

Directional Trading across Stock Limit Order Book and Options Markets

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This article examines the dynamic directional trading across stock limit order book and options markets using a sample of NYSE-listed stocks from November 2007 to January 2008. I find that stock limit order book aggressiveness and directional trading in the options markets Granger-cause each other. Further, percentages of stocks with Granger-Causality running in either or both directions between stock and option variables are bigger at the beginning and at the end of the day, and also bigger for large than for small bid-ask spread at the beginning and at the end of the trading day, and for OTM options.

The dynamic relationship across stock and options markets has spurred a lot of academic interests (see, e.g., Manaster and Rendleman [1982]; Anthony [1988]; Stephan and Whaley [1990]; Vijh [1990]; Kumar, Sarin, and Shastri [1992]; Figlewski and Webb [1993]; Lamoureux and Lastrapes [1993]; Mayhew, Sarin, and Shastri [1995]; Amin and Lee [1997]; Easley, O'Hara, and Srinivas [1998]; Chan, Chun, and Fong [2002]; Chakravarty, Gulen, and Mayhew [2004]; Cao, Chen, and Griffin [2005]; Schlag and Stoll [2005]; Pan and Poteshman [2006]; Ni, Pan, and Poteshman [2008]; Chan, Chang, and Lung [2009]). Besides, the literature documents that stock limit orders are informed (see, e.g., Biais, Hillion, and Spatt [1995];

Handa and Schwartz [1996]; Harris and Hasbrouck [1996]; Cao, Hansch, and Wang [2009]; Kavajecz and Odders-White [2004]; Anand, Chakravarty, and Martell [2005]; Bloomfield, O'Hara, and Saar [2005]; Harris and Panchapagesan [2005]; Kaniel and Liu [2006]). It would be interesting to examine whether and how the stock limit order book may contribute to the cross-market dynamic directional trading. However, little evidence has emerged in this regard.

I analyze how the stock limit order book aggressiveness and option directional trading interact with each other in the cross-market setting. I find that the stock limit order book aggressiveness and option directional trading Granger [1969, 1980] cause each other. Further, percentages of stocks with Granger-Causality running in either or both directions between stock and option variables are bigger at the beginning and at the end of the day, for large than for small bid-ask spread at the beginning and at the end of the trading day, and for OTM options.

Copeland and Galai [1983] and Berkman [1996] show that limit orders are subject to picking off risk which arises when quotes do not timely reflect all available public information. Parlour and Seppi [2008] point out that the picking-off risk and non-execution risk inherent in limit orders indicate that limit order books should contain forward-looking information about

future market conditions. Glosten [1994]; Seppi [1997]; and Foucault [1999] indicate that limit order submitters suffer from a winner's curse, namely, that limit order non-execution risk is negatively related to the probability of incurring a loss. Griffiths et al. [2000] find that the stock limit order traders' monitoring costs and level of patience affect the tradeoff between picking-off and non-execution risk, and thus the price aggressiveness of the stock limit order book.

These studies indicate that stock limit order submitters can adjust the aggressiveness of stock limit order submissions based on directional signals from directional-related option volumes, while option traders can adjust option directional trading based on predicted future changes in stock price direction inferred from the aggressiveness of the stock limit order book. Besides, directional-informed stock traders would place stock buy limit orders more aggressively and adjust their stock sell limit orders less aggressively in response to increasing future stock price as signaled by heightened option directional buy. Directional-informed stock traders would become more aggressive in sell limit order submissions and less aggressive in buy limit order submissions in response to decreasing future stock price as signaled by increasing option directional sell.

Similarly, directional-informed option traders would increase directional buying activities, including buying calls and/or selling puts, and decrease directional selling activities such as selling calls and/or buying puts in response to an increase in the aggressiveness of buy-side stock limit order book, while decreasing directional buying activities and/or increasing directional selling activities in response to a decrease in the aggressiveness of the buy-side stock limit order book.

VARIABLE CONSTRUCTIONS

StockAggressiveBuy and *StockAggressiveSell* are constructed to measure the aggressiveness of the stock limit order book on the buy and sell sides, respectively. I first calculate the total depth on each side of the limit order book and the ratio of the depth at each price step to the total same-side depth of the book. I then construct stock aggressiveness variables by taking the weighted average of the depth ratios on each side of the book, with the weight being the inverse of the absolute value of the difference between the corresponding price and the prevailing midpoint of the inside spread on the limit order book.

For example, suppose the buy side of the stock limit order book only includes one buy limit order with bid price \$100 and depth 200 shares, and another buy limit order with bid price \$102 and depth 300 shares, and the prevailing midpoint of the inside spread on the book is \$103. The total depth on the buy side of the book is 500 shares, which is the sum of 200 shares and 300 shares. The weight for the buy limit order with bid price \$100 and depth 200 shares is $1/|100 - 103|$, and the weight for the buy limit order with bid price \$102 and depth 300 shares is $1/|102 - 103|$. $StockAggressiveBuy = (200/500) * 1/|100 - 103| + (300/500) * 1/|102 - 103| \approx 0.73$.

I construct *OptionDirectionalBuy* by the absolute value of the sum of delta-weighted buyer-initiated calls and seller-initiated puts, and construct *OptionDirectionalSell* by the absolute value of the sum of delta-weighted seller-initiated calls and buyer-initiated puts. I also decompose *OptionDirectionalBuy* into *OptionDirectionalBuy_c* and *OptionDirectionalBuy_p*, where *OptionDirectionalBuy_c* is the absolute value of the total number of delta-weighted buyer-initiated calls, and *OptionDirectionalBuy_p* is the absolute value of the total number of seller-initiated puts, and decompose *OptionDirectionalSell* into *OptionDirectionalSell_c* and *OptionDirectionalSell_p*, where *OptionDirectionalSell_c* is the absolute value of the total number of delta-weighted seller-initiated calls, and *OptionDirectionalSell_p* is the absolute value of the total number of delta-weighted buyer-initiated puts. One option contract is one-option-one-share.

For example, during a five-minute interval on a trading day, there are two buyer-initiated calls and five seller-initiated puts, and the deltas for the two calls and five puts are 0.4, 0.6, 0.3, 0.5, 0.7, respectively. *OptionDirectionalBuy* is $|1*0.4 + 1*0.6 + 1*0.3 + 1*0.5 + 1*0.7| = 2.5$. Another example is that there are two seller-initiated calls and five buyer-initiated puts, and the deltas for the two calls and five puts are -0.4, -0.6, -0.3, -0.5, -0.7, respectively. *OptionDirectionalSell* is $|1*(-0.4) + 1*(-0.6) + 1*(-0.3) + 1*(-0.5) + 1*(-0.7)| = 2.5$.

METHODOLOGIES

I use 78 five-minute intervals on each trading day (9:30 A.M. EST to 4:00 P.M. EST) based on Stephan and Whaley [1990] and Easley, O'Hara, and Srinivas [1998], and construct stock aggressiveness variables and option trading variables for each five-minute interval. I normalize each series by subtracting the mean and

dividing by the standard deviation for each day to control for cross-sectional variations across different stocks and options. Augmented Dickey-Fuller tests on normalized series show that these series are stationary and are then used in the VAR analysis.

I use the following system in the analysis:

$$S_t = \sum_{i=1}^K \alpha_i S_{t-i} + \sum_{i=1}^K \beta_i O_{t-i} + \sum_{i=1}^K \phi_i^S Volume_t^S + \sum_{i=1}^K \theta_i^S RelSpread_{t-i}^S + \sum_{i=1}^K \vartheta_i^S Volume_{t-i}^O + \sum_{i=1}^K \tau_i^S RelSpread_{t-i}^O + \rho_t^S Volatility_t^S + u_t, \quad (1)$$

$$O_t = \sum_{i=1}^K \gamma_i S_{t-i} + \sum_{i=1}^K \delta_i O_{t-i} + \sum_{i=1}^K \phi_i^O Volume_t^S + \sum_{i=1}^K \theta_i^O RelSpread_{t-i}^S + \sum_{i=1}^K \vartheta_i^O Volume_{t-i}^O + \sum_{i=1}^K \tau_i^O RelSpread_{t-i}^O + \rho_t^O Volatility_t^S + \varepsilon_t, \quad (2)$$

where S_t is a 2 by 1 vector that represents the aggressiveness of the buy and sell sides of the stock limit order book, O_t is a 2 by 1 vector that represents the option directional buy and sell, or a 4 by 1 vector that represents the four components of the option directional buy and sell, $Volume^S$ is the stock trading volume in shares, $RelSpread^S$ is the stock relative spread, namely, bid-ask spread divided by the midpoint of the bid-ask spread, $Volume^O$ is the delta-weighted option trading volume summed over all the options for the same underlying stock, $RelSpread^O$ is the option relative spread defined as the option dollar volume-weighted average of option relative spread over all the options for the same underlying stock, and $Volatility^S$ is the square root of the sum of squared five-minute log stock returns over the past 78 five-minute intervals. K is the number of lags. In my empirical estimation, I choose K based on the Akaike, Schwartz, and Hannan-Quinn information criteria. If these three criteria indicate different lag lengths, I choose the lesser one for the sake of parsimony.

I follow the technique described in Kavajecz [1999] and reconstruct each stock's limit order book. In particular, starting with the provided snapshot of the limit order book as of the close of operation of the open

book system on the previous day, I first select incremental changes to the number of shares for each price point for each stock before the chosen time, and then sum shares by price point on the buy and sell sides. Finally, I eliminate price points where the total number of shares is zero. The resulting set of orders is the estimate for the limit order book for the chosen time on that day. I sequentially update limit order book estimates every five minutes from 9:30 A.M. EST until 4:00 P.M. EST.

DATA

There are several data sources for this article. The NYSE OpenBook History (Openbook) database provides the aggregate limit-order volume at every bid and offer price for all NYSE-traded securities throughout each trading day. I exclude the quotes posted far from the mid-quote, since these quotes are stale and not informative most of the time (Cao, Hansch, and Wang [2009]), and use the top 10 levels of the book to construct the aggressiveness variables of the stock limit order book from this database. Option volumes are extracted from the Options Price Reporting Authority (OPRA) database, which contains a complete record of quote and trade prices of options traded on all U.S. options exchanges time-stamped to the nearest second. Data on ex-dividend dates and daily cash dividends are from the Center for Research in Security Prices (CRSP) database. Ask yields of daily Treasury bills matching maturities of options are hand-collected from Bloomberg as risk-free rates. High-frequency quotes and trades at five-minute intervals are obtained from the trade and quote (TAQ) database. My sample period is from November 1, 2007, to January 31, 2008, since my OPRA data only cover this period, and my sample covers 529 firms with 6,889 pairs of option-stock days.

I discard stocks in financial services (SIC 6000-6999), stocks in regulated utilities (SIC 4800-4829 and 4910-4949), foreign stocks, stocks with prices less than \$5, stocks that split, stocks that experience mergers and acquisitions, and stocks with no data in TAQ during my sample period. I apply the following exclusion filters to the option data to obtain a clean options sample: I delete quotes not satisfying the no-arbitrage restrictions, quotes lower than \$0.375, trades with condition code P with code P representing the option portion of an order involving a single option leg (buy or sell of a call or a put) and stock, trades with less than or equal to a week

to maturity, option-stock days with less than or equal to 50 option trades per day, trades on ex-dates of underlying stocks, trades on split days of underlying stocks, and trades that are time-stamped after 3:00 P.M. CST. I also aggregate option trades occurring within five seconds of each other with the same trade price, same trade direction, and same prevailing quotes into one trade to mitigate possible reporting mistakes of multiple trades.

I follow Lee and Ready [1991] and Easley, O'Hara, and Srinivas [1998] to classify trades. For each trade, I use the most recent quote that is no older than 30 minutes. I classify a trade that occurs above (below) the midpoint as a buy (sell). I apply the "tick test" to those trades occurring at the midpoint with the current trade price being different from its previous one. In particular, I classify a trade with the current trade price being higher (lower) than its previous one as a buy (sell). I then apply the "zero-tick test" to those trades occurring at the midpoint with the current trade price being the same as its previous one. In particular, I classify a trade with the previous price being higher (lower) than its previous one as a buy (sell). I discard trades that cannot be classified using the above steps.

SUMMARY STATISTICS

Exhibit 1 reports summary statistics of the variables (before normalization) of interest. For example, Panel A of Exhibit 1 shows that mean and median *StockAggressiveBuy* are 5.30 and 4.24, respectively, while mean and median *StockAggressiveSell* are 3.71 and 2.95, respectively.

Pairwise Granger-Causality Tests

Exhibit 2 reports the results from a VAR with endogenous variables in the order of *StockAggressiveBuy*, *StockAggressiveSell*, *OptionDirectionalBuy*, and *OptionDirectionalSell* in Panel A, and from a VAR with endogenous variables in the order of *StockAggressiveBuy*, *StockAggressiveSell*, *OptionDirectionalBuy_c*, *OptionDirectionalBuy_p*, *OptionDirectionalSell_c*, and *OptionDirectionalSell_p* in Panel B, with control variables including stock trading volume, stock relative spread, option trading volume, option relative spread, and stock volatility. Each VAR is estimated with three lags.

I observe the feedback effect between the stock limit order book aggressiveness and option directional trading, and between the stock limit order book

EXHIBIT 1 Summary Statistics

Variable Name	Mean	Median	Std. Dev.	Min.	Max.
Panel A: Summary Statistics for Stock Aggressiveness Variables					
<i>StockAggressiveBuy</i>	5.30	4.24	4	0.09	151
<i>StockAggressiveSell</i>	3.71	2.95	2	0.24	136
Panel B: Summary Statistics for Option Trading Variables					
<i>OptionDirectionalBuy</i>	10.44	0.16	998	0.00	642,866
<i>OptionDirectionalBuy_c</i>	5.30	0.02	610	0.00	42,9218
<i>OptionDirectionalBuy_p</i>	5.14	0.04	707	0.00	534,119
<i>OptionDirectionalSell</i>	11.44	0.29	1,005	0.00	384,691
<i>OptionDirectionalSell_c</i>	5.04	0.17	501	0.00	171,049
<i>OptionDirectionalSell_p</i>	6.40	0.01	857	0.00	316,693

Note: This exhibit reports summary statistics of the aggressiveness variables of the stock limit order book and option directional trading variables. *StockAggressiveBuy* and *StockAggressiveSell* are the weighted averages of the depth at each price step on the buy and sell sides to the total same side depth of the book, respectively, with the weights being the inverse of the absolute value of the difference between the corresponding price and the prevailing midpoint of the inside spread on the limit order book. *OptionDirectionalBuy* is the absolute value of the total number of delta-weighted buyer-initiated calls and seller-initiated puts. *OptionDirectionalBuy_c* is the absolute value of the total number of delta-weighted buyer-initiated calls. *OptionDirectionalBuy_p* is the absolute value of the total number of delta-weighted seller-initiated puts. *OptionDirectionalSell* is the absolute value of the total number of delta-weighted seller-initiated calls and buyer-initiated puts. *OptionDirectionalSell_c* is the absolute value of the total number of delta-weighted seller-initiated calls. *OptionDirectionalSell_p* is the absolute value of the total number of delta-weighted buyer-initiated puts. All variables are constructed over five-minute intervals. All series are before normalization.

aggressiveness and components of option directional trading variables. For example, the null hypothesis that *StockAggressiveBuy* does not Granger-cause *OptionDirectionalBuy* is rejected with a Wald test statistic of 49.54, significant at the 1% level. This implies that *StockAggressiveBuy* Granger-causes *OptionDirectionalBuy*. Besides, the null hypothesis that *OptionDirectionalBuy* does not Granger-cause *StockAggressiveBuy* is rejected with a Wald test statistic of 18.01, significant at the 1% level. This implies that *OptionDirectionalBuy* Granger-causes *StockAggressiveBuy*. This indicates the feedback effect between the stock limit order book aggressiveness and option directional trading. The feedback effect documented in Exhibit 2 is likely attributable to cross-market hedging activities.¹ For example, it is likely that a market maker buys a stock and simultaneously sells a call on the stock to hedge his or her long position in the stock market, and a market maker sells a call to an

EXHIBIT 2

Pairwise Granger-Causality Tests

Panel A: Using a VAR with Endogenous Variables of *StockAggressiveBuy*, *StockAggressiveSell*, *OptionDirectionalBuy*, and *OptionDirectionalSell*

	<i>StockAggressiveBuy</i>	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	<i>OptionDirectionalSell</i>
<i>StockAggressiveBuy</i>			49.54	78.50
<i>StockAggressiveSell</i>			52.25	63.62
<i>OptionDirectionalBuy</i>	18.01	6.83		
<i>OptionDirectionalSell</i>	20.36	7.41		

Panel B: Using a VAR with Endogenous Variables of *StockAggressiveBuy*, *StockAggressiveSell*, *OptionDirectionalBuy_c*, *OptionDirectionalBuy_p*, *OptionDirectionalSell_c*, and *OptionDirectionalSell_p*

	<i>StockAggressiveBuy</i>	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy_c</i>	<i>OptionDirectionalBuy_p</i>	<i>OptionDirectionalSell_c</i>	<i>OptionDirectionalSell_p</i>
<i>StockAggressiveBuy</i>			42.94	50.74	64.47	81.55
<i>StockAggressiveSell</i>			50.80	58.62	54.66	65.17
<i>OptionDirectionalBuy_c</i>	20.42	5.53				
<i>OptionDirectionalBuy_p</i>	6.81	9.04				
<i>OptionDirectionalSell_c</i>	17.06	8.92				
<i>OptionDirectionalSell_p</i>	23.12	6.83				

Note: This exhibit reports the results from a VAR with endogenous variables in the order of *StockAggressiveBuy*, *StockAggressiveSell*, *OptionDirectionalBuy*, and *OptionDirectionalSell* in Panel A and from a VAR with endogenous variables in the order of *StockAggressiveBuy*, *StockAggressiveSell*, *OptionDirectionalBuy_c*, *OptionDirectionalBuy_p*, *OptionDirectionalSell_c*, and *OptionDirectionalSell_p* in Panel B, with control variables including stock trading volume, stock relative spread, option trading volume, option relative spread, and stock volatility. Each VAR is estimated with three lags. Wald test statistics of pairwise Granger-Causality tests between each aggressiveness variable of the stock limit order book and each option directional trading variable are reported. The null hypothesis is that the row variable does not Granger-cause the column variable. All variables used have been normalized. All the Wald test statistics are significant at the 1% level. See Exhibit 1 for variable definitions.

aggressive customer and then turns around to hedge his or her new short call position by aggressively bidding for the stock.

Exhibit 3 reports the results from a VAR with endogenous variables in the order of *StockAggressiveBuy*, *StockAggressiveSell*, *OptionDirectionalBuy*, and *OptionDirectionalSell*, with control variables including stock trading volume, stock relative spread, option trading volume, and option relative spread for data points in the afternoon (from noon to 4:00 P.M.) in our sample. The VAR is estimated with three lags. Consistent with results in Exhibit 2, the feedback effect between the stock limit order book aggressiveness and option directional trading remains for afternoon data points.

Pairwise Granger-Causality Tests by Time of Day

Trading is more likely to be informed at the beginning and at the end of the day, as Foster and

Viswanathan [1990] point out that larger trade impacts at the beginning and at the end of the day. This indicates that the percentages of stocks with Granger-Causality running in either or both directions between the stock aggressiveness and option directional trading variables are bigger at the beginning and at the end of the day. Consistent with Foster and Viswanathan [1990], Exhibit 4 shows that the percentages of stocks in the categories of both “Stock to Option” and “Option to Stock” are higher at the beginning (9:30 A.M. to 11:00 A.M.) and at the end (2:30 P.M. to 4:00 P.M.) of the day, where “Option to Stock” means the option directional trading variables Granger-causing the stock aggressiveness variables. Unreported results of difference tests show that the differences in the percentage stocks between the 9:30 A.M. to 11:00 A.M. interval and the 11:00 A.M. to 2:30 P.M. interval, and between the 2:30 P.M. to 4:00 P.M. interval and 11:00 A.M. to 2:30 P.M. interval, are significant at the 5% level for each pair of stock aggressiveness variable and option

EXHIBIT 3

Pairwise Granger-Causality Tests Using Only Afternoon Data Points

	<i>StockAggressiveBuy</i>	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	<i>OptionDirectionalSell</i>
<i>StockAggressiveBuy</i>			44.35	76.21
<i>StockAggressiveSell</i>			50.18	63.44
<i>OptionDirectionalBuy</i>	14.74	6.01		
<i>OptionDirectionalSell</i>	18.87	6.79		

Note: This exhibit reports the results from a VAR with endogenous variables in the order of *StockAggressiveBuy*, *StockAggressiveSell*, *OptionDirectionalBuy*, and *OptionDirectionalSell*, with control variables including stock trading volume, stock relative spread, option trading volume, and option relative spread for data points in the afternoon (from noon to 4:00 P.M.) in our sample. The VAR is estimated with three lags. Wald test statistics of pairwise Granger-Causality tests between each aggressiveness variable of the stock limit order book and each option directional trading variable are reported. The null hypothesis is that the row variable does not Granger-cause the column variable. All variables used have been normalized. All the Wald test statistics are significant at the 1% level. See Exhibit 1 for variable definitions.

EXHIBIT 4

Pairwise Granger-Causality Tests by Time of Day

Time Interval	Stock Variable	Option Trading Variable	Stock to Option	Option to Stock
9:30 A.M.–11:00 A.M.	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	45.42	16.14
	<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	53.89	16.48
	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	45.57	10.49
	<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	55.81	15.72
11:00 A.M.–2:30 P.M.	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	32.92	3.85
	<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	34.25	2.08
	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	30.88	11.79
	<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	27.36	8.16
2:30 P.M.–4:00 P.M.	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	52.74	16.44
	<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	43.47	7.34
	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	63.72	15.61
	<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	50.98	19.93

Note: This exhibit reports the percentages of the stocks in the sample with statistically significant Granger-Causality at the 5% level based on *F*-tests using three lags by time of day. “Stock to Option” means the aggressiveness variables of the stock limit order book Granger-causing the option directional trading variables. “Option to Stock” means the option directional trading variables Granger-causing the aggressiveness variables of the stock limit order book. All variables used have been normalized. See Exhibit 1 for variable definitions.

directional trading variable for “Stock to Option” and “Option to Stock,” respectively.

Pairwise Granger-Causality Tests by Time of Day and Bid–Ask Spread

Exhibit 5 shows that the percentage of stocks in the category of “Stock to Option” is generally bigger for large than for small bid–ask spread at the beginning

and at the end of the trading day, and the difference is statistically significant at the 1% level. Exhibit 5 also shows that percentages of stocks in the category of “Stock to Option” at the beginning and at the end of the trading day are larger when the bid–ask spread is large or medium, and that the percentage of stocks in “Stock to Option” is bigger than that in “Option to Stock.” Unreported results of difference tests show that these differences are significant at the 5% level.

EXHIBIT 5

Pairwise Granger-Causality Tests by Time of Day and Bid-Ask Spread

Time Interval	Bid-ask Spread	Stock Aggressiveness Variable	Option Trading Variable	Stock to Option	Option to Stock
9:30 A.M.–11:00 A.M.	Large	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	56.33	5.76
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	57.63	13.82
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	53.91	10.19
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	57.63	12.71
	Medium	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	54.25	8.71
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	50.34	14.38
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	55.17	18.75
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	65.11	10.04
	Small	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	41.41	2.27
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	44.11	1.21
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	48.94	6.43
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	51.98	10.77
11:00 A.M.–2:30 P.M.	Large	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	32.98	2.37
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	26.49	7.67
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	25.43	20.38
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	29.69	2.46
	Medium	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	32.34	8.89
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	26.58	8.66
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	17.52	5.18
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	24.76	3.51
	Small	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	37.37	1.53
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	27.07	2.50
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	23.45	4.81
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	33.12	2.69
2:30 P.M.–4:00 P.M.	Large	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	51.48	17.14
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	52.78	12.52
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	56.06	13.87
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	52.63	24.45
	Medium	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	56.17	16.61
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	57.74	5.99
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	55.40	26.65
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	53.02	21.59
	Small	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	47.48	15.92
		<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	51.99	2.59
		<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	62.92	14.46
		<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	43.10	30.12

Note: This exhibit reports the percentages of the stocks in the sample with statistically significant Granger-Causality at the 5% level based on *F*-tests using three lags by time of day and bid-ask spread. The sample stocks are sorted into terciles by decreases in the inside bid-ask spread on the snapshot of the stock limit order book at the beginning of November 1, 2007. “Stock to Option” means the aggressiveness variables of the stock limit order book Granger-causing the option directional trading variables. “Option to Stock” means the option directional trading variables Granger-causing the aggressiveness variables of the stock limit order book. All variables used have been normalized. See Exhibit 1 for variable definitions.

EXHIBIT 6

Pairwise Granger-Causality Tests by Option Moneyness

Moneyness	Stock Variable	Option Trading Variable	Stock to Option	Option to Stock
ATM	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	48.08	6.78
	<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	49.10	1.63
	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	50.45	2.49
	<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	42.61	9.37
ITM	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	39.48	6.50
	<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	39.61	6.89
	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	49.20	6.27
	<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	43.65	9.13
OTM	<i>StockAggressiveBuy</i>	<i>OptionDirectionalBuy</i>	45.88	3.34
	<i>StockAggressiveBuy</i>	<i>OptionDirectionalSell</i>	40.50	1.08
	<i>StockAggressiveSell</i>	<i>OptionDirectionalBuy</i>	30.18	14.10
	<i>StockAggressiveSell</i>	<i>OptionDirectionalSell</i>	35.90	15.20

Note: This exhibit reports the percentages of the stocks in the sample with statistically significant Granger causality at the 5% level based on *F*-tests using three lags by option moneyness. In-the-money options are call options with moneyness less than 0.95 and put options with moneyness more than 1.05. Out-of-the-money options are call options with moneyness greater than 1.05 and put options with moneyness less than 0.95. At-the-money options are options with moneyness between 0.95 and 1.05, inclusively. "Stock to Option" means the aggressiveness variables of the stock limit order book Granger-causing the option directional trading variables. "Option to Stock" means the option directional trading variables Granger-causing the aggressiveness variables of the stock limit order book. See Exhibit 1 for variable definitions.

Pairwise Granger-Causality Tests by Option Moneyness

Exhibit 6 reports the percentages of stocks in the sample with statistically significant Granger-Causality at the 5% level based on *F*-tests using three lags by option moneyness. In-the-money (ITM) options are call options with moneyness less than 0.95 and put options with moneyness more than 1.05. Out-of-the-money (OTM) options are call options with moneyness greater than 1.05 and put options with moneyness less than 0.95. At-the-money (ATM) options are options with moneyness between 0.95 and 1.05, inclusively. Results in Exhibit 6 show that the percentages of stocks in the category of "Stock to Option" for OTM options are smaller than those for ATM options. Results from Exhibit 6 also show that the percentages of stocks in the category of "Option to Stock" for OTM options are mostly bigger than those for ATM options. The only exception is for the pair of *StockAggressiveBuy* and *OptionDirectionalBuy* in the "Option to Stock" category. Unreported results of difference tests show that these differences are significant at the 5% level. Consistent with Lee and Yi [2001] and Chakravarty, Gulen, and Mayhew [2004], my results provide evidence that informed option trading is more

concentrated in OTM options resulting from their higher leverage effects.

My results are also robust to alternative measure of the stock aggressiveness variables,² to including forward-looking stock skew³ in the VAR, and to using one-minute time intervals.

CONCLUSION

This article provides empirical evidence that stock limit order book aggressiveness and option directional trading are informative for predicting one another. Further, the documented Granger-Causality varies with time of day, bid-ask spread, and option moneyness.

ENDNOTES

¹I am grateful to the editor, Stephen Figlewski, for this point.

²Defined as the weighted averages of the depth at each price step on the buy and sell sides to the total same side depth of the book, respectively, where depth is calculated only from orders placed on that day rather than from all top 10 levels of the book.

³Skew is moneyness-based forward looking stock skewness or volume-based forward looking stock skewness. Moneyness-Based Forward Looking Stock Skewness is the difference between the implied volatilities of an OTM put and an ATM call, where I choose one OTM put option with its moneyness closest to 0.95 and one ATM call option with its moneyness closest to 1. Volume-Based Forward Looking Stock Skewness is the difference between the option-volume weighted implied volatilities of OTM puts and ATM calls, where all OTM puts with moneyness between 0.80 and 0.95, and all ATM calls with moneyness between 0.95 and 1.05 are used.

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