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Can order exposure be mandated?☆

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Abstract

In this paper, we examine whether the hidden portion of limit orders represents depth that would be revealed if traders were not allowed to hide it, and the associated market quality implications. Specifically, we examine the decisions by the Toronto Stock Exchange to first abolish the use of hidden limit orders in 1996, and then reintroduce them in 2002. We find that quoted depth does not change following either decision, suggesting that the hidden portion of orders represents depth that would otherwise not be exposed. Using confidential order data for the period following the reintroduction of hidden limit orders, we find that total inside depth increases. For both events, volume does not change and the usage of the limit order book increases if hidden limit orders are allowed. This suggests that if traders are required to expose their orders they will not exit the market, but instead will switch to using market orders. We also find evidence to suggest that informed traders use hidden limit orders to minimize price impact if the probability of non-execution is small.

JEL classification: G20

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Transparency in the trading process has recently emerged as an area of sharp disagreement among regulators, exchanges, market participants and academics. The Securities and Exchange Commission is clear on its stand that the more transparent

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a market, the better it is for the investors.[1] In contrast, recent studies suggest that while some forms of transparency improve market quality, others may actually result in a decline in market quality. These academic studies have also shown differing trader behavior for different types and levels of transparency.

In this paper, we contribute to the pre-trade transparency literature by examining the impact of mandated order exposure on market quality and trader behavior. Specifically, we examine the Toronto Stock Exchange's decisions first to abolish the use of hidden limit orders for the stocks traded on its electronic Computer Aided Trading System (CATS) on March 18, 1996, and then to reintroduce them six years later, on April 12, 2002.[2] These exogenous shocks with opposite predictions over two different time periods provide us with a unique opportunity to study the market quality implications of hidden limit orders. The availability of confidential order data for the 2002 sample also allows us to observe hidden liquidity and thus allows us to directly test hypotheses regarding the usage and placement of hidden limit orders.

The exchange's decision in 1996 to abolish hidden limit orders may have been an attempt to improve quoted depth in the belief that higher displayed liquidity would attract additional order flow from market order traders. If such an influx of additional order flow were to occur, then the probability of execution for limit order traders would increase as well, thus making the market more attractive to limit order traders. However, market participants determine the success of any regulation. Therefore, we focus our study on the motivations for the use of hidden limit orders. Limit order traders hide quantity in the limit order book to limit the option value of their order, to reduce the risk of being front run, to minimize losses due to trading with informed investors, or, if they are informed, to hide their information and minimize price impact. Once order size can no longer be hidden, traders are faced with three choices: (1) display the hidden portion of their order, (2) exit the market, or (3) manage their orders actively. Each of these choices would have significant, and different, implications for market quality.

We find that spreads, quoted depth, total liquidity (measured by Kyle's lambda) and volume are not affected by the abolition of hidden limit orders. This leads us to conclude that limit order traders did not simply reveal the hidden portion of their orders, but instead actively managed their orders. This is corroborated by a decrease in the number of quote updates indicating fewer limit orders being placed on the book. We find no evidence that market quality either improved or deteriorated as a result of the exchange's decision to disallow the use of hidden orders.

The results of the period surrounding re-introduction of hidden limit orders are consistent with those around their abolition. We find that once again spreads, execution costs and visible depth remain unchanged. The availability of order data allows us to directly observe hidden depth in this period. We find that total depth at the inside, which includes displayed as well as undisclosed depth, shows a statistically

[1] SEC Market 2000 Study.

[2] Orders which allow a part of the order to be hidden are also known as iceberg orders or undisclosed limit orders.

significant increase after the re-introduction of hidden limit orders. Further, consistent with the increased use of the limit order book, we find that quote updates increase significantly once the exchange allows traders to hide liquidity in the book.

We find evidence to suggest that traders hide part of their limit orders to manage their exposure. We also find that informed traders are more likely to use hidden limit orders to reduce price impact if they can minimize the risk of non-execution. In particular, we find that the greatest usage of hidden limit orders occurs in the most active stocks where the chance of non-execution is smallest. Additionally we find that order placement aggressiveness is directly related to a stock's activity level. Since informed traders are generally the most impatient, we view this as further evidence that informed traders seek to hide size so as to reduce price impact, while balancing the cost of non-execution.

This paper should be of interest to regulators as well as markets who seek rules to improve market quality.[3] It should also be of interest to traders and academics since it sheds light on the behavior of market participants. In the next section we provide a review of related research. Section 2 develops our hypotheses, Section 3 describes the data and gives a brief description of trading on TSX, Sections 4 and 5 discuss the results and Section 6 concludes.

1. Literature review

In the past few years a number of papers have been published that study the relationship between transparency and various measures of market quality. These papers have used both experimental and empirical designs to examine various aspects of pre-trade and post-trade transparency. For example, Bloomfield and O'Hara (1999) use experimental economics to study aspects of market transparency. They find that trade disclosure (post-trade transparency) leads to greater informational efficiency (prices converge to their true values faster), higher bid–ask spreads and welfare effects that involve a transfer from informed and uninformed traders to market makers. With regard to pre-trade transparency, Bloomfield and O'Hara find no discernible effects beyond that found for trade disclosure.

Flood et al. (1999) also conduct an experimental study to examine the impact of transparency in a foreign exchange market. Theirs is a multiple-dealer market with inter-dealer trading. The opaque market structure does not allow dealers to view each other's quotes. They find the same trade-off as Bloomfield and O'Hara (1999) but in the opposite direction. In particular, they find that opaque markets are more efficient but have higher spreads as compared to transparent markets.

[3] In their request for comment, File S7-12-98, the SEC states. "The Commission, however, requests comment on whether alternative trading systems should be required to display the full size of the best priced order, even if the full size is hidden from alternative trading system subscribers through use of a 'reserve size' or similar feature."

In an empirical analysis of the Toronto Stock Exchange's decision to disseminate real-time information on the contents of the limit order book to the public, Madhavan et al. (2003) find that spreads widen and the adverse selection component of spread increases with this increase in transparency.

In a study closely related to ours, Harris (1996) explores the relation between tick size and order exposure on the Paris CAC and Toronto CATS systems. Harris discusses the trade-off exchanges face between attracting liquidity and getting traders to display liquidity and conjectures that forcing traders to display might result in driving away liquidity from the market. There are two more recent studies which have focused on the role of hidden limit orders in an electronic market. Aitken et al. (2001) study the use of hidden limit orders on the Australian Stock Exchange (ASX). The authors find that, on the ASX, hidden limit orders are used more to limit the option value of the order than as a tool for informed traders. The study also analyzes quoted spreads and volume around two events where the ASX increased the minimum disclosed amount that a trader could hide liquidity behind. The results indicate that quoted spreads are unchanged by the events but volume declines in one of the two events, with the implication that some limit order traders actually withdraw from the market and cease trading altogether. However, this volume decline is significant for the smaller change and not for the larger. The study does not analyze any measure of depth and does not shed any light on how traders strategically react to changes in pre-trade transparency.

Tuttle (2002) studies the use of hidden orders in Nasdaq's SuperSOES system. She finds that hidden liquidity accounts for 22% of the inside depth for the Nasdaq 100 stocks, and mitigates adverse selection costs for limit order traders. She also documents an increase in depth around the implementation of the SuperSOES system and attributes this increase to the ability to hide depth in the system. As the author notes, the Nasdaq market is highly fragmented and alternative systems such as ECNs allow a much higher degree of anonymity (for example, Island allows traders to hide all of their order size). Further, the ability to hide depth on ECNs was available even before the introduction of the SuperSOES system which also contaminates the experiment.

Our study analyzes a unique set of experiments in which a centralized market attempts to mandate order exposure and then six years later reverses its decision reintroducing the ability to hide liquidity. This provides us an opportunity to directly test opposing hypotheses concerning market quality and trader behavior on the two events. In so doing, we attempt to shed light on the issue of order display from the perspective of transparency as well as the policy debate on increasing the competitiveness of an exchange.

2. Hypotheses development

The issue of transparency in securities markets is inevitably linked to liquidity. Bloomfield and O'Hara (1999) find that an increase in post-trade transparency leads to an increase in spreads and poorer execution for all classes of traders (to the benefit

of market makers). Further, they find no additional benefit from increasing pre-trade transparency. Madhavan et al. (2003) find that an increase in pre-trade transparency is associated with wider spreads. Flood et al. (1999) find in their experiments that opaque markets have higher spreads than transparent markets. Although these studies involve different market structures and different types of transparency they all find that transparency impacts spreads. Since hidden limit order usage is closest to the transparency definition used in Madhavan et al., we structure our first hypothesis as

H1. Increased transparency in the form of the display of size of the limit orders in the book leads to wider spreads and higher execution costs.

If an exchange decides to abolish hidden limit orders, traders can choose to display part or all of their previously hidden depth, or they can remove that liquidity from the book. Therefore, as Harris (1996) points out, exchanges face a dilemma in mandating display of depth as it might serve to drive away liquidity instead. This is so due to the increased risk traders now face of trading with informed traders or being front-run. The move to mandate display limits the choices limit order traders have in managing their exposure. If traders do not expose their previously hidden depth, then *quoted* depth will not change, thus our second hypothesis

H2. Increased transparency in the form of the display of size of the limit orders in the book is associated with no change in quoted depth.

If they do not expose the previously hidden portion of their orders, traders may find other ways to trade (e.g., switch to market orders) or may completely withdraw the previously hidden depth from the market. Rindi (2003) develops a model of pre-trade transparency assuming endogenous information acquisition where informed traders are the natural suppliers of depth. Her model predicts that increases in transparency will cause informed traders to withdraw depth from the market since informed traders will now have less incentive to acquire information in a transparent market. Without information acquisition, they will not provide liquidity. This would result in a reduction in volume, therefore

H3a. Increased transparency in the form of the display of size of the limit orders in the book is associated with a reduction in volume.

Alternatively, traders may monitor markets actively and trade through market orders when conditions warrant. This is consistent with the "gravitational pull" argument of Cohen et al. (1981) whereby the attractiveness of the opposite quote increases causing limit order traders to switch away from limit orders to market orders. Handa and Schwartz (1996) develop a model analogous to that of Cohen et al., wherein a higher probability of trading with informed traders also makes market orders more attractive than limit orders. Decreased usage of limit orders should cause a reduction in the number of observed quote updates. Therefore, we have our next hypothesis

H3b. Increased transparency in the form of the display of size of the limit orders in the book is associated with a reduction in the number of quote updates.

It's also important to study where these orders are likely to be more attractive and hence have the most significant impact. As discussed earlier, hiding liquidity can be useful to limit order traders since it lets them limit the option value of the order, avoid being front-run, limit the probability of trading with an informed trader, or hide valuable information that the trader does not wish to be revealed to the market. It is obvious that not all traders will have all of the above needs. The length of time necessary to execute a large limit order is inversely related to trading activity in a stock. Since increasing an option's duration increases its value, we would expect traders to seek to limit the option value by using hidden orders more often in inactive stocks. Similarly, uninformed traders concerned with the increased adverse selection are more likely to hide liquidity in the less liquid stocks where information asymmetry is higher. On the other hand, informed traders may seek to limit price impact by placing hidden limit orders. In doing so, they face the risk of non-execution. The risk of non-execution will generally be smallest in more active stocks. Therefore, we would expect informed traders to use hidden limit orders more often in the most active stocks. Our hypothesis then is

H4. Traders will seek to limit option values by using hidden limit orders more in less liquid stocks. Informed traders will use hidden limit orders more often in more active stocks. The aggregate effect is indeterminate.

The risk of a parasitic trader stepping ahead of an order is more likely to vary by trader type. Traders who monitor the market less actively are more likely to be front run than more active traders and would be more likely to use hidden orders. Thus our final hypothesis

H5. Registered traders and members are less likely to use hidden orders than public customers.

In the following sections, we describe the data, detail the empirical methods used to test these hypotheses and discuss the results.

3. Data

Until April 23, 1997, stocks trading on the TSX were assigned to one of two trading systems: an automated trading system, CATS and a floor-based system which was organized much like the NYSE specialist system.[4] On March 18, 1996, the TSX disallowed the ability to hide quantity on the limit order book on the CATS system.[5] Prior to that date, traders could "hide" any portion of an order that

[4] For a detailed description of the organization of trading on the TSX floor please refer to Madhavan et al. (2003).

[5] No such provision existed on the TSX floor.

exceeded 5,000 shares.[6] A hidden order 'flag' was displayed next to any quote that included hidden orders, letting market participants know there was more size behind that quoted.

To examine this rule change we employ time-stamped trade and quote data for two 19 trading day periods before (February 5, 1996 to February 29, 1996) and after (March 18, 1996 to April 12, 1996) the rule change. We restrict our sample to common stocks, trading in Canadian dollars that trade throughout the sample period (pre and post) and those that have at least 50 valid quotes in the period before the rule change. We only include trades and quotes between 9:30 a.m. and 4:00 p.m., only includes quotes that represent positive spreads, and are no wider than $5. For firms with more than one class of common stock, we only include the most active class. We also exclude a stock if it trades on two different ticks any time during the sample period. Our final sample consists of 272 stocks.

On April 12, 2002 the TSX reintroduced hidden limit orders.[7] The minimum disclosed size was set at 2,000 shares (as opposed to 5,000 prior to being disallowed in 1996) and there is no longer any indication that quotes contain additional depth beyond that quoted. Traders could hide as little as 100 shares.[8] Due to a lack of archiving by the TSX, order data are not available for the period surrounding the abolition of hidden limit orders, but is available for the period surrounding their reintroduction. The level of detail in the order data allows us to study the use of hidden orders by trader type (described below). Order data include whether the order is a buy or a sell, the identity of the submitter (broker) along with their trader type (public customer; registered trader; member trading for their firm's account; or member trading for their personal account), and details of the order (new order of change, price, quantity, duration, and flags for hidden and/or short qualifications). Trade data contain the identities of each side of the trade.

The TSX provided us with data for a period before (March 1 to March 28, 2002) and after (September 3 to 27, 2002) the reintroduction of hidden limit orders. We use the same criteria to select stocks for this event as we do for the first.

The TSX closed down their floor trading system and transferred all stocks to their automated system, CATS, by April 23, 1997. As a result of this transfer we have 575 stocks in the sample periods surrounding the reintroduction of hidden limit orders. Due to the different sample memberships between the 1996 and 2002 events, as well as differences in individual stock characteristics and exchange rules (e.g., all TSX

[6] The 5,000 share minimum disclosed size applied to stocks trading for more than $1 a share. The minimum disclosed size was 25,000 shares for stocks trading between C$0.10 and C$1.00, and 50,000 shares for less than C$0.10.

[7] Conversations with TSX officials revealed that academic studies of transparency were partly responsible for their reintroduction of this order type.

[8] For shares trading above C$1 the hidden portion of an order has a minimum of 100 shares, for stocks trading between C$0.10 and C$1 the minimum hidden is 500 shares. For stocks trading below C$0.10 the minimum hidden size is 1,000 shares.

stocks now have penny ticks), we treat each event individually.[9] We first examine the April 1996 abolition of hidden limit orders.

4. Abolition of hidden limit orders

As discussed earlier, we expect different usage of hidden limit orders in stocks with different activity levels. Therefore, the impact of disallowing hidden limit orders may vary according to activity level. Accordingly, we rank stocks in our sample by the average number of trades and form quartiles. We find that results across quartiles are qualitatively similar to our overall results. Therefore we only report overall results in Table 1.[10]

4.1. Spreads

To test our first hypothesis, we analyze the impact of the abolition of hidden limit orders on spreads. Panel A of Table 1 presents univariate results for different measures of spread. The results show that time weighted quoted dollar spreads as well as volume weighted effective dollar spreads increased consistent with H1. However, only the change for quoted dollar spreads is statistically significant at traditional levels. Both measures of percentage spread (time weighted quoted and volume weighted effective) exhibit a statistically insignificant reduction. While these results provide some weak support for our first hypothesis, they do not control for changes in other factors known to influence spread. Accordingly we perform a multivariate analysis by regressing average spreads on the log of average price, the log of the average number of trades, average volatility of returns and a dummy variable for the post period. If the change in spread width is related to the abolition of hidden limit orders, as Hypothesis 1 predicts, we would expect the parameter estimate for the dummy to be positive and significant.

The results of the multivariate analysis are contained in Table 2. An examination of the parameter estimates for the dummy variable reveals that none are statistically significant. Therefore, we reject H1. Our findings are consistent with those of Aitken et al. (2001), who also find no significant change in spread width following a change in the parameters affecting hidden limit order exposure in Australia.

4.2. Depth and quote updates

Our second hypothesis predicts that quoted depth will be unchanged by the abolition of hidden limit orders. Returning to Panel A of Table 1 and examining the change in quoted depth reveals that consistent with H2, quoted depth did not change by a statistically significant amount. It is important to note here that, all else equal, if

[9] For example the average daily number of trades in the pre period for the first event are 22.26 , while the average for the second event is 120.12.

[10] Quartile results are available from the authors on request.

Table 1
Univariate results—abolition of hidden limit orders

In this table, we summarize univariate changes for various measures following the Toronto Stock Exchange's rule change eliminating hidden limit orders. The pre-period data covers the period from February 5, 1996 to February 29, 1996 and the post-period data from March 18, 1996 to April 12, 1996. The numbers are calculated for each stock and then summarized cross-sectionally. Our sample consists of 272 stocks traded on the TSX's CATS trading system. Panel A contains results for spread and depth, as well as trade and quote activity measures. Quoted dollar (Canadian) and percentage spreads are time-weighted averages for each stock and then aggregated across the sample, while effective spreads are volume weighted. Quoted depth is the time-weighted average inside depth. Volume is the average daily number of shares traded in each period. Quote updates are used as a measure of limit orders submitted into the book and count the average daily frequency of quote updates.

Panel B, lists the average parameter estimates of a regression run to obtain Kyle's lambda. The regression equation is of the form

$$\Delta p_t = (\lambda_0 + \lambda_1 D_t) q_t + (\gamma_0 + \gamma_1 D_t)\mu_t + \varepsilon_t,$$

where Δp_t is the change in price ($p_t - p_{t-1}$), q_t is the signed order flow (positive for buy orders and negative for sell orders), μ_t is a market index used to control for positive drift in returns and ε_t is a random noise term. D_t is a dummy which takes on the value 1 for the post-period and 0 for the pre-period. λ_1 and γ_1 capture changes that occur in the two coefficients as a result of the rule change. λ is an inverse measure of liquidity. Parameter t-statistics are below the parameter estimates.

Measure	Pre	Post	Change	t-Statistic for change
A. Changes before and after the abolition of hidden limit orders				
Quoted dollar spreads	0.1788	0.1921	0.0134	*2.33*
Quoted percentage spreads	0.0329	0.0320	−0.0010	*−1.22*
Effective dollar spreads	0.1544	0.1590	0.005	*0.33*
Effective percentage spreads	0.0288	0.0268	−0.002	*−1.04*
Quoted inside depth	1,025.20	942.99	−82.17	*−1.32*
Volume	62,860	59,586	−3,274	*−0.38*
Daily quote updates	28.57	24.26	−4.30	*−4.91*
B. Kyle's lambda				
Signed order flow	Signed order flow Post	Returns index	Returns index Post	
9.97E-06	−1.22E-06	0.00016	−7.7372E-05	
4.53	*−0.53*	*1.55*	*−0.76*	

the exchange had succeeded in its objective and traders exposed all available depth then we should see an increase in quoted depth since the hidden portion would be exposed. An absence of this increase indicates that traders did not simply reveal the hidden portion of their orders in the book.

Since order data are unavailable for the period surrounding the abolition of hidden limit orders in 1996, we cannot directly measure whether total depth available in the market changed as well. Thus, to further examine whether erstwhile limit order traders simply change their trading strategies or withdraw from the market (as predicted by Rindi (2003)), we first use a comprehensive measure of liquidity

Table 2
Multivariate results—abolition of hidden limit orders

This table summarizes multivariate results for various measures on the sample used in the analysis of the Toronto Stock Exchange's rule change eliminating hidden limit orders. The pre-period data covers the period from February 5, 1996 to February 29, 1996 and the post-period data from March 18, 1996 to April 12, 1996. The numbers are calculated for each stock and then summarized cross-sectionally. Our sample consists of 272 stocks traded on the TSX's CATS trading system. The numbers are calculated for each stock and then summarized cross-sectionally. Therefore, each stock has two observations in the data used for the regression: one for the pre-period and one for post. The results pertain to quoted spreads (in Canadian dollars and as a percentage of the midpoint of the bid-ask price), effective spreads (in Canadian dollar and percentage terms), quoted depth and quote activity. Quoted dollar and percentage spreads are time-weighted averages for each stock and then aggregated across the sample, while effective spreads are volume weighted. Depth is the time-weighted average inside depth. Quote updates are used as a measure of limit orders submitted into the book and count the average daily frequency of quote updates involving a change in price. Control variables employed are a dummy variable assigned the value 1 if the observation is from the post period, the log of average price for the period, log of daily average number of trades, and the standard deviation of 30 minute returns based on the midpoint of the bid–ask quotes. Parameter *t*-statistics are in italics.

	Dependent variable	Intercept	Post dummy	Log (price)	Log (number of trades)	Volatility	R^2
Overall	Quoted dollar	0.05	0.01	0.11	−0.03	5.16	0.51
	spreads	*1.39*	*0.70*	*20.07*	*−5.01*	*6.47*	
	Quoted percentage	0.03	0.00	0.00	0.00	1.32	0.82
	spreads	*9.88*	*−0.24*	*−6.51*	*−6.63*	*23.11*	
	Effective dollar spreads	0.07	0.00	0.10	−0.03	4.50	0.47
		1.87	*0.09*	*18.50*	*−5.04*	*5.69*	
	Effective percentage	0.03	0.00	0.00	0.00	1.37	0.71
	spreads	*6.60*	*−1.29*	*−4.95*	*−4.31*	*16.90*	
	Log(quoted	7.37	−0.02	−0.44	0.45	−3.29	0.59
	inside depth)	*38.83*	*−0.35*	*−16.34*	*18.08*	*−0.84*	
	Daily quote updates	−59.44	−2.01	−0.10	34.61	139.11	0.54
		−44.33	*−2.77*	*−0.34*	*95.66*	*3.92*	

(which includes depth) given by Kyle (1985) and known as Kyle's lambda. Intuitively lambda measures the volume required to move price by a dollar and is an inverse measure of liquidity (the higher the lambda, the lower the liquidity and vice versa). Details of the methodology used to estimate Kyle's lambda are in the appendix.

Examining the results in Panel B of Table 1 shows that the coefficient for signed order flow in the pre period, λ_0, is positive and significant; however, the slope dummy coefficient, λ_1, is insignificant. Thus, liquidity largely remained unchanged after the exchange imposed order display on its participants. This suggests traders did not exit the market.

To explore further whether traders withdrew from the market or found other ways to supply liquidity, we examine trading activity. Hypothesis 3a predicts a reduction in volume if traders exit the market. Returning to Table 1 Panel A, we find that while volume reduces following the abolition of hidden limit orders the change is not statistically significant at traditional levels. As a further test we obtain the average

daily volume for all stocks trading in the U.S. from CRSP for the same periods as our sample. We determine the change in volume between the two periods for stocks trading on the NYSE, AMEX, and NASDAQ. We find stocks trading on the three American markets experienced a statistically significant decline between the two periods suggesting that the observed decline for stocks in our sample may be related to an overall downturn in trading activity and not due to traders exiting the market. This result is in contrast to the findings of Aitken et al. (2001) who find a significant decrease in volume following an increase in transparency. Our findings lead us to reject H3a.

In contrast Hypothesis 3b predicts that, following the abolition of hidden limit orders, traders will convert the previously hidden portion of their limit orders to market orders. This would imply that the quoted depth does not increase (as it would if hidden quantity were revealed), effective spreads remain constant and total liquidity in the market (as measured by Kyle's lambda) stays at previous levels. We find support for all these predictions in our results. We should also be able to observe a smaller number of limit orders being submitted by measuring changes in the number of quote updates surrounding the abolition of hidden limit orders. Our analysis supports this prediction. We find that the number of quote updates reduces by a statistically significant amount (Table 1, Panel A). This decline is not accompanied by any significant change in the total number of shares traded, lending further weight to our conclusions.

In summary, we find that following the abolition of hidden limit orders by the TSX, traders appear to increase their usage of market orders to replace the previously hidden orders. We next examine the decision by the TSX to reintroduce hidden limit orders. Since the second event is the opposite of the first, we expect the results of the analysis to be a mirror image of those discussed above, i.e., we would expect no change in spreads and visible depth, an increase in total depth and an increase in the use of limit orders reflected in an increase in the number of quote updates.

5. Reintroduction of hidden limit orders

The TSX reintroduced hidden limit orders on April 12, 2002. As with the first event, we form activity quartiles. Unlike the period surrounding the abolition of hidden limit orders, we find significant differences between activity quartiles. Therefore we report the results for this section both overall and by activity quartile. The previously absent differences between activity quartiles may be due to the increased number of stocks affected (575 versus 272) and the accompanying wider range of activity levels. It may also be due to the fact that the minimum displayed portion was set at 2,000 shares compared to the 5,000 share minimum in existence prior to 1996.

5.1. Spreads

The univariate results for spreads are presented in Table 3. Examining the results reveals that overall and for each quartile, spreads generally increased following the

Table 3
Univariate results—reintroduction of hidden limit orders

In this table, we summarize univariate changes for various measures following the Toronto Stock Exchange's reintroduction of hidden limit orders on April 12, 2002. The pre-period data covers the period from March 1, 2002 to March 28, 2002, and the post-period data from September 3, 2002 to September 27, 2002. Our sample consists of 575 stocks traded on the TSX's CATS trading system. The numbers are calculated for each stock and then summarized cross-sectionally. The table contains results for spread and depth, as well as trade and quote activity measures. Quoted dollar (Canadian) and percentage spreads are time-weighted averages for each stock and then aggregated across the sample, while effective spreads are volume weighted. Quoted inside depth is the time-weighted average inside depth, while total inside depth includes any hidden quantity at the inside quotes. By definition, visible depth and total depth are equal in the pre-period since hidden limit orders were not allowed in the system. Quote updates are used as a measure of limit orders submitted into the book and count the average daily frequency of quote updates involving a change in price (i.e., those involving just a change in size are excluded). Results are also presented for quartiles based on number of trades in the sample (from least to most active).

Activity quartile	Measure	Pre	Post	Change	*t*-Statistic for change
Overall	Quoted dollar spreads	0.21	0.24	0.02	*1.12*
	Quoted percentage spreads	0.02	0.03	0.01	*4.26*
	Effective dollar spreads	0.17	0.19	0.02	*0.88*
	Effective percentage spreads	0.02	0.03	0.01	*3.71*
	Quoted inside depth	5,191.08	5,450.54	259.46	*0.96*
	Total inside depth	5,191.08	6,701.33	1510.25	*4.58*
	Volume	142,191	136,053	−61,37.2	*−0.30*
	Daily quote updates	178.60	222.39	43.79	*1.50*
1 Least liquid	Quoted dollar spreads	0.42	0.44	0.02	*0.23*
	Quoted percentage spreads	0.05	0.06	0.01	*2.15*
	Effective dollar spreads	0.34	0.36	0.01	*0.22*
	Effective percentage spreads	0.04	0.05	0.01	*1.86*
	Quoted inside depth	4,257.03	4,897.47	640.44	*1.36*
	Total inside depth	4,257.03	5,226.37	969.35	*1.96*
	Volume	7,834	9,949	2115	*1.22*
	Daily quote updates	98.36	106.07	7.72	*0.16*
2	Quoted dollar spreads	0.20	0.24	0.04	*1.22*
	Quoted percentage spreads	0.03	0.04	0.01	*4.13*
	Effective dollar spreads	0.15	0.18	0.03	*1.18*
	Effective percentage spreads	0.02	0.03	0.01	*3.83*
	Quoted inside depth	5,404.08	5,873.98	469.89	*0.64*
	Total inside depth	5,404.08	6,801.21	1,397.13	*1.79*
	Volume	28,680	20,341	−8,339	*−1.65*
	Daily quote updates	93.24	131.60	38.35	*0.64*
3	Quoted dollar spreads	0.13	0.16	0.03	*2.35*
	Quoted percentage spreads	0.01	0.02	0.01	*5.48*
	Effective dollar spreads	0.10	0.13	0.02	*2.00*
	Effective percentage spreads	0.01	0.02	0.01	*4.16*
	Quoted inside depth	5,604.19	5,723.98	119.79	*0.22*
	Total inside depth	5,604.19	6,963.01	1,358.81	*2.04*
	Volume	74,906	78,015	3,108	*0.24*
	Daily quote updates	65.15	84.93	19.78	*1.56*

Table 3 (*continued*)

Activity quartile	Measure	Pre	Post	Change	*t*-Statistic for change
4 Most Liquid	Quoted dollar spreads	0.10	0.10	0.01	*0.70*
	Quoted percentage spreads	0.01	0.01	0.00	*3.11*
	Effective dollar spreads	0.09	0.08	0.00	*−0.13*
	Effective percentage spreads	0.00	0.01	0.00	*2.74*
	Quoted inside depth	5,492.53	5,302.88	−189.65	*−0.57*
	Total inside depth	5,492.53	7,804.50	2,311.97	*3.58*
	Volume	456,409	435,033	−21376	*−0.31*
	Daily quote updates	457.10	566.14	109.04	*1.43*

reintroduction of hidden limit orders. Further, quoted and effective percentage spreads increase by a statistically significant amount. As with the first event, we again use regressions to control for factors other than the rule change. Table 4 presents the results of this multivariate analysis and shows that the increases appear to be related to changes in other factors known to influence spread width. In particular, none of the Post Dummy parameter estimates are significant at traditional levels for any of the spread regressions. Therefore, we again find that changes in pre-trade transparency relating to the ability to hide a portion of an order has no discernable impact on spreads.

5.2. Depth and quote updates

For testing our second hypothesis, we return to Table 3 to examine changes in quoted inside depth. Consistent with our previous results, we find no significant change in quoted depth following the reintroduction of hidden limit orders. This leads us to again accept hypothesis 2.

For the period surrounding the abolition of hidden limit orders in 1996, data constraints do not allow us to measure previous usage of hidden limit orders. However, the existence of order data for the period surrounding the reintroduction allows us to directly measure the time weighted total depth at the inside (quoted plus hidden). We find that total inside depth increased from 5,191 to 6,701 and that the change is statistically significant. The multivariate results for total inside depth contained in Table 4 do not alter our conclusion. Therefore, our findings here confirm our results from the 1996 sample. We find that traders withdraw liquidity from the book when hidden orders are abolished and start using the book again when these orders are reintroduced. Further, this behavior is limited to additional liquidity that would otherwise be undisclosed and does not impact quoted or effective spreads, implying that traders do not leave the market altogether.

Focusing on the univariate as well as the multivariate results by activity quartiles, however, shows that the greatest increase in total inside depth occurs for the most liquid quartile. The usage of hidden limit orders in most active securities runs

Table 4
Multivariate results—reintroduction of hidden limit orders

This table summarizes multivariate results for various measures on the sample used in the analysis of the Toronto Stock Exchange's decision to re-introduce hidden limit orders on April 12, 2002. The pre-period data covers the period from March 1, 2002 to March 28, 2002, and the post-period data from September 3, 2002 to September 27, 2002. The numbers are calculated for each stock and then summarized cross-sectionally. Therefore, each stock has two observations in the data used for the regression: one for the pre-period and one for post. The results pertain to quoted spreads (in Canadian dollars and as a percentage of the midpoint of the bid–ask price), effective spreads (in Canadian dollar and percentage terms), two measures of quoted depth and quote activity measures. Quoted dollar and percentage spreads are time-weighted averages for each stock and then aggregated across the sample, while effective spreads are volume weighted. Visible depth is the time-weighted average inside depth, while Total depth includes any hidden quantity at the inside quotes. By definition, visible depth and total depth are equal in the pre period since hidden limit orders were not allowed in the system. Quote updates are used as a measure of limit orders submitted into the book and count the average daily frequency of quote updates involving a change in price (i.e., those involving just a change in size are excluded). Control variables employed are a dummy variable assigned the value 1 if the observation is from the post period, the log of average price for the period, log of daily average number of trades, and the standard deviation of 30 minute returns based on the midpoint of the bid–ask quotes. Results are also presented for quartiles based on number of trades (from least to most active). Parameter t-statistics are in italics.

Activity quartile	Dependent variable	Intercept	Post dummy	Log (price)	Log (number of trades)	Volatility	R^2
Overall	Quoted dollar spreads	0.36	−0.01	0.23	−0.12	12.60	0.48
		9.83	*−0.69*	*28.15*	*−24.45*	*8.31*	
	Quoted percentage spreads	0.06	0.00	0.00	−0.01	2.52	0.67
		23.82	*1.17*	*−5.55*	*−23.77*	*23.04*	
	Effective dollar spreads	0.28	−0.01	0.18	−0.09	11.17	0.42
		8.42	*−0.90*	*25.05*	*−21.62*	*8.08*	
	Effective percentage spreads	0.05	0.00	0.00	−0.01	2.15	0.59
		19.43	*0.56*	*−4.70*	*−19.49*	*19.86*	
	Log(quoted inside depth)	8.31	0.02	−0.43	0.17	−11.36	0.54
		138.01	*0.64*	*−33.30*	*22.23*	*−4.61*	
	Log(total inside depth)	8.18	0.18	−0.44	0.20	−12.75	0.52
		124.62	6.41	−31.09	23.35	−4.75	
	Daily quote updates	−747.23	82.98	176.43	70.68	14,465.01	0.27
		−12.83	*3.31*	*13.98*	*9.46*	*6.06*	
1 Least liquid	Quoted dollar spreads	0.30	−0.03	0.39	−0.17	13.72	0.54
		2.00	*−0.64*	*17.54*	*−5.40*	*4.79*	
	Quoted percentage spreads	0.14	0.00	−1.01	−0.02	2.32	0.63
		13.81	*0.58*	*−8.57*	*−9.89*	*11.69*	

	Effective dollar spreads	0.32	−0.04	0.32	−0.16	12.00	0.47
		2.26	*−0.73*	*14.98*	*−5.29*	*4.44*	
	Effective percentage spreads	0.12	0.00	−0.01	−0.02	2.04	0.52
		10.86	*0.63*	*−6.47*	*−7.97*	*9.73*	
	Log(quoted inside depth)	8.15	0.16	−0.43	0.018	−3.70	0.44
		38.75	*2.16*	*−13.48*	*4.01*	*−0.91*	
	Log(total inside depth)	8.18	0.18	−0.44	0.20	−12.75	0.44
		124.62	*6.41*	*−31.09*	*23.35*	*−4.75*	
	Daily quote updates	−404.03	27.52	153.09	40.66	6859.72	0.17
		−3.13	*0.61*	*7.88*	*1.48*	*2.75*	
2	Quoted dollar spreads	0.24	−0.01	0.21	−0.10	18.61	0.52
		2.16	*−0.26*	*16.81*	*−5.09*	*5.76*	
	Quoted percentage spreads	0.09	0.00	0.00	−0.01	2.52	0.73
		14.06	*0.23*	*−5.78*	*−11.92*	*14.03*	
	Effective dollar spreads	0.16	0.00	0.16	−0.07	14.76	0.48
		1.76	*−0.20*	*15.65*	*−4.53*	*5.73*	
	Effective percentage Spreads	0.07	0.00	0.00	−0.01	1.89	0.63
		10.61	*0.57*	*−5.95*	*−8.53*	*9.94*	
	Log(quoted inside depth)	8.62	0.02	−0.45	0.14	−25.17	0.54
		36.13	*0.34*	*−16.55*	*3.38*	*−3.67*	
	Log(total inside depth)	8.19	0.18	−0.45	0.22	−27.15	0.50
		31.44	*3.06*	*−15.36*	*4.84*	*−3.62*	
	Daily quote updates	−271.69	17.58	225.95	−43.55	26,791.16	0.17
		−1.04	0.29	7.61	−0.93	3.55	
3	Quoted dollar spreads	0.22	0.01	0.11	−0.06	9.33	0.72
		5.28	*1.38*	*24.87*	*−9.68*	*7.96*	
	Quoted percentage spreads	0.07	0.00	0.00	−0.01	1.86	0.84
		17.89	*2.28*	*−5.01*	*−17.14*	*16.93*	
	Effective dollar spreads	0.20	0.01	0.09	−0.05	7.10	0.58
		4.54	*0.68*	*18.39*	*−7.72*	*5.75*	
	Effective percentage spreads	0.05	0.00	0.00	−0.01	1.47	0.71
		11.63	*0.65*	*−5.01*	*−10.47*	*11.67*	
	Log(quoted inside depth)	8.86	0.00	−0.57	0.17	−50.25	0.64
		35.82	*0.05*	*−21.44*	*4.76*	*−7.34*	

Table 4 (*continued*)

Activity quartile	Dependent variable	Intercept	Post dummy	Log (price)	Log (number of trades)	Volatility	R^2
	Log(total inside depth)	8.96	0.16	−0.59	0.16	−57.80	0.60
		32.53	*3.10*	*−19.78*	*4.22*	*−7.58*	
	Daily quote updates	−376.93	43.69	38.67	48.26	5,205.98	0.22
		−5.86	*3.61*	*5.55*	*5.30*	*2.92*	
4 Most liquid	Quoted dollar spreads	0.21	0.00	0.10	−0.05	11.69	0.58
		5.71	*−0.61*	*18.49*	*−12.54*	*8.29*	
	Quoted percentage spreads	0.03	0.00	0.00	0.00	0.90	0.80
		15.15	*1.06*	*−5.05*	*−12.86*	*13.68*	
	Effective dollar spreads	0.18	−0.01	0.10	−0.05	12.24	0.30
		2.82	*−1.08*	*10.62*	*−6.96*	*4.90*	
	Effective percentage spreads	0.02	0.00	0.00	0.00	0.86	0.71
		10.58	*0.54*	*−3.37*	*−9.35*	*11.80*	
	Log(quoted inside depth)	7.97	−0.02	−0.48	0.25	−33.22	0.65
		47.66	*−0.54*	*−20.14*	*12.72*	*−5.22*	
	Log(total inside depth)	7.92	0.27	−0.50	0.26	−34.96	0.56
		35.29	*6.23*	*−15.79*	*10.09*	*−4.09*	
	Daily quote updates	−3706.90	228.53	295.71	342.94	63,257.89	0.47
		−12.73	*4.03*	*7.14*	*10.19*	*5.71*	

counter to our expectation that such orders would be more valuable in less active securities. However, it does support the notion that informed traders use hidden limit orders to minimize price impact when the risk of non-execution is small (H5) We return to this issue later when we focus on hidden order submission by order type.

Recall that we find no statistically significant change in volume following the abolition of hidden limit orders suggesting that traders did not leave the market and leading us to reject hypothesis H3a. Rindi (2003) predicts that after the reintroduction of hidden limit orders there will be an increase in volume as informed traders reenter the market. We do not find a statistically significant change in share volume associated with the ability to submit hidden limit orders. As a control, we again examine stocks traded on each of the three American markets. We find a statistically insignificant increase in trading activity on the NYSE and AMEX and a statistically significant decrease for Nasdaq stocks for the same period as our TSX sample. These facts suggest that traders did not reenter the market following the reintroduction of hidden limit orders, leading us once again to reject hypothesis H3a.

Examining Table 3 for the impact of the reintroduction on quote updates reveals that, consistent with our previous finding, the number of quote updates again appears to be inversely related to transparency level. Both the univariate results in Table 3 and the multivariate results in Table 4 suggest that traders began using the limit order book more frequently following the reintroduction of hidden limit orders.[11] This is consistent with some traders choosing limit orders over market orders if they can hide a portion of their order. We also find that the largest increases following reintroduction of hidden orders on quote updates occurs in the most active quartiles, once again emphasizing the role of informed traders in using such orders.

6. Hidden limit order usage and location

The availability of order data following the reintroduction of hidden limit orders allows us to examine whether the usage and location (relative to the spread) of these orders varies by trader type. The order data used in this study identifies each order submitter as a member of one of four trader types. The Public Customer trader type represents non-member traders. We treat the three exchange member trader types (registered traders, members trading for their firm's account, and those trading for their own private accounts) as a single type denoted Member. Overall, and by activity quartile, we calculate several measures. We first determine the number of hidden limit orders submitted, and then compare that number to the total number of limit orders placed on the book by each trader type.[12] We then calculate the percentage of limit *orders* submitted that are hidden as well as the percentage of limit

[11] In measuring quote updates for this sample, we eliminate any updates that do not involve a change in price so that we don't just capture hidden orders replenishing depth. As expected, results are in the same direction and stronger if this filter is not used.

[12] Marketable limit orders are excluded.

order *volume* submitted. We also calculate the mean size (size = hidden + exposed) for each group. Finally, overall and by quartile we calculate the percentage of total hidden limit orders submitted by each group. The results of this analysis are contained in Table 5.

Overall we find that hidden limit orders represent less than one percent of all limit orders placed on the book, but 6.54 percent of the share volume submitted. Examining the usage of hidden limit orders as a percentage of limit order volume, we find that overall, they represent 9.09% of Public Customer limit order volume. Members' usage of hidden limit orders represents roughly half of that by Public Customers or 4.73%. The same qualitative result is present in each activity quartile as well, which supports our hypothesis (H5) that members will use hidden limit orders less frequently than public customers.

Some interesting patterns emerge when we examine trader types by activity quartile. First, the mean size of hidden limit orders is inversely related to activity level for both Public Customers and Members. In addition, Public Customers represent 82.5% of the hidden limit orders submitted in the least active quartile. We again find that hidden limit orders are used more frequently in more active stocks. We find that both Public Customers and Members use hidden limit orders to a larger extent in more active stocks. For example the percentage of Members' limit orders submitted that contains a hidden portion is 0.40% for the least active quartile and 5.89% for the most active quartile.

Harris (1996) points out that informed traders tend to quote more aggressively. If the observed direct relationship between hidden limit order usage and activity is due to informed traders, we would expect hidden limit orders to be placed more aggressively in active stocks than in inactive stocks. We therefore next examine the location of the price of hidden limit orders relative to the inside quote at the time the order is submitted.

To do this we compare the submission time stamp for every hidden limit order to the standing inside quote. We then determine whether the order is being placed At, Inside, or Away from the inside quote on the same side as the order. The results, presented in Table 6, are partitioned by trader type, activity quartile, and location. The percentage column shows the percentage of hidden limit orders submitted for that relative location for that trader type and activity quartile.

Overall we find that Public Customers place hidden limit orders at the quote or inside the quote $31.72 + 41.62 = 73.34\%$ of the time, while Members place them at or inside the quote only 59.65% of the time. To the extent that Public Customers are more informed than Members, this would support our contention that informed traders place hidden limit orders to minimize price impact.[13] Examining Table 6 by activity quartile reveals a direct relationship between order aggressiveness and

[13] Our contention that public customers are likely to be more informed than members is based on the definition of information as knowledge about the fundamental value of the company. Members are likely to have information on order flow but are not as likely to be informed about the long term prospects of the company. Also, we recognize that public customers will include informed as well as uninformed traders. However, by this definition, informed traders form a subset of the public customers, thus leading us to look for informed trader effects in this category.

Table 5
Hidden order usage

In this table, we categorize the usage of hidden limit orders by trader type following the Toronto Stock Exchange's rule change reintroducing hidden limit orders on April 12, 2002. The data covers 575 stocks over the period September 2 to September 27, 2002. Trader type Public Customer self is self explanatory. Trader type Members includes orders submitted by registered traders and by members either for their firm's account or a member's personal account. Results are presented overall, and by trading activity (numbers of trades) quartile. Reported is the number of hidden limit orders submitted by trader type in each quartile as well as the percentage of *orders* submitted to the limit order book by a trader type that are hidden limit orders (i.e., market and marketable limit orders are excluded), the percentage of *share volume* submitted to the limit order book by a trader type that is hidden limit orders (again, market and marketable limit orders are excluded), and the percentage of hidden orders represented by *each trader type* (either overall or by quartile). The last two columns contain the average and median hidden limit order trade size, in shares.

Trader type	Activity quartile	Hidden limit orders				
		Number submitted	Percentage of orders submitted	Percentage of volume submitted	Percentage of quartile	Mean order size
All	Overall	23,502	0.52	6.54	100.00	16,819
	1—Least liquid	306	0.09	1.67	100.00	24,717
	2	863	0.19	3.07	100.00	19,123
	3	2,944	0.74	8.89	100.00	18,785
	4—Most liquid	19,389	0.58	7.13	100.00	16,293
Public customers	Overall	12,270	0.61	9.09	52.21	18,680
	1—Least liquid	252	0.36	6.63	82.35	24,338
	2	735	0.52	7.45	85.16	19,267
	3	2,090	0.88	11.39	70.99	19,193
	4—Most liquid	9,193	0.59	8.95	47.41	18,361
Members	Overall	11,231	1.03	4.73	47.79	14786
	1—Least liquid	54	0.18	0.40	17.63	26,473
	2	128	0.29	0.67	14.83	18,302
	3	854	0.58	5.63	29.01	16,293
	4—Most liquid	10,195	1.20	5.80	52.59	14,429

Table 6
Hidden order location

In this table, we examine the location of hidden limit order placement relative to the standing quote on the same side of the market as the order (bid or ask) by trader type following the Toronto Stock Exchange's rule change reintroducing hidden limit orders on April 12, 2002. The data covers 575 stocks over the period September 2 to September 27, 2002. Trader type Public Customer self is self explanatory. Trader type Members includes orders submitted by registered traders and by members either for their firm's account or a member's personal account. To determine location we compare the price indicated on the hidden limit order to the standing quote and classify the order as Inside if the order improves the standing quote, Away if it is worse than the standing quote, or At Quote if they are equal. Results are presented overall, and by trading activity (numbers of trades) quartile. Reported is the percentage of hidden limit orders for each trader type by location category for each quartile.

Trader type	Activity quartile	Location	Percentage
Public customers	Overall	At quote	31.72
		Away	26.66
		Inside	41.62
	1 (Least liquid)	At quote	31.60
		Away	39.20
		Inside	29.20
	2	At quote	26.44
		Away	47.13
		Inside	26.44
	4 (Most liquid)	At quote	30.55
		Away	29.72
		Inside	39.73
Members	Overall	At quote	31.97
		Away	25.29
		Inside	42.75
	1 (Least liquid)	At quote	22.41
		Away	40.35
		Inside	37.24
	2	At quote	20.37
		Away	55.56
		Inside	24.07
	3	At quote	15.87
		Away	51.59
		Inside	32.54
	4 (Most liquid)	At quote	20.64
		Away	47.26
		Inside	32.10
		At quote	22.65
		Away	39.54
		Inside	37.81

activity for both Public Customers and Members. This is consistent with our hypothesis that informed traders will use hidden limit orders to limit price impact when the risk of non-execution is small (H4).

In summary, we find evidence to suggest that traders use hidden limit orders in inactive stocks to limit the option value of their orders. We also find evidence to suggest that informed traders use hidden limit orders to minimize price impact when the chance of non-execution is smallest.

7. Conclusion

Previous research has shown that transparency has significant impact on market quality and the behavior of traders. This paper contributes to that literature by examining one type of pre-trade transparency—the ability to hide a portion of an order. We analyze the issue from the perspectives of market quality and trader behavior. As Harris (1996) points out limit order traders are concerned with being front-run, trading with informed traders and limiting the option value of their orders. Hiding size in the limit order book is a mechanism to manage these concerns. Faced with not being allowed to hide size, traders face the choice of exiting the market or using some other trading strategy.

Our evidence points towards limit order traders switching from limit orders to market orders to manage the hidden part of their orders. In support of this conclusion we find that quoted spreads and quoted depths do not change in the periods surrounding the TSX's decision first to abolish them and then to reintroduce hidden limit orders. However, the number of quote updates is larger if traders are allowed to hide a portion of their orders, suggesting that more frequent usage of the limit order book accompanies the ability to hide size. Evidence on total liquidity in the market indicates that markets remained as liquid as they were prior to the rule change. Effective spreads do not change, trading volumes do not change significantly, and liquidity as measured by Kyle's lambda does not change. This suggests that users of hidden limit orders will switch to market orders if they cannot hide size.

Examining confidential order data following the reintroduction of hidden limit orders reveals that total depth (quoted plus hidden) increases significantly. We find support for our hypothesis that traders who actively monitor the market use hidden limit orders less often than other traders. We also find that while traders appear to use hidden size to reduce the option value of limit orders stocks of all activity levels, informed traders are more likely to use hidden limit orders if the risk of non-execution is small. In particular, while stocks in all activity levels exhibit an increase in hidden limit order usage, actively traded stocks (smallest probability of non-execution) experience the largest increase as well as the most aggressive order placement.

This paper therefore suggests that order exposure cannot be mandated and that attempts to mandate exposure will cause traders to seek other methods to trade, instead of displaying liquidity and increasing quoted depth. Thus, markets and regulators seeking to increase liquidity would be best served by not attempting to mandate order exposure.

Appendix. Estimation of Kyle's lambda

We modify the following equation to study the impact on total depth in the system:

$$\Delta p_t = \lambda q_t + \gamma \mu_t + \varepsilon_t, \tag{A.1}$$

where Δp_t is the change in price ($p_t - p_{t-1}$), q_t is the signed order flow (positive for buy orders and negative for sell orders) μ_t is a market index used to control for positive drift in returns and ε_t is a random noise term. λ is an inverse measure of liquidity. The market index is constructed using all 272 stocks and measures the per-second return on all the stocks in the sample.

To identify buy and sell orders we use the Lee and Ready (1991) algorithm. Instead of a 5-s lag suggested for NYSE by Lee and Ready, we lag quotes by one second only since CATS is a fully automated market. Exchange officials suggested the lag and an examination of the data confirms the adjustment. Trades at the ask are classified as customer buys, at the bid as customer sales, a price higher than the midpoint indicates a buy and one lower than the bid–ask midpoint a customer sale. For trades at the midpoint, we examine the last price change and classify the trades as buys for up ticks and sales for downticks.

The modified equation to study the liquidity effects of the rule change is presented below:

$$\Delta p_t = (\lambda_0 + \lambda_1 D_t) q_t + (\gamma_0 + \gamma_1 D_t) \mu_t + \varepsilon_t \tag{A.2}$$

The only new term, D_t is a dummy which takes on the value 1 for the post-period and 0 for the pre-period. λ_1 and γ_1 capture changes that occur in the two coefficients as a result of the rule change. A positive value for λ_1 would indicate lower liquidity in the post period and a negative value would point towards an increase in liquidity.

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