the written open interest for the public customers are significant implies that there is no evidence that stock price manipulation by these investors contributes to the clustering of stock prices at strike prices on expiration days. We also estimate specifications in which the open written volumes and written open interest of three subgroups of public customers (customers of discount brokers, customers of firm proprietary traders, and other public customers) are included separately. The estimated coefficients on these variables are not significantly different from zero at conventional levels, and the estimated coefficients on the other variables are similar to those reported in Table 2.

If the open written volume of the firm proprietary traders were the only independent variable in the regressions, then a positive coefficient estimate could be interpreted either as evidence that they

[38] It seems unlikely that firm proprietary traders write the options in order to exploit information that the underlying stock prices will decrease or increase, because this hypothesis does not explain the result that option writing by firm proprietary traders predicts clustering at option strike prices. Further, because the profit potential is limited to the option premia, call and put writing are not the most natural strategies to use to profit from information about the direction of future price movements.

manipulate stock prices or that they write options during expiration week in order to exploit clustering caused by other mechanisms, for example, hedge rebalancing. Since there are independent variables that control for other potential causes of the clustering, stock price manipulation by firm proprietary traders appears to be the appropriate interpretation of the positive coefficient estimate. Of course, the controls for other potential causes may be imperfect. As a check, the final column of Table 2 reports regression results when market-maker net long open interest (the variable which measures clustering pressure from hedge rebalancing) is removed. We also remove public customer written open interest, because it is highly correlated with market-maker net long open interest.[39] The magnitude and significance of the coefficient estimate for firm proprietary trader open written volume is nearly identical in these regressions. If firm proprietary traders were merely trading on knowledge of clustering caused by other factors (and not manipulating the stock price themselves), then we would expect (counterfactually) that the magnitude and significance of the coefficient would increase when a measure for one of the other important factors is removed.[40]

5.3. Further evidence on manipulation by firm proprietary traders

Subsection 5.1 demonstrates that hedge rebalancing by likely delta hedgers and at least one other mechanism produce the clustering of optionable stocks at strike prices on expiration dates. The logistic regressions presented in the previous subsection indicate that only one other mechanism contributes to the clustering, namely, stock price manipulation by firm proprietary traders who write new options in the week leading up to expiration. We now provide further evidence on the hypothesis that firm proprietary traders who write options in the week leading up to expiration manipulate the prices of underlying stocks so that their written options expire OTM.

If the firm proprietary traders engage in such behavior, then the expiring options they write during expiration week should be profitable if held until expiration. We check their profitability by

[39] Firm proprietary traders are a much smaller part of the market than public customers. For this reason firm proprietary trader written open interest is not highly correlated with market-maker net purchased open interest, and we leave firm proprietary trader written open interest in the regression. Removing it, however, leads to the same conclusions.

[40] In unreported results, we rerun the regressions from Table 2 under the assumption that market makers plus firm proprietary traders are the predominant delta hedgers in the option market. All of the main features of the regressions are also observed under this alternative assumption.

estimating the total premia that firm proprietary traders receive from writing expiring options and the total liability they would face if those written option positions were held until expiration. We estimate the total premia under the assumption that each written option is sold at the option's daily closing bid price, and compute the liability at expiration by $\max\left[0,\text{Friday Closing Stock Price } - K\right]$ for calls and $\max\left[0, K - \text{Friday Closing Stock Price}\right]$ for puts. There are three reasons that the use of closing option bid prices results in a conservative estimate of the premia received, and thus a conservative estimate of the profitability of the option writing. First, time decay of option values tends to make the closing option prices lower than the prices of the same options earlier in the day. Second, the (unknown to us) underlying stock price at the time the option is written is approximately symmetrically distributed about the closing stock price. This symmetric distribution, combined with the convexity of option values in underlying stock prices, makes the closing option prices downward-biased estimates of the prices at which the options were actually sold. This convexity effect and the time decay effect are both particularly strong for at- and close-to-the-money options with only a few days to expiration. Third, the use of bid prices results in a conservative estimate of the premia received to the extent that firm proprietary traders are skillful at transacting inside the bid-ask spread. An offsetting factor that tends to make the estimate based on bid prices less conservative is that sizable options trades will likely have some market impact.

The estimate of the total premia received by firm proprietary traders for options written on the Tuesday through Thursday of expiration weeks over the January 1996 through December 2001 period is \$118.8 million while the liability faced is only \$46.4 million. Not only do the firm proprietary traders take in about 2.6 times more in premia than they would have to pay out at expiration a few days later, but they also profit quite consistently. On 67 of the 72 expiration weeks, the premia exceeds the pay out.

Subsection 5.2 discusses the possibility that firm proprietary traders write options during expiration week in order to take advantage of strike price clustering caused by market makers rebalancing their delta hedges, and presents logistic regression results showing that option writing by firm proprietary traders helps explain strike price clustering even when the regression specification includes variables to control for the magnitude of hedge rebalancing. We provide further evidence that firm proprietary traders are not simply taking advantage of clustering caused by hedge rebalancing by recomputing premia and liabilities separately for stock-expiration date pairs, where at the Thursday close of expiration week, market makers have net purchased or net written positions in expiring options with a strike price closest to the underlying stock price. If the high profitability of option writing by firm proprietary traders during the expiration week comes about because they exploit knowledge of the hedge rebalancing effect, then the option writing should be more profitable when market makers have net purchased positions. When market makers have net purchased option positions, the premia is 2.5 times as great as the liabilities; when they have net written positions the premia is 2.7 times as great. Since the profitability is greater when market makers have net written rather than net purchased positions, it is unlikely that the profitability comes from firm proprietary traders taking advantage of clustering that results from market makers with net purchased option positions rebalancing their delta hedges.[41]

We next test another implication of stock price manipulation by firm proprietary traders who write new options during expiration week. The analysis of Avellaneda and Lipkin summarized in Subsection 4.1 implies that when delta-hedging option investors have net purchased (written) option positions, their stock market trading pushes stock prices toward (away from) strike prices at option expiration. It also shows that for a given net option position, the attraction to (or repulsion from) a strike price is of equal intensity regardless of whether the stock price is a given distance above or below the strike price and regardless of the composition of bought and written puts and calls that constitute the net option position. The stock price manipulation mechanism, on the other hand, implies an asymmetry depending upon whether the manipulators write calls or puts. In particular, when a manipulator writes calls, he will push the stock price downward to get it (or keep it) below the strike price. He will not, however, manipulate the stock price upward. Similarly, when a manipulator writes puts, he will push the stock price upward to get it (or keep it) above the strike price but will not manipulate the stock price downward.

[41] The results are similar when stock-expiration date pairs are divided into net purchased or net written according to the option holdings of market makers plus firm proprietary traders. Although the fact that the option writing of firm proprietary traders in the week leading up to expiration is quite profitable is another piece of evidence that they manipulate stock prices in order to make their written option positions more valuable, a caveat is in order: It is not clear how to benchmark the profitability of these written option positions.

The fact that the hedge rebalancing mechanism has symmetric implications for stock price changes and the manipulation mechanism has asymmetric implications can be used to test whether manipulation contributes to the clustering. In particular, we compute the difference between the probability that a stock price that closes above the nearest strike price on the Thursday of expiration week closes just below the strike price on the Friday of expiration week (i.e., at expiration) and the probability that a stock price that closes below the nearest strike price on the Thursday of expiration week closes just above the strike price on the Friday of expiration week. Specifically, we compute the quantity

$$P\left\{S_{Fri} \in [K-0.125, K] \middle| S_{Thurs} > K\right\} - P\left\{S_{Fri} \in [K, K+0.125] \middle| S_{Thurs} < K\right\}. \qquad (10)$$

According to the hedge rebalancing mechanism, this quantity will be unrelated to firm proprietary traders writing calls or puts in the week leading up to expiration, because any change in the net option positions of delta hedgers that results from such option writing will impact both probability terms in expression (10) equally. According to the manipulation mechanism, however, expression (10) will be larger when manipulators write calls and smaller when they write puts. To see why, consider the case in which a manipulator writes calls. If the stock price closes above the strike price on Thursday, then the manipulator will push the stock price down on Friday so that his written calls finish OTM. This manipulation will increase the value of expression (10) by increasing the first probability. If, on the other hand, the stock price closes below the strike price on Thursday, then the manipulator will prevent the stock price from rising above the strike price on Friday, which will also increase the value of expression (10) by decreasing the second probability (which enters with a negative sign.) Similar considerations show that expression (10) will tend to be smaller when manipulators write puts.

We compute the value of expression (10) by replacing the probabilities with their sample frequencies. When firm proprietary traders write neither calls nor puts on the Tuesday through Thursday of expiration week, the estimate of expression (10) is 0.014. When firm proprietary traders write calls but not puts on the Tuesday through Thursday of expiration week, the estimate of expression (10) is 0.030, which (as predicted by the stock price manipulation hypothesis) is greater than the value when firm proprietary traders write neither calls nor puts. Using a binomial test, the difference is significant at the 5% level. Finally, when firm proprietary traders write puts but not calls on the Tuesday through Thursday of expiration week, the estimate of expression (10) is -0.012, which is less than the value when the firm proprietary traders write neither calls nor puts. This difference is also in accordance with the stock price manipulation hypothesis and significant at the 5% level.

These results about asymmetric stock price movements that differ depending on whether firm proprietary traders have written calls or puts are also consistent with the hypothesis that firm proprietary traders possess information that the underlying stock prices will decrease or increase, respectively, and write options in order to profit from such information. However, this hypothesis that firm proprietary traders write options to exploit simple directional information does not explain the result in Subsection 5.2 that option writing by firm proprietary traders predicts clustering at option strike prices. Further, because the profit potential is limited to the option premia, call and put writing are not the most natural strategies to use to profit from simple directional information.

6. Conclusion

Despite substantial interest and concern that the trading of listed equity options would alter the prices of underlying stocks, to date there has been little indication of any significant impact. This paper provides striking evidence that the presence of options perturbs the prices of underlying stocks. In particular, we show that over the 1996 to 2002 period, optionable stocks had a greater propensity to cluster around strike prices on option expiration dates than on other trade dates. This result is clearly associated with option expiration. There is no such clustering for optionable stocks on nonexpiration Fridays or for the universe of nonoptionable stocks. Nor is clustering present for nonoptionable stocks that later become optionable or for nonoptionable stocks that were once optionable.

We estimate that the returns of optionable stocks are altered by an average of at least 16.5 bps per expiration date and that at least 2% of optionable stocks have their returns changed on a typical expiration date. During our sample period, there are on the order of 2,500 optionable stocks on any given expiration date. Consequently, these estimates imply that if all optionable stocks are impacted 2,500 stocks have their returns changed by 16.5 bps, if half of the optionable stocks are impacted 1,250 have their returns changed by 33 bps, and if the minimum 2% are impacted 50 have their returns changed by 825 bps. Regardless of the percentage impacted, the associated change in the market capitalization of optionable stocks is roughly $9.1 billion per expiration date.

We investigate four possible explanations for the expiration date clustering of optionable stock prices at strike prices. Our tests indicate that delta-hedge rebalancing by investors with net purchased option positions and stock price manipulation by investors who write options in the week leading up to expiration both contribute to the clustering. We find no evidence that the clustering is related to delta hedging of new option positions or unwinding by non-delta hedgers of combined stock and option positions.

An interesting question, which we leave for future research, is how effectively the stock price deviations can be predicted from publicly available information prior to expiration Friday. If these predictions can be made with sufficient precision, then it may be possible to devise a trading strategy that exploits the expiration date clustering to produce abnormal profits after trading costs.

Appendix

Proof of Proposition 1. The quantity $|\hat{r}_i - r_i|$ is always greater than or equal to the quantity $|\hat{a}_i - a_i|$. Consequently,

$$E|\hat{r}_i - r_i| \geq E|\hat{a}_i - a_i|. \tag{A.1}$$

Since $|\hat{a}_i - a_i|$ is a convex function of the difference $\hat{a}_i - a_i$, Jensen's inequality implies that

$$E|\hat{a}_i - a_i| \geq |E(\hat{a}_i) - E(a_i)|. \tag{A.2}$$

Combining (A.1) and (A.2) yields the inequality (1).

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Table 1
Summary statistics

This table provides summary statistics for the independent variables used in the logistic regressions. The data period is January 1996 through December 2001. Stock prices are from OptionMetrics LLC, while the trading volume and open interest for public customers and firm proprietary traders are obtained directly from the CBOE. There is one observation for each underlying stock and option expiration date that meet the following conditions: (1) the stock has a strictly positive closing price on both the expiration Friday and the preceding Thursday; (2) the distance between the Thursday closing stock price and the strike price nearest the expiration Friday closing stock price is less than $10; and, (3) written open interest (which may be zero) for the firm proprietary traders and public customers is available in the data set. The net purchased open interest variable is calculated from open interest at the close of trading on the Thursday before expiration. The new delta hedging variable measures potential clustering pressure from delta hedging of changes in option positions from the close of trading on Thursday to the close of trading on Friday, while the unwinding variables measure potential clustering pressure from the unwinding on Friday of covered calls and protective puts by non-delta-hedging investors. The open written volume variables aggregate the daily trading volume of the different groups of investors over the Tuesday through Thursday of the expiration week. The written open interest variables are for the Thursday prior to option expiration. The Thursday stock price distance to strike variable is the absolute value of the difference between the expiration Thursday stock closing price and the strike price nearest to the expiration Friday stock closing price. Except where otherwise indicated, the units are option contracts.

Variable	Mean	Std. Dev.	Min	Max
Market-maker net purchased open interest	222.07	1,265.28	–67,153	51,214
New delta hedging	0.96	911.08	–68,937	86,467
Covered call and protective put unwinding	1,437.75	9,054.53	0	573,482
Firm proprietary trader open written volume	5.78	80.06	0	6,465
Public customer open written volume	28.47	184.43	0	10,830
Firm proprietary trader written open interest	127.38	704.51	0	35,218
Public customer written open interest	877.40	2,864.62	0	112,039
Thursday stock price distance to strike ($)	1.12	1.08	0	10
Number of observations:	75,690			

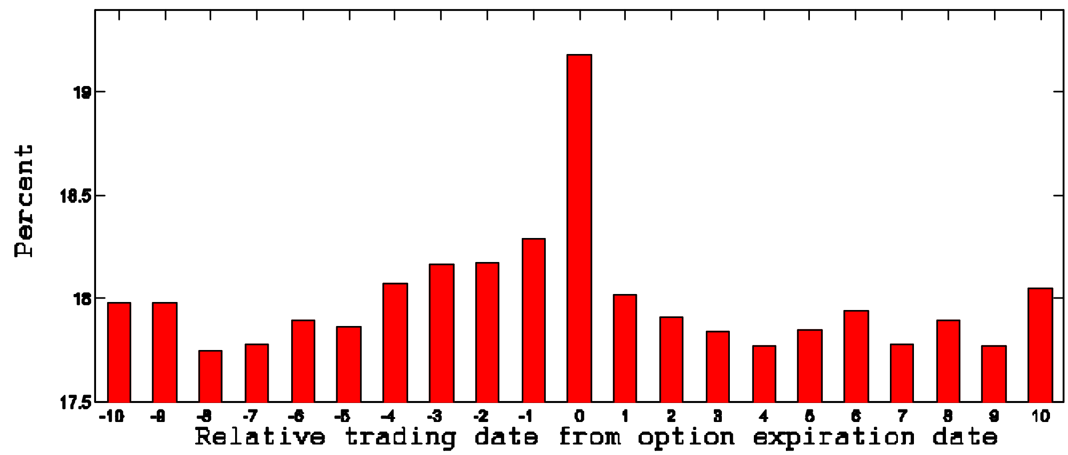
Table 2
Logistic regressions for stocks closing within $0.125 of an option strike price on an expiration Friday assuming that market makers are the predominant delta hedgers in the option market

This table reports coefficient estimates and estimated standard errors from logistic regressions with fixed effects in which the dependent variable takes the value of one for optionable stock-expiration date pairs in which the stock closes within $0.125 of an option strike price on an expiration Friday, when it is assumed that market makers are the predominant delta hedgers in the option market. The numbers reported in the table are coefficient estimates and standard errors (in parentheses), multiplied by 10,000. The data period is January 1996 through December 2001, and there are a total of 75,690 observations. Stock prices are from OptionMetrics LLC, while the trading volume and open interest for public customers and firm proprietary traders are obtained directly from the CBOE. There is one observation for each underlying stock and option expiration date that meet the following conditions: (1) the stock has a strictly positive closing price on both the expiration Friday and the preceding Thursday; (2) the distance between the Thursday closing stock price and the strike price nearest the expiration Friday closing stock price is less than $10; and, (3) written open interest (which may be zero) for the firm proprietary traders and public customers is available in the CBOE data. The net purchased open interest variable is calculated from open interest at the close of trading on the Thursday before expiration. The new delta hedging variable measures potential clustering pressure from delta hedging of changes in option positions from the close of trading on Thursday to the close of trading on Friday, while the unwinding variable measures potential clustering pressure from the unwinding on Friday of covered calls and protective puts by non-delta hedgers. The open written volume variables aggregate the daily trading volume of the two groups of investors over the Tuesday through Thursday of the expiration week. The written open interest variables are for the Thursday prior to option expiration. The Thursday stock price distance to strike variable is the absolute value of the difference between the expiration Thursday stock closing price and the strike price nearest to the expiration Friday stock closing price. Standard errors are provided in parentheses. Statistical significance at 5% and 1% levels is indicated by * and **, respectively.

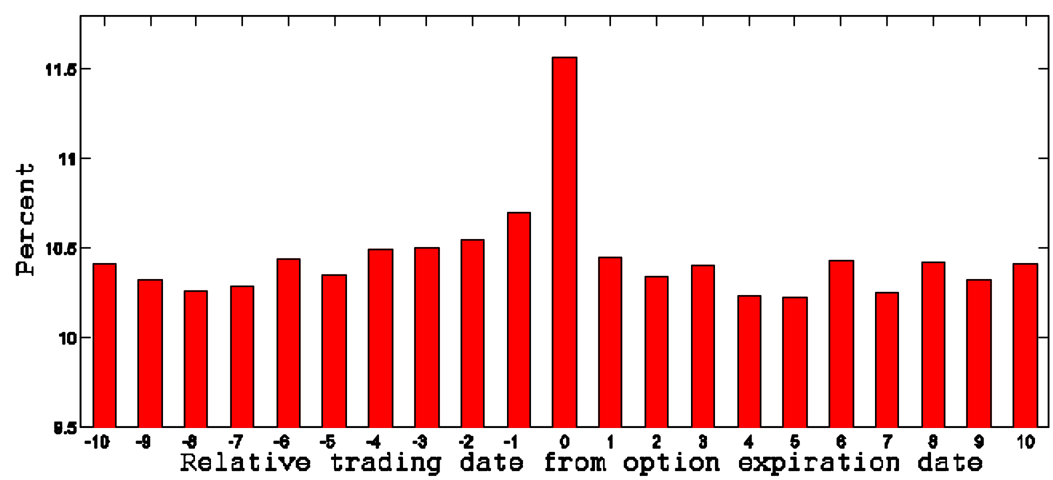
Table 2 – *Continued*

Variable	Coefficient Estimates (standard errors)×10,000 All Variables	 Excluding market-maker and public customer open interest
Market-maker net purchased open interest	0.27** (0.11)	
New delta hedging	–0.08 (0.12)	–0.06 (0.11)
Covered call and protective put unwinding	0.02 (0.01)	0.02 (0.01)
Firm proprietary trader open written volume	3.15** (1.26)	3.14** (1.26)
Public customer open written volume	–0.83 (0.78)	–0.58 (0.76)
Firm proprietary trader written open interest	–0.02 (0.19)	0.10 (0.18)
Public customer written open interest	0.04 (0.06)	
Thursday stock price distance to strike	–15,346.37** (258.80)	–15,359.74** (258.68)

Panel A. Percentage of optionable stocks closing within $0.25 of a strike price



Panel B. Percentage of optionable stocks closing within $0.125 of a strike price



Panel C. Percentage of optionable stocks closing on a strike price

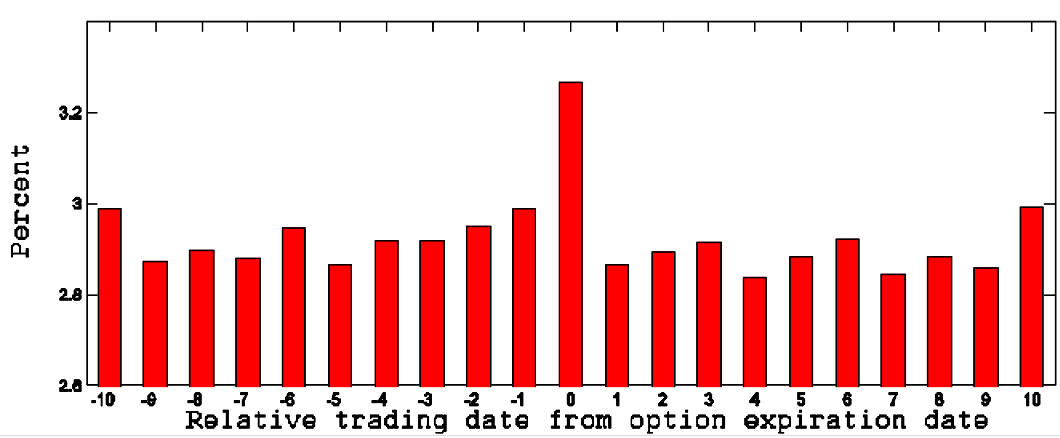
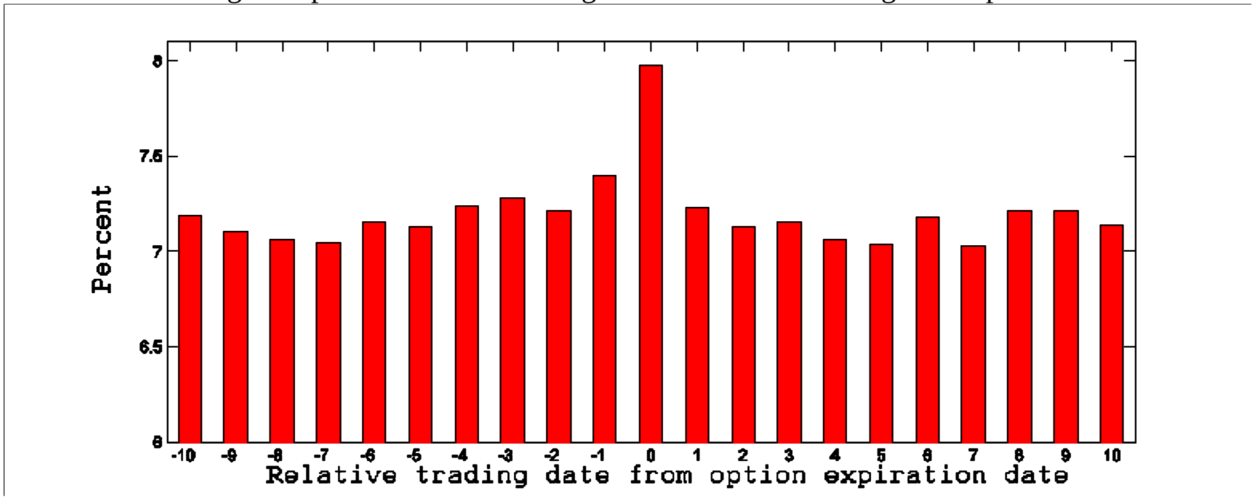


Fig. 1. Percentage of optionable stocks closing various distances from an option strike price. Expiration Fridays are trade date ‘0’ relative to the option expiration date, the Thursdays before are trade date ‘–1’ relative to the option expiration date, the Mondays after are trade date ‘1’ relative to the option expiration date, etc. For each trade date relative to the expiration date, the plots give the percentage of stocks that close within a specified distance from a strike price of an option listed on the stocks. Panel A shows the percentage of optionable stocks that close less than or equal to $0.25 from a strike price of an option listed on the stocks. Panel B shows the percentage of optionable stocks that close less than or equal to $0.125 from a strike price of an option listed on the stocks. Panel C shows the percentage of optionable stocks that close on a strike price of an option listed on the stocks. The data period covers the 80 option expirations from January 1996 through August 2002.

Panel A. Percentage of optionable stocks closing within $0.125 of an integer multiple of $5



Panel B. Percentage of nonoptionable stocks closing within $0.125 of an integer multiple of $5

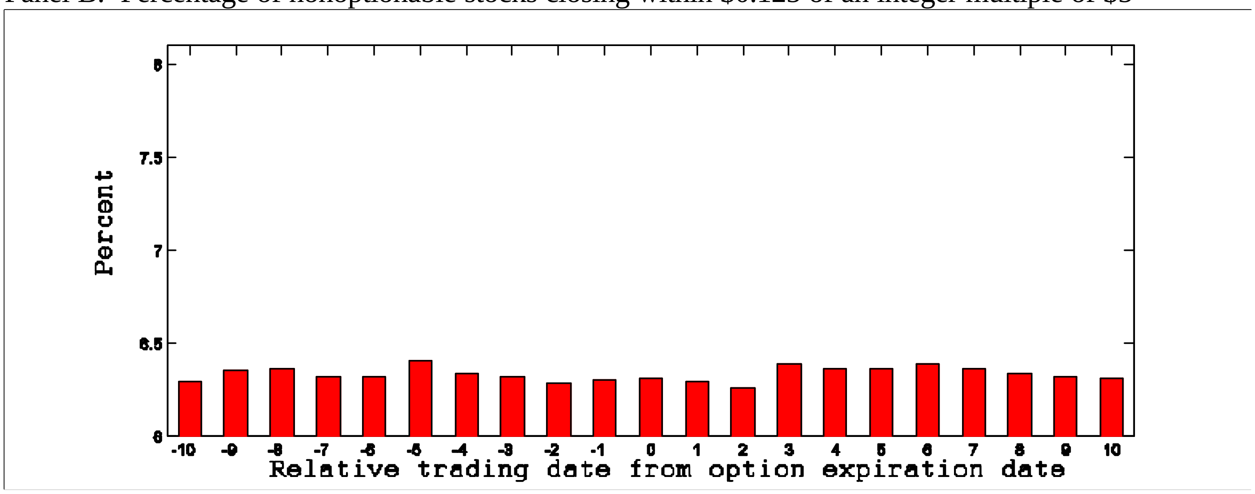
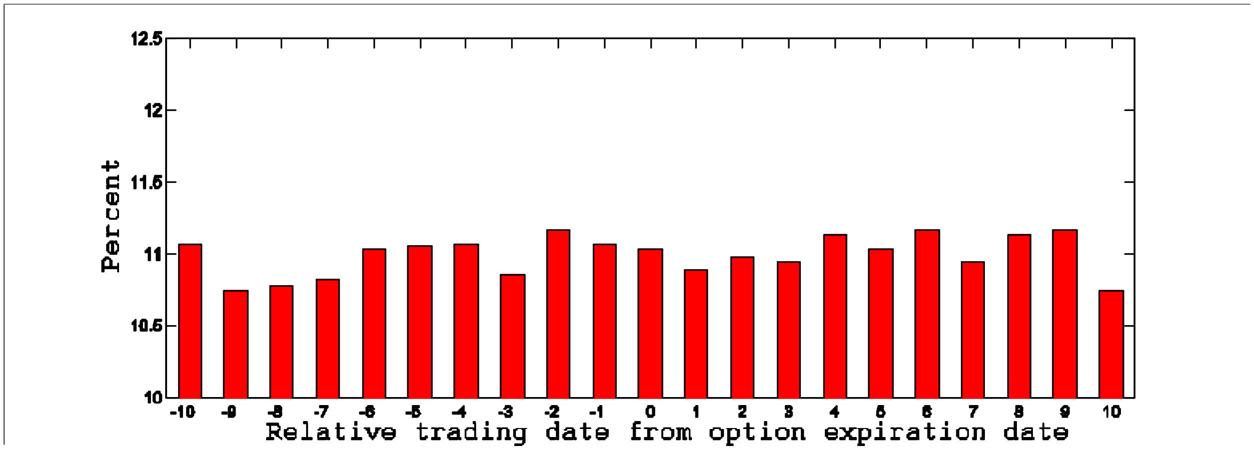


Fig. 2. Percentage of optionable and nonoptionable stocks closing within $0.125 of an integer multiple of $5 as a function of the number of trade dates before or after an option expiration date. Expiration Fridays are trade date ‘0’ relative to the option expiration date, the Thursdays before are trade date ‘–1’ relative to the option expiration date, the Mondays after are trade date ‘1’ relative to the option expiration date, etc. For each trade date relative to the expiration date, the plots give the percentage of stocks that close less than or equal to $0.125 from an integer multiple of $5.00. Panel A shows the percentage of optionable stocks (i.e., stocks that have exchange-listed options) that close less than or equal to $0.125 from an integer multiple of $5.00. Panel B shows the percentage of nonoptionable stocks (i.e., stocks that do not have exchange-listed options) that close less than or equal to $0.125 from an integer multiple of $5.00. The data period covers the 80 option expirations from January 1996 through August 2002.

Panel A. Percentage of nonoptionable stocks that subsequently become optionable closing within \$0.125 of an integer multiple of \$2.50



Panel B. Percentage of optionable stocks that were previously nonoptionable closing within \$0.125 of an integer multiple of \$2.50

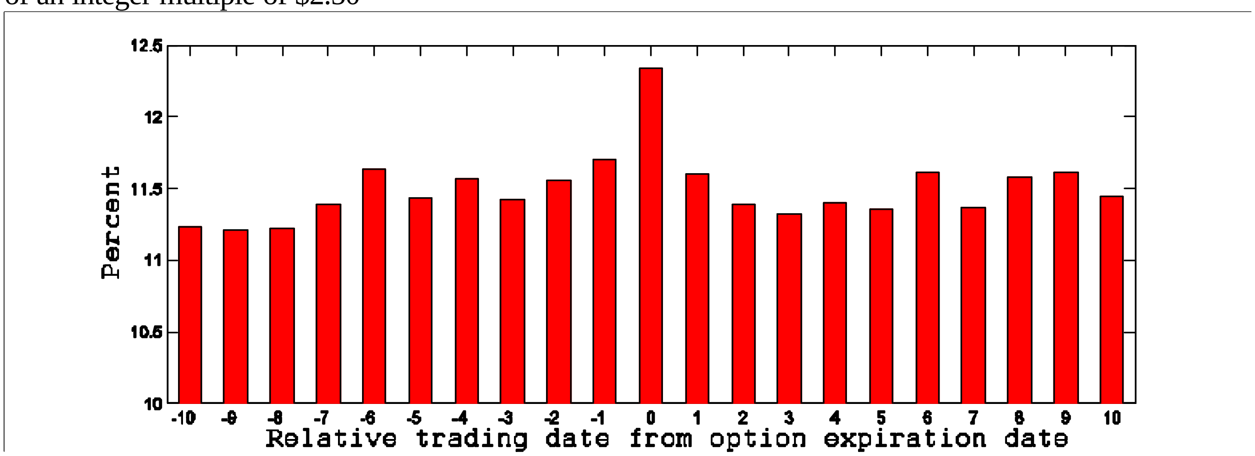
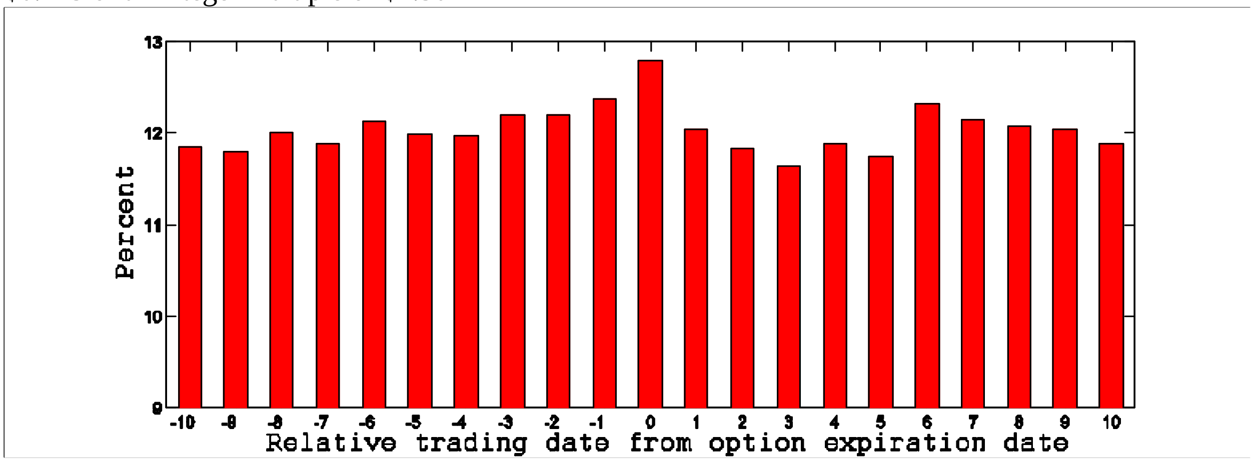


Fig. 3. Percentage of nonoptionable stocks which subsequently become optionable and percentage of optionable stocks that previously were nonoptionable closing within \$0.125 of an integer multiple of \$2.50 as a function of the number of trade dates before or after an option expiration date. Expiration Fridays are trade date '0' relative to the option expiration date, the Thursdays before are trade date '−1' relative to the option expiration date, the Mondays after are trade date '1' relative to the option expiration date, etc. For each trade date relative to the expiration date, the plots give the percentage of stocks that have closing prices less than or equal to \$0.125 from an integer multiple of \$2.50. Panel A shows these percentages for stocks that are nonoptionable but subsequently become optionable during the sample period. Panel B shows these percentages for optionable stocks that earlier in the sample period were nonoptionable. The sample period is January 1996 through August 2002.

Panel A. Percentage of optionable stocks that subsequently become nonoptionable closing within $0.125 of an integer multiple of $2.50



Panel B. Percentage of nonoptionable stocks that were previously optionable closing within $0.125 of an integer multiple of $2.50

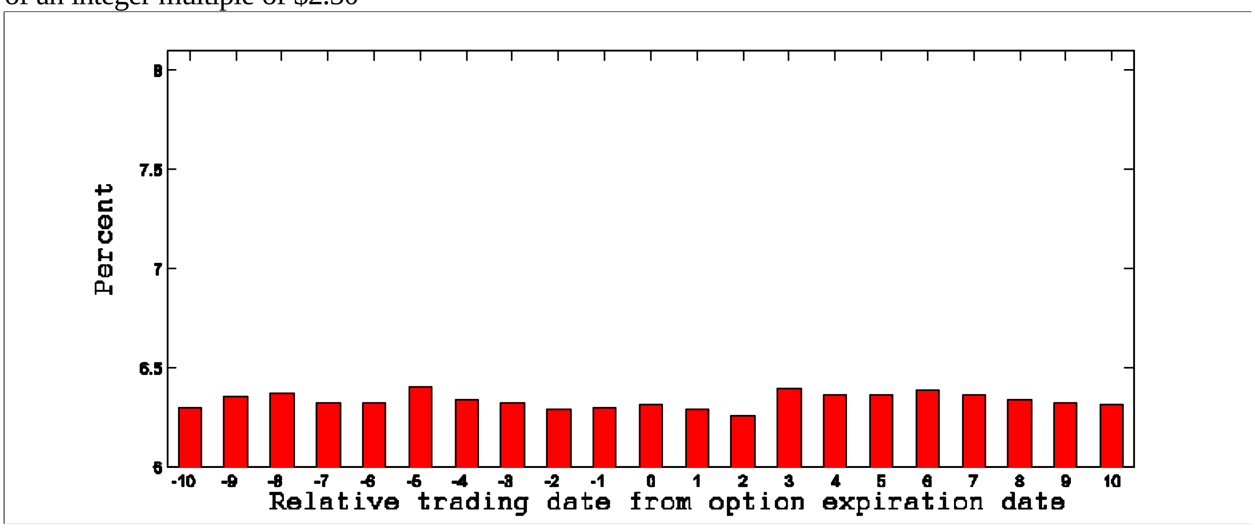
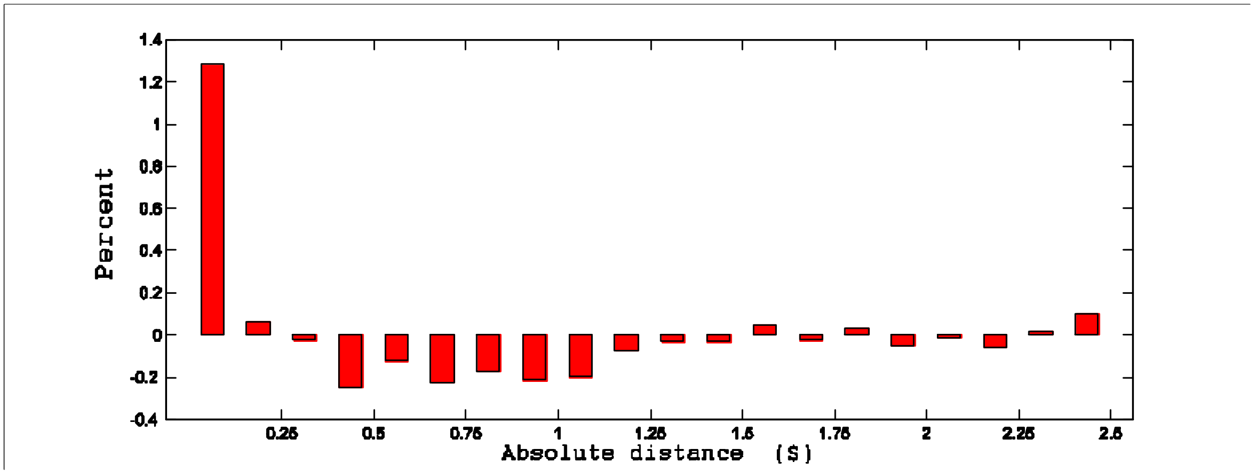


Fig. 4. Percentage of optionable stocks which subsequently become nonoptionable and percentage of nonoptionable stocks that previously were optionable closing within $0.125 of an integer multiple of $2.50 as a function of the number of trade dates before or after an option expiration date. Expiration Fridays are trade date ‘0’ relative to the option expiration date, the Thursdays before are trade date ‘−1’ relative to the option expiration date, the Mondays after are trade date ‘1’ relative to the option expiration date, etc. For each trade date relative to the expiration date, the plots show the percentages of stocks that have closing prices less than or equal to $0.125 from an integer multiple of $2.50. Panel A shows these percentages for stocks that are optionable but subsequently become nonoptionable during the sample period. Panel B shows these percentages for nonoptionable stocks that earlier in the sample period were optionable. The sample period is January 1996 through August 2002.

Panel A. Percentage of optionable stocks that close various absolute distances from a strike price on option expiration Fridays minus the percentage on the Fridays before and after option expiration



Panel B. Percentage of optionable stocks with absolute returns of various sizes on option expiration Fridays minus the percentage on the Fridays before and after option expiration

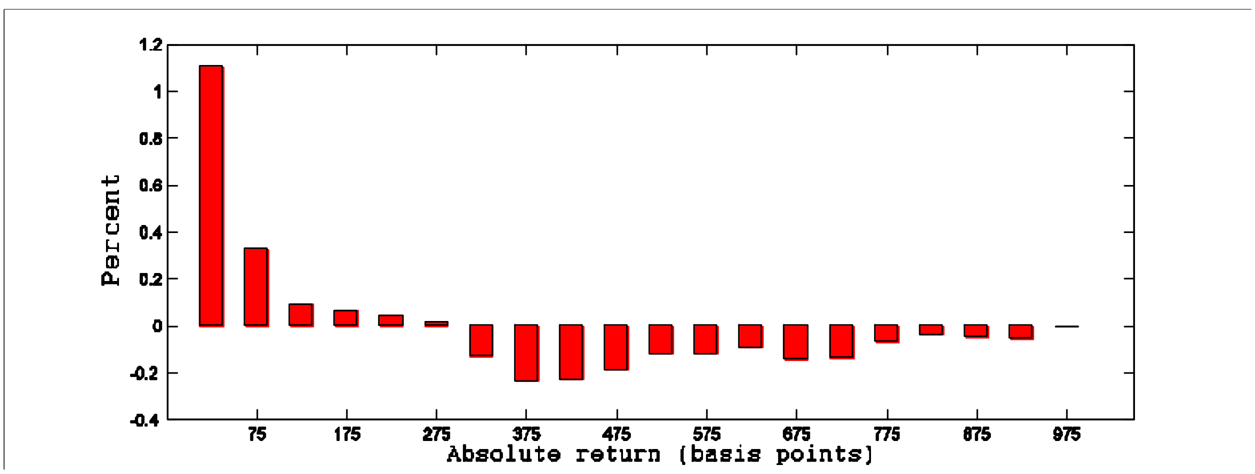
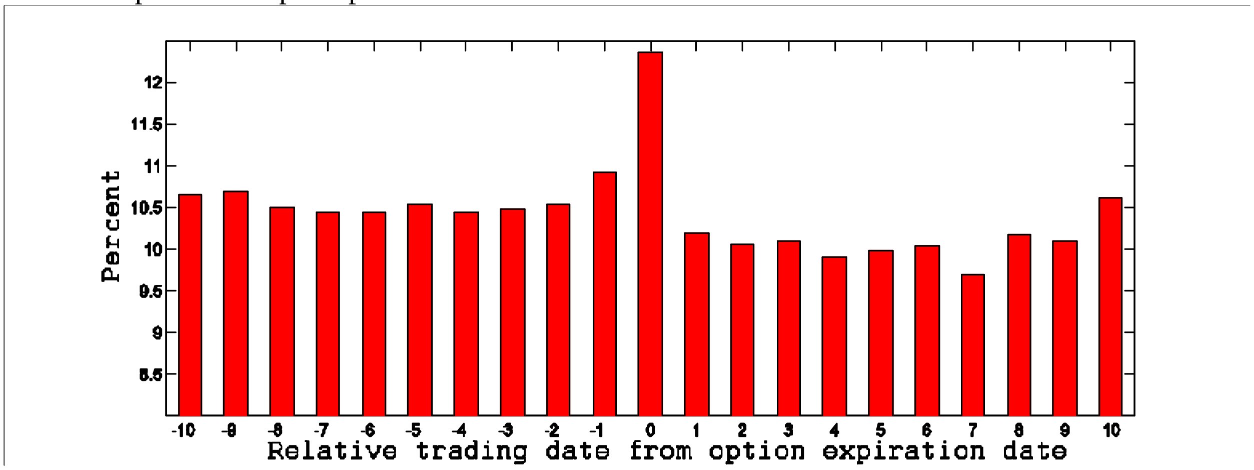


Fig. 5. Difference in optionable stock distributions on option expiration Fridays and the Fridays before and after expiration. In Panel A the absolute dollar distance (*AD*) between the closing prices of optionable stocks and the nearest option exercise price is divided into 20 disjoint intervals: $AD \leq \$0.125$, $\$0.125 < AD \leq \$0.25$, $\$0.25 < AD \leq \$0.375$, $\ldots$, $\$2.375 < AD \leq \$10.00$. (Absolute dollar distances greater than $10.00 are eliminated.) Panel A then displays the percentages of optionable stocks with closing prices in each of the intervals on option expiration Fridays minus the percentage on the Fridays before and after expiration. In Panel B the daily absolute stock returns are divided into 20 absolute return intervals: $0 \text{ bps} \leq |r| < 50 \text{ bps}$, $50 \text{ bps} \leq |r| < 100 \text{ bps}$, $\ldots$, $950 \text{ bps} \leq |r| < 1{,}000 \text{ bps}$. Panel B then displays the percentage of optionable stocks with positive option volume that have returns in each interval on expiration Fridays minus the percentage on the Fridays before and after expiration. The sample period is January 1996 through August 2002.

Panel A. Percentage of optionable stocks closing within $0.125 of a strike price when market makers have a net purchased option position



Panel B. Percentage of optionable stocks closing within $0.125 of a strike price when market makers have a net written option position

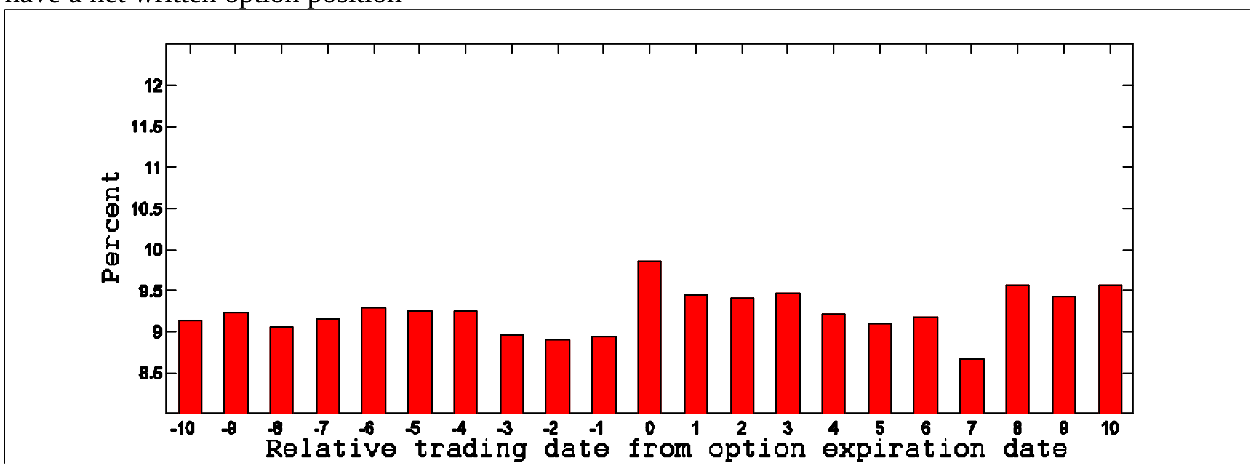


Fig. 6. Percentage of optionable stocks closing within $0.125 of an option strike price as a function of the number of trade dates before or after an option expiration date, for subsets of stock-expiration date pairs in which market makers have net purchased or net written positions on the closest to expiration options with strike price nearest to the closing stock price. Expiration Fridays are trade date ‘0’ relative to the option expiration date, the Thursdays before are trade date ‘–1’ relative to the option expiration date, the Mondays after are trade date ‘1’ relative to the option expiration date, etc. For each trade date relative to the expiration date, the plots show the percentages of stocks that close within $0.125 of a strike price of an option listed on the stocks. Panel A shows the percentages for the option expirations dates on which market makers have a net purchased position in the closest to expiration options with strike price nearest to the closing stock price. Panel B shows the percentages for the option expiration dates on which market makers have a net written position on these options. The data period is January 1996 through December 2001.