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Stealth Trading in Options Markets

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Abstract

We investigate how price discovery occurs in the options markets through traders' trade size choice. By employing transactions data on all options traded on a sample of 100 firms, we show that informed traders fragment their orders into small (medium) trades for low (high) volume contracts. We also find that almost 60% of the price discovery occurs in the exchange with the largest market share for a given option, where informed traders favor medium size trades. Upon examining distinct option series for a given stock, we find that at-the-money calls display the highest information share.

I. Introduction

In theory, as well as in practice, the problem of identifying informed traders has received significant attention. A problem exists because informed traders use various strategies to camouflage their intent making it difficult to distinguish them from liquidity motivated traders (see Kyle (1985)). An example of such an action is the strategic fragmentation of their trades. Yet, such trades, based on the private information they possess about the firm, influence the price of the firm's traded securities and drive it to its unobservable "true" value. The process of discovering the true price is collectively known as price discovery and is one of the most important functions of a securities exchange. While there exists a significant body of research on price discovery in the equity markets, spearheaded by Hasbrouck (1991), (1995) and Easley and O'Hara (1992), relatively little research has been accomplished to further our understanding of what drives price discovery in the derivatives markets. In recent studies, Chakravarty, Gulen, and Mayhew (2004), Pan and Poteshman (2003), and Cao, Chen, and Griffin (2005) demonstrate that significant price discovery also takes place in the options markets. In a separate, but related, stream of literature, Barclay and Warner (1993) and Chakravarty (2001) find significant evidence of strategic trade size fragmentation by informed traders within the context of the equity markets. Barclay and Warner (1993) find

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that most informed trading occurs on medium size trades. The authors label this the "stealth-trading" hypothesis and demonstrate its validity with a sample of 108 tender offers between 1981 and 1984.

Given the distinct microstructure characteristics of the equity and options markets,[1] it is relevant to know if informed traders camouflage their trades in options markets through their choice of trade sizes. Such an analysis of informed traders' behavior defines the goal of this study. In doing so, we also connect the literature on price discovery with that on stealth trading by examining how price discovery takes place vis-à-vis traders' choice of trade sizes in the options markets.

To understand how price discovery occurs in options markets, we use Hasbrouck's (1995) information shares methodology for the problem on hand. We employ a transaction level data set from the Options Price Reporting Authority (OPRA) on *all* options traded on a sample of 100 firms over a three-month period between July 26, 1999 and October 28, 1999. More details about the data are provided in Section IV.

We find that a significant amount of price discovery takes place in options markets primarily through medium and small size trades. Specifically, in the overall sample small size trades account for approximately 40% of the price discovery, while medium size trades contribute 41%. Further, for liquid contracts (i.e., higher option volume), the largest contribution to price discovery comes from medium size trades while for relatively illiquid contracts the largest price discovery is associated with small size trades. The implication is that informed traders act strategically in fragmenting their orders depending on the liquidity of the contract (which affects their ability to hide). This dynamic aspect of stealth trading in the options markets has not been demonstrated in the equity markets. We also show that this relation between trade size-based price discovery in options markets and the volume of the options contract dominates other characteristics of options contracts such as moneyness and time-to-maturity (TTM).[2]

If volume is an important determinant of informed trading strategies, we would expect informed traders to seek the most liquid venue for trading and to choose trade sizes appropriately based on the market share (trading volume) of the venue. Within the context of the equity markets, Chowdhry and Nanda (1991) theoretically show that both liquidity- and information-based traders tend to concentrate in one venue. Combined with our results on the importance of volume in the informed trader's trade size choice, Chowdhry and Nanda's result implies that the choice of trade size by informed traders is also a function of the market share of the exchange.

We find that approximately 60% of the price discovery in options of an underlying firm occurs in the exchange with the largest market share for those options (defined as the dominant exchange). Further, medium size trades on the

[1] It is well established that the stock and options markets differ in terms of anonymity/transparency, leverage, margin requirements, and transactions costs, which makes it difficult to extrapolate from studies in the equity markets.

[2] The moneyness of an option is defined as the spot price divided by the strike price for call options and the strike price divided by the spot price for put options. Thus, lower moneyness implies higher leverage and vice versa.

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dominant exchange are the most informative (economically and statistically), contributing from 22% for lower volume to around 28% of the price discovery for higher volume options. Hence, once again, we see that the significance of liquidity (this time in the overall exchange-related liquidity for a given option contract) in the informed traders' decision to i) route their trades and ii) strategically fragment their trades within the chosen trading center.

We also examine how informed traders with private information about a given stock may wish to trade across the various option series traded on that stock. To do so, we focus on 20 stocks in our data set with the highest option volume traded on them over our data period. We then calculate the equivalent stock price corresponding to each option trade price using the Black-Scholes formula, and construct three distinct price series corresponding to at-the-money (ATM) calls, all other calls, and all puts for each of the 20 stocks. Our estimations of information shares (for each stock on each trading day) across the three price series show that the largest information share is associated with ATM calls. Puts do not appear to contribute significantly to price discovery. The information share of puts, while higher on days where the underlying stock shows a sharp decline in price, still lags behind that of ATM calls and other calls. Our findings indicate that ATM calls are the desired trading vehicle for informed traders.

The rest of the paper is as follows. Section II provides the background and motivation for the research. Section III describes the methodology adopted for our analysis. Section IV discusses the data and the classification procedures used. Section V discusses our results, and Section VI concludes.

II. Background and Motivation

Informed traders might sometimes opt to trade in the options market rather than in the stock market due to the greater financial leverage that options offer (Black (1975)). Therefore, options markets are not redundant from the point of view of price discovery. Easley, O'Hara, and Srinivas (1998), for example, develop and test an asymmetric information model in which informed traders may trade in either market. In particular, the authors develop conditions under which informed traders trade options. John, Koticha, Narayanan, and Subrahmanyam (2000) investigate the relative differences in margin requirements in the stock and options markets and find that, regardless of the margin rules, the introduction of options improves market efficiency.[3]

A significant empirical research stream also investigates the lead-lag relation between the stock and options prices (see, for example, Manaster and Rendleman (1982), Stephan and Whaley (1990), Vijh (1990), Chan, Chung, and Johnson (1993), Chan, Chung, and Fong (2002), Cao, Chen, and Griffin (2005), Schlag and Stoll (2002), and Finucane (1999)). These studies provide mixed evidence on informed trading in options markets with some studies (Cao, Chen, and Griffin (2005) and Finucane (1999), for example) finding support for informed trading

[3]The remaining (and relatively sparse) theoretical research on the informational role of options markets focuses mostly on the impact of options trading on stock and options prices (see, for example, Grossman (1988), Biais and Hillion (1994), and Brennan and Cao (1996)).

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through options, and others (such as Vijh (1990) and Chan, Chung, and Fong (2002)) finding evidence against informed trading in options.

Recent studies focus on investigating the microstructure of stock and options markets in order to fully understand how information is transmitted between the two markets. These studies are characterized by their usage of high frequency transactions and quote data in the stock and options markets. Lee and Yi (2001), for example, explore the intuition that large trades in the options market may not be anonymous, which might enable options market makers to screen large informed trades more effectively than in the stock market. This lack of anonymity in the options market will then cause large investors with private information to behave differently than small investors. Using intraday data from 1989 to 1990 for a sample of firms with options listed on the Chicago Board of Options Exchange (CBOE) and the underlying stocks listed on the NYSE, they find a higher adverse selection component for smaller options trades vis-à-vis the underlying stock trades of the same size. Kaul, Nimalendran, and Zhang (2002) report that adverse selection is higher for ATM and slightly out-of-the-money (OTM) options contracts. Chakravarty, Gulen, and Mayhew (2004) use the Hasbrouck (1995) information shares approach to estimate the fraction of information share attributable to the options market. Using intraday data from the stock and options markets, the authors report that the average information share attributable to the options (versus stock) market is about 17%. Finally, Pan and Poteshman (2003) find evidence of information appearing in the options market first and then diffusing into the underlying stock prices. Their results indicate that the put/call volume ratios are a significant predictor of the underlying stock's future performance. Thus, significant price discovery appears to occur in the options market.[4] However, while all of the above studies examine the impact of informed traders collectively on the stock and options markets, none studies *how* informed traders might trade in the options market vis-à-vis their trade size choice, and the relation of this trade size choice and price discovery to the moneyness, TTM, and liquidity of the options.

III. Methodology

A. The Empirical Model

Price discovery analysis has its roots in the econometrics of cointegrated vector autoregressions (VAR). Hasbrouck (1995) presents a robust VAR-based technique for estimating an exchange's contribution to price discovery given that each NYSE-listed stock trades simultaneously in the NYSE as well as in the regional stock exchanges. We use the same methodology to examine the information content inherent in options trades of various trade size classes. Specifically, we consider three trade size classes: small, medium, and large. Underpinning our approach is the assumption that prices of the three trade size classes for the same

[4]de Jong, Koedijk, and Schnitzlein (2006) use a controlled economic experiment to investigate the informational linkages between a stock and a traded call option on that stock. Their main findings are that an insider trades aggressively using both the stock and the option and that this leads to important feedback effects between the two markets.

option series (an option series is characterized by option type (call/put), underlying stock, strike price, and maturity date), in a trading session, share a common random walk component—commonly referred to as the efficient price. The information share of transactions within a given trade size class is then measured as that group's contribution to the total variance of the random walk component.

In particular, if we denote a price vector p that includes p_{st}, the unit-contract transaction price of a small size option trade, and p_{mt} (p_{lt}), the unit-contract transaction price of a medium (large) size option trade—all in the same option series during a trading session—then we can express p_t as

$$p_t = \begin{bmatrix} p_{st} \\ p_{mt} \\ p_{lt} \end{bmatrix} = \begin{bmatrix} V_t + e_{s,t} \\ V_t + e_{m,t} \\ V_t + e_{l,t} \end{bmatrix}. \tag{1}$$

The common efficient price V_t is assumed to follow a random walk given by

$$V_t = V_{t-1} + u_t, \tag{2}$$

where $E(u_t) = 0$, $E(u_t^2) = \sigma_u^2$ and $E(u_t u_s) = 0$ for $t \neq s$. Then, by the Granger representation theorem (see Engle and Granger (1987)), these cointegrated prices can be expressed as a vector error correction model (VECM) of order N as

$$\Delta p_t = A_1 \Delta p_{t-1} + \ldots + A_N \Delta p_{t-n} + \gamma(z_{t-1} - \mu_z) + \varepsilon_t, \tag{3}$$

where p_t is a 3×1 vector of prices, A_i is a 3×3 matrix of autoregressive coefficients corresponding to lag i, $\gamma(z_t - \mu_z)$ is the error correction term, and $\mu_z = E(z_t)$. The covariance matrix of the error term above can be expressed as

$$\text{Cov}(\varepsilon_t) = E\varepsilon_t\varepsilon_t' = \Omega. \tag{4}$$

Also note that in our case we have three cointegrating vectors given by

$$z_t = \begin{bmatrix} p_{mt} - p_{st} \\ p_{mt} - p_{lt} \\ p_{lt} - p_{st} \end{bmatrix} = Fp_t, \tag{5}$$

$$\text{where} \quad F = [\iota - I_3]$$

for I_3, the identity matrix of order 3, ι is an appropriate vector of ones, and μ_z is the mean vector for the price deviations while the elements of γ are error correction coefficients.

The vector moving average (VMA) representation of the model given by equation (1) is

$$\Delta p_t = B_0\varepsilon_t + B_1\varepsilon_{t-1} + B_2\varepsilon_{t-2} + , \ldots, \tag{6}$$

$$\text{where} \quad B_0 = I,$$

and ε is a 3×1 vector of zero-mean innovations with a variance-covariance matrix given by Ω that is of order 3×3. Also notice that in (6), the identity matrix, I, is

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3×3, and the sum of all moving average coefficients $B(1) = I + B_1 + B_2 + \ldots$ has identical rows B. Since B reflects the impact of innovations on the permanent price component rather than transitory components, the total variance of the implicit efficient price changes can be expressed as $\sigma_T^2 = B\Omega B'$. Following Hasbrouck (1995), the contribution to price discovery by each order size class is expressed as that order size class's contribution to this total innovation variance.

Now, if Ω happens to be a diagonal 3×3 matrix, we can express it very simply as

$$\Omega = \begin{bmatrix} \sigma_s^2 & 0 & 0 \\ 0 & \sigma_m^2 & 0 \\ 0 & 0 & \sigma_l^2 \end{bmatrix}.$$

In this case, the information share of a medium size trade, for example, is *uniquely* defined as

$$IS_m = \frac{B_m^2 \sigma_m^2}{\sigma_T^2},$$

where B_m represents the element corresponding to medium size trades in the B vector.

However, if Ω is not diagonal, then IS_m is not uniquely defined as above. Instead, we have to resort to determining the upper and lower bounds, given by $\overline{IS_m}$ and $\underline{IS_m}$, by performing Cholesky factorizations of all possible rotations (i.e., permutations) of the disturbance term, ε. The information shares for the other trade size classes, small and large, are estimated similarly.

B. Operationalizing the Information Shares Metric

In our application of the Hasbrouck (1995) methodology, the price vector given by equation (1) comprises the transaction prices of small, medium, and large trades in the same option series during a trading session. The use of actual trade prices, although different from quotes that Hasbrouck (1995) uses, is similar to the inclusion of last sale trade prices in the price vector in Hasbrouck (2003), transactions prices in Chakravarty, Gulen, and Mayhew (2004), and trade prices of regular and E-mini S&P 500 and Nasdaq 100 futures contracts in Kurov and Lasser (2004), who also use the methodology on prices within a market (rather than across markets). Lehmann ((2002), p. 275), in his discussion of information shares technology, notes that "the market for trades of different size in a given market might be considered distinct (albeit related) venues even in the absence of a comprehensive model for both prices and quantities." Hasbrouck ((2003), p. 2385) discusses the appropriateness of using transaction prices for the analysis of price discovery.[5] For each option series (defined by the option type (call or put), the underlying stock, strike price, and the maturity date), we estimate the information share of small, medium, and large trades separately for each trading day. Each day of estimation is referred to as an "option-series-day," which

[5] Hasbrouck ((1995), p. 1184) discusses the generalization of the methodology to different kinds of price series or even non-price information such as trades or orders.

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represents each trading day for a particular option series that meets our selection criteria (outlined in Section IV.A).

The estimation procedure involves building a second by second series of prices for small, medium and large trades for each option series every trading day. We follow Hasbrouck in not including any inter-day price changes. Using this price vector, we estimate the VECM model in equation (3) using a lag of five minutes (300 seconds). We limit the number of coefficients using Hasbrouck's (2003) suggestion of second degree polynomial distributed lags over lags 1–10, 11–20, and 21–30, and moving averages over lags 31–60, 61–120, and 121–300. We set the number of periods in the VMA representation (to compute the impulse response functions) as 3,600 seconds (one hour). This number is set sufficiently high to allow forecasted prices to converge. We find that one hour is sufficient for options prices. Thus, the analysis yields a set of lower and upper bounds of information share estimates for each option series on each trading day that is included in the sample. We then calculate (and present in the tables) the means of these estimates (similar to Hasbrouck (2003)), and the *t*-statistics based on the standard errors of these means, either overall or based on a specific partitioning of the data. The number of option-series-days in the tables provides the number of distinct estimates comprising each aggregation category. The intraday option transactions data used for the estimations are described below.

IV. Data and Classification

A. Data

For our analysis, we use data from OPRA, the disseminator of options price and quote data for all options markets. Thus, we have time-stamped data on all trades that occur on all options exchanges from July 26, 1999 to October 28, 1999. We restrict our study to normal trading hours for options markets (9:30 AM–4:02 PM), and select all options traded on a sample of 100 firms displaying the highest option volume (including both puts and calls) over the sample period.[6] The nature of our data gives us two advantages over related studies in options markets that are based on the Berkeley Options data. First, it allows us a look at a more recent snapshot of options market trading activity, and second, it allows us to analyze informed trading activity using data from all options markets. We include *all* traded put and call option series on each underlying stock for each day in the sample that meets our selection criteria. For a particular option series to be included on a trading day, we require at least two trades in each of the trade size categories—small, medium, and large.[7] The Hasbrouck (1995) information shares estimation is performed on a daily basis, and requires an observation in all price series. We filter the data for obvious data errors. Prices equal to zero are eliminated. Trades are also identified as errors if they are more than four standard deviations away from the average price for the particular day.

[6]Data on total volume traded in options on an underlying stock is taken from the Options Clearing Corporation Web site (www.theocc.com).

[7]Thus, it is possible that different options series for a particular firm on a given day are not included if there are insufficient trades in that series that day. It could be included the next day, however, if there are sufficient trades in that series.

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Given that a national market system did not exist in options markets during our sample period, our choice of combining trades from all exchanges needs some discussion. The national market system in equities has three dimensions: i) availability of real-time quotes, ii) the trade through rule, and iii) the intermarket trading system, which allows order routing to a different exchange to avoid trade-throughs. In the options markets, real-time quotes from all exchanges are disseminated by OPRA and are available to market participants. Thus, brokers can make the appropriate order routing decisions that can lead to integrated options markets. The question then is: how frequently do trade-throughs occur in the options markets? The Securities and Exchange Commission (SEC) report on the "Firm Quote and Trade-Through Disclosure Rules for Options" (*Federal Register* (2000), Vol. 65, No. 151) provides an answer:

> . . . the considerable growth in the number of options classes traded on more than one exchange has significantly increased the likelihood that an order may be executed at a price that is inferior to a quoted price available on another exchange (i.e., intermarket trade through). According to preliminary data analyzed by the Commission's Office of Economic Analysis during the week of June 26, 2000, *only 5%* (emphasis added) of all trades in the 50 most active multiply-listed equity options were executed at prices inferior to the best price quoted on a competing market.

Thus, even in the absence of SEC mandated linkages, options markets seem to be linked either through best practices of the exchanges or the order routing decisions of brokers to make the issue less of a problem for our analysis.[8]

B. Trade Size Classification

We recognize that the classification of trades into small, medium, and large size categories is somewhat arbitrary and that these classifications, defined in the context of equity markets, may not be appropriate in options markets. Nevertheless, absent any strong priors about what these size classifications should be and mindful of the fact that options contracts are traded in units of 100 shares, we choose to follow the prescription of Barclay and Warner (1993) and Chakravarty (2001), and define small option trades as transactions of less than five contracts, medium option trades as transactions ranging from five to 99 contracts, and large option trades as transactions of 100 contracts or greater.

C. Summary Statistics

For the cross section of all option series in our data, Table 1, Panel A reports the mean price, average daily number of contracts traded, average moneyness, and TTM for all option-series-days used in the study for each trade size category

[8]The SEC report also notes that June 2000 represents a period in which the problem of trade-throughs is more severe than during our sample period. Hence, we believe that the 5% figure cited above is the worst case scenario for trade-throughs in our sample. Separately, in their analysis of the National Market System in options markets, Battalio, Hatch, and Jennings (2004) report a trade-through rate of 4.39% for retail orders in options markets in June 2000.

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in the sample. The averages are computed from the 15,146 option-series-days in our sample. For example, for each option-series-day we calculate the mean price for the day. Table 1, Panel A then presents the average of these daily mean prices. All other statistics are similarly calculated. The moneyness of an option series is calculated daily as the spot price divided by the strike price for call options and the strike price divided by the spot price for put options. Daily prices of the underlying stocks are obtained from the Center for Research in Securities Prices (CRSP) database.

There are three factors of interest in our analysis—moneyness, TTM, and liquidity of the option series—and their impact on informed traders' trade size choice. Hence, we provide sample statistics partitioned along these three criteria. Accordingly, Table 1, Panel B presents summary statistics for three moneyness categories: out-of-the-money (OTM) if moneyness is less than 0.9; ATM if it is between 0.9 and 1.1; and in-the-money (ITM) if it is greater than 1.1. ATM options account for a majority of the sample (10,672 option-series-days of a total of 15,146 option-series-days) since near-term ATM options tend to be the most actively traded option series. Furthermore, as expected, the average price for OTM options is the lowest while that of ITM options is the highest. The average moneyness ranges from 0.83 for OTM options to 1.19 for ITM options. Similarly, Table 1, Panel C describes the data by TTM. Once again, we divide the sample into three TTM categories: greater than 180 days to maturity; between 30 and 180 days to maturity; and less than 30 days to maturity. As mentioned above, we find that short-term (TTM less than 30 days) option series dominates the sample (8,275 of 15,146 option-series-days) followed by TTM 30–180-day options, and lastly by long-term (TTM greater than 180 days) option series. Average TTM ranges from 15 days for the short-term options to more than 200 days for long-term option series. Finally, Table 1, Panel D describes the sample by our third factor of interest: liquidity. We divide the sample into activity quartiles based on the number of trades during a trading day. While the average price across the four quartiles is similar (ranging from a high of \$4.33 for the lowest volume quartile to \$3.34 for the second-highest volume quartile), the average volume increases from an average of approximately 978 contracts traded a day in the lowest quartile to approximately 3,758 contracts traded a day in the highest activity quartile. We expect trading activity to increase as options move closer to maturity. This is reflected in the declining TTM across activity quartiles. For example, for the lowest volume quartile, the average TTM is 63 days, which reduces monotonically to around 26 days for the most active options.

V. Results

We now examine if significant price discovery in the options market occurs through trades of a particular trade size class in comparison to others. The work of Barclay and Warner (1993) and Chakravarty (2001) suggests that informed traders in the equity markets trade through medium size trades in place of small and large size trades. Thus, for example, if informed traders in the options markets fragment their trades into intermediate (or medium) sizes, we would expect medium size option trades to display a higher information share relative to small

TABLE 1

Descriptive Statistics

Table 1 describes the sample used in the study. Panel A describes the full sample. Panel B provides summary statistics for the three moneyness categories. Moneyness is defined as OTM if moneyness is less than 0.9, ATM if it is between 0.9 and 1.1, and ITM if it is greater than 1.1. Panel C describes the data in the three TTM categories. Panel D provides summary statistics for the sample divided into volume quartiles from the lowest to highest volume contracts. Every option series on each day is assigned into one of the four quartiles based on the number of trades during the day.

	No. of Underlying Stocks	No. of Option-Series-Days	Average Price	Average No. of Contracts Traded per Day	Average Daily Return of Underlying Stock	Moneyness	Time-to-Maturity (days)
Panel A. Overall	100	15,146	3.65	1,955.8	0.31%	0.96	43.54
Small (1–4 contracts)				49.34			
Medium (5–99 contracts)				763.09			
Large (100+ contracts)				1,143.37			
Panel B. Moneyness							
ATM	100	10,672	3.43	2,119.50	0.29%	0.98	36.73
ITM	89	1,092	11.28	1,649.34	1.42%	1.19	45.96
OTM	97	3,382	1.86	1,542.42	0.01%	0.83	64.12
Panel C. Time-to-Maturity							
$>$ 180 days	44	197	7.20	1,414.23	0.04%	0.92	205.83
30–180 days	100	6,674	4.39	1,596.21	0.22%	0.95	72.21
$<$ 30 days	100	8,275	2.95	2,267.76	0.39%	0.98	15.77
Panel D. Volume Quartiles							
1 (lowest)	100	3,799	4.33	977.93	0.06%	0.96	63.11
2	100	3,740	3.42	1,309.90	0.15%	0.96	48.24
3	97	3,860	3.34	1,770.96	0.37%	0.96	37.31
4 (highest)	79	3,747	3.52	3,757.56	0.65%	0.98	25.82

and large trades. Further, we expect this result to hold even after controlling for the respective proportions of trades and volume of the different trade size categories.

We begin our analysis by presenting the average of the estimated Hasbrouck information shares across small, medium, and large trade size categories (including puts and calls) for the overall sample (15,146 option-series-days). In Table 2, we see that price discovery occurs primarily in medium and small size trades in the options markets. For the overall sample, small size trades have an information share of approximately 40%.[9] Similarly, the information share of medium size trades is approximately 41%. Informed traders do not favor large trades. The difference between medium and small size trades is not significant at conventional levels. We should point out here that our comparison of the information share of medium and small size trades is based on a difference between the lower bound of the information share of medium size trades and the upper bound of the infor-

[9]This number includes estimates from 15,146 option-series-days. So, for example, if $i_{\min,s,n}$ is the lower bound of the information share associated with small trades on day n, then the number presented in Table 2 is simply $(\sum_{n=1}^{15,146} i_{\min,s,n})/15{,}146 = 39.87\%$. In our tables, we only present the midpoint of the upper and lower bounds of information shares as the bounds tend to be very narrow given that we compute information shares on a second by second basis. Recognizing that options are relatively illiquid compared to stocks, we also estimate information shares for small, medium, and large trades based on a one-minute interval (instead of the one-second interval used in the paper). The results are similar to the ones presented in the paper, although as expected the difference between upper and lower bounds of information share estimates is larger. Thus, the results reported in the paper are robust to interval choice.

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mation share of small size trades. This comparison provides the strongest test of differences between medium and small size trades.[10]

TABLE 2

Information Shares by Volume, Moneyness, and Maturity

Table 2 summarizes information shares for each trade size category—small (1–4 contracts), medium (5–99 contracts), and large (100 or more contracts) for volume quartiles within each of the 9 moneyness and TTM categories. Moneyness is defined as OTM if moneyness is less than 0.9, ATM if it is between 0.9 and 1.1, and ITM if it is greater than 1.1. Volume quartiles are based on number of trades during the day. The information share estimation is performed separately for each option series each trading day. The table presents the averages of these estimates. *t*-statistics are based on the standard errors of the means. We present the midpoint of the lower and upper bounds only. The upper and lower bounds are generally close with a maximum difference in any of the averages of 0.10 percentage points. The number of estimates in each category is reflected in the number of option-series-days.

							Comparing Medium and Small Trades			
Volume Quartiles	Moneyness	Maturity	No. of Option-Series-Days	Small	Medium	Large	Small Min–Medium Max	*t*-Statistic	Medium Min–Small Max	*t*-Statistic
Overall			15,146	39.89%	40.82%	19.29%			0.90%	1.81
1 (lowest)	ATM	> 180 days	64	57.40%	26.13%	16.48%	31.23%	3.34		
2	ATM	> 180 days	29	41.11%	28.19%	30.71%	12.89%	1.10		
3	ATM	> 180 days	9	30.51%	49.46%	20.04%			18.94%	0.85
4 (highest)	ATM	> 180 days	1	39.90%	39.34%	20.77%			−0.63%	
1 (lowest)	ATM	30–180 days	1,188	47.32%	36.09%	16.59%	11.21%	5.17		
2	ATM	30–180 days	1,092	45.32%	37.59%	17.10%	7.71%	3.96		
3	ATM	30–180 days	1,082	38.29%	42.65%	19.06%			4.33%	2.47
4 (highest)	ATM	30–180 days	779	34.02%	44.29%	21.69%			10.21%	6.60
1 (lowest)	ATM	< 30 days	887	42.74%	37.89%	19.39%	4.84%	1.94		
2	ATM	< 30 days	1,343	42.00%	39.20%	18.80%	2.78%	1.55		
3	ATM	< 30 days	1,785	37.61%	42.34%	20.07%			4.70%	3.43
4 (highest)	ATM	< 30 days	2,413	31.01%	48.79%	20.21%			17.71%	19.86
1 (lowest)	ITM	> 180 days	7	29.55%	51.68%	18.78%	−22.14%	−0.75		
2	ITM	> 180 days	3	37.83%	55.96%	6.21%	−18.14%	−0.43		
3	ITM	> 180 days	1	51.36%	48.64%	0.00%			−2.74%	
4 (highest)	ITM	> 180 days								
1 (lowest)	ITM	30–180 days	240	42.91%	34.96%	22.14%	7.89%	1.68		
2	ITM	30–180 days	131	44.06%	34.34%	21.61%	9.71%	1.8		
3	ITM	30–180 days	71	34.60%	47.01%	18.40%			12.39%	1.58
4 (highest)	ITM	30–180 days	26	41.26%	44.66%	14.09%			3.33%	0.39
1 (lowest)	ITM	< 30 days	213	45.92%	35.28%	18.82%	10.63%	2.17		
2	ITM	< 30 days	151	43.78%	38.85%	17.38%	4.92%	0.92		
3	ITM	< 30 days	141	31.02%	47.90%	21.09%			16.85%	3.41
4 (highest)	ITM	< 30 days	108	33.76%	48.90%	17.34%			15.08%	3.42
1 (lowest)	OTM	> 180 days	54	42.82%	41.66%	15.52%	1.09%	0.11		
2	OTM	> 180 days	24	63.57%	18.59%	17.85%	44.95%	3.88		
3	OTM	> 180 days	4	42.87%	42.94%	14.20%			0.02%	0
4 (highest)	OTM	> 180 days	1	42.54%	28.33%	29.13%			−14.29%	
1 (lowest)	OTM	30–180 days	835	45.79%	36.06%	18.16%	9.72%	3.73		
2	OTM	30–180 days	622	45.28%	37.41%	17.32%	7.86%	2.93		
3	OTM	30–180 days	413	42.72%	38.32%	18.96%			−4.45%	−1.58
4 (highest)	OTM	30–180 days	195	36.34%	39.51%	24.16%			3.12%	0.94
1 (lowest)	OTM	< 30 days	311	41.27%	41.91%	16.83%	−0.65%	−0.15		
2	OTM	< 30 days	345	43.02%	36.91%	20.08%	6.09%	1.71		
3	OTM	< 30 days	354	40.38%	37.37%	22.25%			−3.05%	−0.67
4 (highest)	OTM	< 30 days	224	33.62%	40.26%	26.13%			6.58%	2.23

From the above analysis, we find evidence of trade size fragmentation, but we are unable to say anything about when either medium or small size trades would be preferred by informed traders. This brings us to the second objective of this study, wherein we investigate the relation (if any) between price discovery attributable to distinct trade size classes and the role of option volume, money-

[10]We thank the referee for suggesting this comparison.

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ness (i.e., leverage), and TTM of the option series in our data. Recent research (see, for example, Lee and Yi (2001), Kaul, Nimalendran, and Zhang (2002), and Chakravarty, Gulen, and Mayhew (2004)) on the microstructure of stock and option markets suggests that there might be important linkages between price discovery and the aforementioned option characteristics.

A. Leverage/Liquidity Trade-Off and Price Discovery

In this section, we attempt to disentangle the effects of moneyness, TTM, and liquidity of an option contract on the informed trader's trade size choice.

To tease out the relation between stealth trading, option leverage, and option volume, we first partition our sample into moneyness categories (ATM, ITM, and OTM) and then, within each of these categories, by TTM and then, within each TTM class, by the option volume quartiles from the lowest (quartile 1) to the highest (quartile 4). The corresponding average information shares are provided in Table 2. Note that by construction different categories will have different numbers of option-series-days in this table, which occur because the volume quartiles are constructed across all option-series-days. Thus, if ATM, TTM less than 30 days options tend to be more liquid, then more of these options will fall in the highest volume quartile, than, for instance, for ATM, TTM greater than 180 days options. We test for differences across information shares of small and medium size trades by comparing the lower bound of the trade size category with the higher information share and the upper bound of the trade size category with the lower information share. In the current context, this is operationalized by using the difference between the lower bound of information share of small size trades and the upper bound of information share for medium size trades for volume quartiles 1 and 2, and the difference between the lower bound of information share of medium size trades and the upper bound of information share of small size trades for volume quartiles 3 and 4.

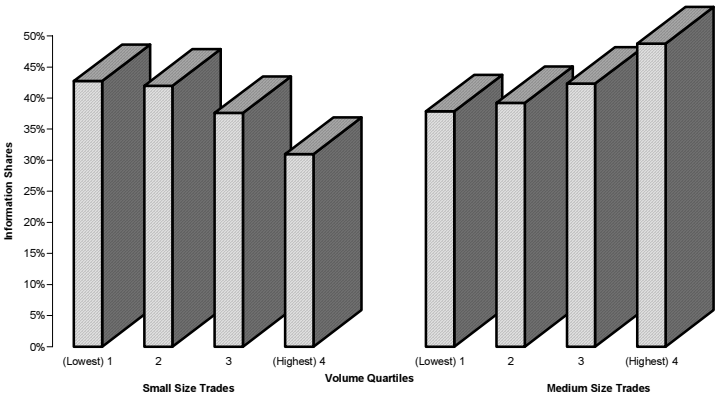
From Table 2, we see that for ATM, TTM greater than 180 days options, the price discovery either lies primarily with small size trades or is, at best, indistinguishable between small and medium size trades. This is also a very small subsample, as is evident from the frequency of the option-series-days, which ranges from 64 to one. As we move to ATM, TTM 30–180 days options, the subsample size increases considerably (ranging from 779 option-series-days to 1,188 option-series-days). Here, the trade-off between volume, moneyness, and TTM is easy to see. For higher volume option series (volume quartiles 3 and 4), medium size trades account for the largest information share, while for lower volume option series (quartiles 1 and 2), small size trades are associated with a higher information share. These differences are also statistically significant. The same pattern is observed for the contracts with TTM less than 30 days. Next, we look at ITM contracts. Here, focusing on the contracts with the largest subsample size (i.e., the closest to maturity contracts), we see the same pattern of price discovery, i.e., largest contribution from small size trades for the relatively lower volume contracts and from medium size trades for the relatively higher volume contracts holds.

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To better illustrate the pattern in Table 2, we plot the midpoints of lower and upper bounds of information shares of small and medium size trades for near-term (TTM less than 30 days) ATM options in Figure 1. The information shares are plotted separately for each volume quartile. We see that small size trades tend to have a higher information share in lower volume quartiles and medium size trades contribute more in higher volume quartiles.

FIGURE 1

Figure 1 plots the midpoints of information shares of small and medium trades for ATM options with less than 30 days to maturity. Results are plotted separately for each volume quartile.



We also want to ensure that our analysis captures informed stealth trading to the exclusion of reasonable alternatives. For instance, if the price discovery attributed to a given trade size class is proportional to the fraction of transactions in that trade size category, it would indicate that the price discovery is caused by the release of public information (the public information hypothesis). Yet, another possibility, following the intuition laid out in Easley and O'Hara (1987), is that relatively larger trades are associated with greater price discovery than smaller trades. If this is indeed the case, we would expect to see the price discovery in each trade size category to be proportional to the fraction of the total trading volume in that category (the trading volume hypothesis). Consistent with these arguments, we compare the predictions of the stealth-trading hypothesis with those of the two alternatives—the trading volume hypothesis and the public information hypothesis. Our alternative hypotheses thus provide the needed benchmark against which to test for the presence of stealth trading in the options markets.

To test the trading volume hypothesis, we estimate the least squares regressions of the midpoints of the estimated lower and upper bounds of information shares attributable to each option trade size category on an option-series-day, dummy variables for each trade size category, and the percentage of the total trading volume occurring in that category on the particular option-series-day. These regressions are similar to those estimated by Barclay and Warner (1993) and, in our case, are estimated separately for each moneyness, maturity, and volume category (we are not able to estimate the regressions for options with maturity greater

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than 180 days due to the paucity of observations in the category). According to the trading volume hypothesis, the coefficient on each trade size dummy variable should be zero and the coefficient on the proportion of volume in that trade size category should be one. Across all estimated categories, the test of the volume coefficient being one is rejected convincingly (at the 1% level). Thus, we rule out the trading volume hypothesis. Further, we find that small and medium size trades continue to contribute most to price discovery. Similar to the trend we saw in Table 2 for ATM options, small trades contribute more in the lower volume quartiles and medium size trade in the higher volume quartiles. The differences are highly statistically significant (except for one category, ATM, LT 30 days, volume quartile 2, where the information share of small and medium size trades is statistically indistinguishable). ITM options display a similar trend (small trades with a higher information share for lower volume quartiles and medium trades with a higher information share for higher volume quartiles). OTM options either show a higher information share for small size trades (in the lower volume quartiles) or a statistically indistinguishable information share of medium and small trades (in the higher volume quartiles). Thus, these results are consistent with those reported in Table 2.

The regressions to test the public information hypothesis use the percentage of trades occurring in a size category on the particular option-series-day as the control variable. According to the public information hypothesis, the coefficient on each trade size dummy variable should be zero and the coefficient on the proportion of trades in that trade size category should equal one. Once again, the test of the coefficient of proportion of trades being one is rejected convincingly (at the 1% level in all but two of the estimations where it is rejected at the 5% level). The results on small and medium size trades are similar to those discussed above in the test of the trading volume hypothesis, and once again confirm our finding of a higher information share of small trades in the lower volume quartiles and medium size trades in the higher volume quartiles.[11]

So far we categorize options by three criteria (moneyness, maturity, and volume) likely to factor into the informed trader's choice of trade size. Our univariate results indicate that volume is perhaps the most important of the three. To confirm and clearly establish this result, we use a multivariate framework wherein we perform cross-sectional regressions across option-series-days of the information shares (we use the average of the minimum and maximum information share as the dependent variable) attributable to i) medium and ii) small size trades, on dummy variables for each moneyness-TTM category, dummies for volume quartiles, and a measure of volatility in the underlying stock (squared daily return of the underlying stock obtained from CRSP). The inclusion of volatility as a control variable is consistent with the regression specification in Chakravarty, Gulen, and Mayhew (2004). For the regression with the information share attributable to medium size trades as the dependent variable, we see that after controlling for moneyness and TTM, volume remains the one positive significant determinant of price discovery (the dummies for volume quartiles 3 and 4 are positive and highly significant, while the volume quartile 2 dummy is positive but not signif-

[11] For brevity, we do not present detailed tables with these results. The results are available from the authors and similar tests (for fewer aggregations) are presented later in the paper.

icant). The implication is that for higher volume option series, the information share attributable to medium size trades is also higher in the higher volume quartiles, while moneyness and TTM do not seem to play an important role in the trade size choice of informed traders. The second regression has the information share attributable to small size trades as the dependent variable and the same independent variables. Here we see that moneyness and TTM once again do not play any significant role in price discovery while volume has a negative impact on information share of small size trades as displayed by the significant negative coefficients for higher volume quartiles.[12]

In sum, we find that of the three factors—moneyness, TTM, and liquidity—trade size choice by informed traders is driven by liquidity alone. Given the dominant role of liquidity, we focus solely on liquidity in the next section.

B. Price Discovery by Option Volume Quartiles

The results from the previous section indicate clearly that option volume plays the determining role in price discovery attributable to either small or medium size option trades. We now closely examine this relation. Our analysis is also consistent with Brennan and Subrahmanyam (1998) who, within the context of equity markets, formalize the axiomatic intuition that trade sizes used by informed traders vary inversely with market illiquidity. In Table 3, Panel A, we present the upper and lower bounds of the information shares corresponding to the three trade size classes aggregated by option volume quartiles (based on the number of trades during each day of our data).

Table 3 shows that as volume increases, the relative price discovery attributable to small size trades goes down while that attributable to medium size trades goes up. At the two extremes, for the lowest volume quartile (quartile 1), the average information share of small (medium) size trades is 45.1% (36.8%); while for the highest volume quartile (quartile 4), the average information share for small (medium) size trades is about 32.2% (46.8%). Here again we compare the lower bound of information share of small size trades with the upper bound of information share of medium size trades in volume quartiles 1 and 2, and the lower bound of information share of medium size trades with the upper bound of information share of small size trades in quartiles 3 and 4. The differences are highly statistically significant. These results provide strong evidence that price discovery in the options market vis-à-vis traders' trade size choice is a function of the liquidity of the option contract.

As discussed earlier, we need to test the stealth-trading hypothesis against the alternative trading volume and public information hypotheses. In Table 3, Panel B we perform these tests. Accordingly, Table 3, Panel B1 presents results of least squares regressions of the midpoints of the estimated lower and upper bounds of information shares attributable to each option trade size category on an option-series-day, on dummy variables for each trade size category, and the percentage

[12] As a further check of robustness, we reestimate the regressions with the daily number of contracts traded as the measure of volume, instead of volume quartiles. All of our results remain qualitatively similar. We also estimate an alternate specification by using dummies for each moneyness-TTM-volume quartile category. Results, once again, support our conclusions.

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TABLE 3

Information Shares by Volume Quartiles

Panel A summarizes information shares for each trade size category for volume quartiles based on number of trades during the day. The information share estimation is performed separately for each option series each trading day. Table 3 presents the averages of these estimates. *t*-statistics are based on the standard errors of the means. We present the midpoint of the lower and upper bounds only. The upper and lower bounds are generally close with a maximum difference in any of the averages of 0.07 percentage points. The number of estimates in each category is reflected in the number of option-series-days. Panel B1 presents the results of the regressions of the information share associated with a trade size category on a particular option-series-day, on dummies for small, medium, and large trades, and the proportion of volume associated with the trade size category on that option-series-day. Panel B2 uses the proportion of trades associated with the trade size category as the control. In Panel B, ** indicates significance at the 1% level, while * indicates significance at the 5% level using an *F*-test.

Panel A. Volume Quartiles

					Comparing Medium and Small Trades			
Volume Quartiles	No. of Option-Series-Days	Small	Medium	Large	Small Min-Medium Max	*t*-Statistic	Medium Min-Small Max	*t*-Statistic
1 (lowest)	3,799	45.13%	36.80%	18.07%	8.31%	6.85		
2	3,740	43.88%	37.83%	18.29%	6.03%	5.65		
3	3,860	38.30%	41.85%	19.86%			3.52%	3.85
4 (highest)	3,747	32.22%	46.83%	20.95%			14.54%	20.18

Panel B.

Panel B1

Volume Quartiles	No. of Option-Series-Days	Small	Medium	Large	Proportion of Volume	Test Small = Medium	Test Small = Large	Test Medium = Large	Test Proportion of Volume = 1
1 (lowest)	3,799	0.45**	0.35**	0.10**	0.11**	89.88**	229.68**	197.75**	948.72**
2	3,740	0.44**	0.36**	0.15**	0.06**	51.83**	365.18**	488.76**	1,836.98**
3	3,860	0.38**	0.39**	0.17**	0.05**	1.88	335.03**	977.76**	2,480.20**
4 (highest)	3,747	0.32**	0.45**	0.19**	0.04*	149.11**	222.49**	1,501.80**	3,373.91**

Panel B2

Volume Quartiles	No. of Option-Series-Days	Small	Medium	Large	Proportion of Trades	Test Small = Medium	Test Small = Large	Test Medium = Large	Test Proportion of Trades = 1
1 (lowest)	3,799	0.39**	0.26**	0.14**	0.21**	132.04**	743.41**	97.52**	743.17**
2	3,740	0.42**	0.33**	0.18**	0.07**	46.63**	728.09**	97.97**	1,133.12**
3	3,860	0.37**	0.41**	0.20**	0.02	6.62*	357.67**	147.13**	1,254.16**
4 (highest)	3,747	0.25**	0.33**	0.20**	0.22**	48.73**	25.20**	48.13**	702.28**

of the total trading volume occurring in that category on the particular option-series-day. These regressions are estimated separately for each volume quartile. According to the trading volume hypothesis, the coefficient on each trade size dummy variable should be zero and the coefficient on the proportion of volume in that trade size category should be one. From Panel B1, across all volume quartiles we convincingly reject the hypothesis that the coefficient of proportion of volume equals one. This rules out the trading volume hypothesis. Next, we find that for volume quartiles 1 and 2 (the relatively low volume quartiles), the coefficient on the small trade size dummy is statistically the largest, while in volume quartiles 3 and 4 (the relatively high volume quartiles), the coefficient on the medium size dummy is statistically the largest.[13] Thus, from Panel B1, while there appears to be no support for the trading volume hypothesis, the results are consistent with the stealth-trading hypothesis. Further, stealth trading takes place through small

[13]The comparisons are based on *F*-tests. The test statistics are provided in Table 3.

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size option trades in the relatively illiquid option contracts and through medium size trades in the relatively liquid option contracts.

In Table 3, Panel B2 we estimate least squares regressions of the midpoints of the lower and upper bounds of the information share attributable to each option trade size category on an option-series-day, on dummy variables for each category, and the percentage of all transactions occurring in that trade size category on the particular option-series-day. As before, the regressions are run separately for each option volume quartile. Under the public information hypothesis, the coefficient on each dummy variable should be zero and the coefficient on the percentage of transactions in that trade size category should be one. From Panel B2, we see that the coefficient estimates are not consistent with the public information hypothesis. Specifically, the hypothesis that the coefficient for the percentage of option transactions is equal to one can be rejected at the 0.001 level of significance. The hypothesis that all dummy coefficients are equal to each other can also be convincingly rejected. Finally, we see that in volume quartiles 1 and 2, the coefficient on the small trade size dummy is statistically the largest while in volume quartiles 3 and 4, it is the medium size dummy coefficient that is statistically the largest. We conclude that the information share attributable to each option trade size category is not driven by the proportion of trades in that category. We also find that small size trades have the largest information share in volume quartiles 1 and 2, and medium size trades have the largest information share in volume quartiles 3 and 4, even after controlling for their proportion of trades. These findings are highly consistent with the stealth-trading hypothesis to the exclusion of the public information hypothesis.

C. Trading Venue, Trade Size, and Price Discovery

Given our finding that volume drives the trade size choice for informed traders, we take another step to increase our understanding of the importance of liquidity for informed traders by examining the role trading venue plays in an informed investor's trade size choice.[14] Extant literature, either in equities or in options, does not address this question. In related research, Hasbrouck (1995) finds that an overwhelming majority of the price discovery in the Dow 30 stocks occurs on the NYSE, which would imply that informed traders tend to trade on the NYSE (the dominant exchange for the NYSE-listed Dow stocks) in preference to the regional stock exchanges. If these informed traders attempt to hide their information by splitting their trades into medium size trades, we should see medium size trades associated with higher price discovery in the dominant exchange and not in the other (non-dominant) exchanges. Underpinning our analysis is the intuition that an informed trader is likely to choose the options market venue (and option trade size) that best protects her ability to hide. Outside the context of NYSE-listed stocks, however, it is also not clear that a particular exchange would

[14]During our sample period, options in the U.S. trade in the CBOE, The Pacific Exchange, the Philadelphia Stock Exchange, and the American Stock Exchange. The International Securities Exchange has since started trading options as well.

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dominate trading in a class of securities.[15] Thus, such an exchange will vary across different options. Specifically, we classify the option exchange with the highest market share (in contract volume) in options on a particular underlying stock as the "dominant" exchange for options on that stock. Thus, our reference to a dominant exchange does not refer to a particular exchange like the CBOE or Philadelphia but rather to any of the four option exchanges that may have the highest market share for the options of a given stock in our data.

In this analysis, we focus on trade sizes within the dominant exchange and the other three exchanges grouped together. Thus, our estimation of information shares now spans six price series: small, medium and large for the dominant exchange, and other exchanges as a group (defined as other exchanges in Table 4). Other details of the estimation are identical to the description in Section III. The requirement of observations in six price series dramatically reduces the sample size (and skews it toward the more liquid options,) but still allows us to draw the necessary intuitions from the analysis. The results are presented in Table 4. In the results, we present average information shares aggregated by volume quartiles based on the number of trades in the option-series-day (similar in structure to Table 3, Panel A).[16]

From Table 4, we see that a majority of the price discovery occurs in the dominant exchange—around 58% for volume quartiles 1, 2, and 4, and 53% for volume quartile 3. Further, medium size trades on the dominant exchange are responsible for the highest levels of price discovery. The relation between price discovery for medium size trades on the dominant exchange and volume follows a familiar trend, increasing from 22% for the lowest volume quartile to 28% for the highest volume quartile. Also, the price discovery attributable to medium size trades on the dominant exchange is statistically indistinguishable from price discovery in small trades for the two lower volume quartiles, but significantly greater for the higher quartiles. The information share of medium size trades on the dominant exchange is consistently statistically higher than the information share of medium size trades on other exchanges collectively. In sum, the evidence presented in the current section shows that informed traders do in fact look for volume in the options of the firm of interest and then fragment their trades in that exchange.

D. Information Shares across Option Series for a Given Underlying Stock

Our results so far rely on estimation within each option series. While that approach is well suited to answer questions about the trade size choice of informed traders given the characteristics (moneyness, maturity, and volume) of the option series, it does not allow us to examine possible interactions across option series for a given stock. Thus, for example, if an informed trader has information about a given stock, which option series is she likely to prefer for her trades?

[15] In our specific case, option volume tends to concentrate in different exchanges for different options, and although CBOE had the largest market share among options exchanges during our sample period, it is nowhere near as overwhelming as the NYSE's for NYSE-listed stocks.

[16] Given our earlier result that volume is the most important factor in trade size choice, we do not present results by moneyness and TTM.

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TABLE 4

Information Shares—Choice of Exchange

Table 4 summarizes information shares for each trade size category—small (1–4 contracts), medium (5–99 contracts), and large (100 or greater contracts) for the exchange with the largest market share in options on a specific underlying stock (Dominant Exchange) and for the other 3 exchanges combined (Other Exchanges). Results are presented by volume quartiles, which are based on number of trades during the day. The information share estimation is performed separately for each option series each trading day. The table presents the averages of these estimates. *t*-statistics are based on the standard errors of the means. We present the midpoint of the lower and upper bounds only. The upper and lower bounds are generally close with a maximum difference in any of the averages of 0.12 percentage points. The number of estimates in each category is reflected in the number of option-series-days.

Volume Quartiles	1 (lowest)	2	3	4 (highest)
Dominant Exchange				
Number of option-series-days	118	118	118	118
Small	19.95%	21.57%	14.16%	15.26%
Medium	22.21%	22.33%	27.22%	28.36%
Large	15.73%	14.25%	11.62%	14.38%
Medium Min–Small Max	2.23%	0.70%	12.99%	13.00%
t-Statistic	0.65	0.22	5.07	5.41
Other Exchanges				
Small	12.50%	16.09%	14.79%	11.41%
Medium	15.88%	14.17%	16.44%	16.42%
Large	13.75%	11.61%	15.78%	14.18%
Medium Min–Small Max	3.35%	−1.97%	1.60%	4.95%
t-Statistic	1.16	−0.71	0.61	2.3
Dominant Medium Min–Other Exchanges Medium Max	6.30%	8.11%	10.72%	11.84%
t-Statistic	1.97	2.89	4.06	4.63

To examine this issue, we analyze the 20 stocks in our data that have the highest option volume traded on them. We use the standard Black-Scholes option pricing formula with dividends to invert the stock price from the option price. The volatility we use is the implied volatility of the option calculated using a price that is at least 30 minutes old in the same option series identified by a set strike price and maturity.[17] We use a previous price in the same option series to account for the volatility smile documented in the literature. The quoted price of the underlying stock (obtained from the TAQ database), prevailing at the time of the option trade, is used as the price of the underlying stock.

Having constructed an equivalent stock price for each option trade we use Hasbrouck's methodology to conduct the analysis described above. We use three price series: ATM calls, other (ITM and OTM) calls, and all puts. Limiting the price series allows estimation possible in the largest sample, since we need observations in all series (in a normally data intensive procedure) for estimating the information shares.

We see that the largest proportion of the information share is displayed by ATM calls. The average information share for ATM calls is 52.6%. All other call options have an average information share of 34%, while put options have an information share of 13.4%. Furthermore, the differences between the minimum information share for the ATM calls and the maximum information share for the two other categories are statistically significant at the 0.01 level. This finding is robust over the whole sample as well as when partitioned by up days and down days where up days are defined as the top 25% of daily price changes in the underlying stocks while down days are defined as the bottom 25%. In our data,

[17] We limit this analysis to a sample of the most liquid options since we need enough trades to have a recent estimate of implied volatility in our equivalent stock price calculations. Further, we also need trades in option series (on the same underlying stock) in the three categories on the same day.

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this translates into up days having a return greater than 1.3% and down days as a return of less than −1.8%. Puts do not appear to contribute significantly to price discovery, although they contribute more on down days (the information share of put options on down days is 16.4% as compared to 12.61% on up days). In sum, we find strong evidence to suggest that informed traders appear to favor trades in ATM calls.

VI. Concluding Discussion

We examine the issue of price discovery in the options markets through transactions of various trade size classes. In so doing, we also address the issue of strategic fragmentation of informed trades into intermediate sizes, or stealth trading, in options transactions. While recent research establishes that a significant amount of price discovery takes place in the options market, it is not able to identify *how* this price discovery takes place. The current study takes the crucial next step. Using proprietary intraday transactions data and a robust empirical methodology proposed by Hasbrouck (1995), we show that price discovery in the options markets primarily occurs through small and medium size trades. For liquid contracts (i.e., higher option volume), the largest contribution to price discovery comes from medium size trades while for relatively illiquid contracts the largest fraction of price discovery is associated with small size trades. We also show that the strategic fragmentation of trades by informed traders, and the price discovery that follows such actions, is a function of the volume of the options contract: the moneyness and the time-to-maturity of the options do not appear to play a major role after controlling for liquidity. The implication is that informed traders act strategically in fragmenting their orders depending on the liquidity in the contract that affects their ability to hide.

Our investigation into price discovery across the dominant versus non-dominant options exchanges yields insights consistent with our earlier findings. A majority of the price discovery occurs in the dominant market for a given option contract. The relation between price discovery attributable to medium size trades in the dominant exchange and volume follows the familiar positive trend. The information share attributable to medium size trades in the dominant exchange is also significantly higher than that in the non-dominant markets.

Finally, we analyze informed traders' choice of option series for each of the 20 stocks in our data with the highest option volume traded on them. Our analysis is motivated by the desire to understand which of the several option series traded on a stock are preferred by informed traders. We find that the largest information share is exhibited by at-the-money calls. Puts do not appear to contribute significantly to the price discovery process except in those days when the underlying stocks go down significantly in price, but even then their relative information share is superseded by at-the-money calls. Our findings imply that informed traders prefer at-the-money calls to execute their option trades.

Our findings enhance our understanding of how informed traders trade in the options markets and the price discovery that follows such strategic trade fragmentation as a function of the volume of the option contract.

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