Lifting the Veil:
An Analysis of Pre-Trade Transparency at the NYSE

Ekkehart Boehmer, Gideon Saar, and Lei Yu

First Draft: November 2002
This version: August 2003

Ekkehart Boehmer is from the Mays Business School, Texas A&M University, College Stations, TX 77843-4218 (Tel: 979-845-1224, EBoehmer@cgsb.tamu.edu). Gideon Saar and Lei Yu are from the Stern School of Business, New York University, 44 West Fourth Street, New York, NY 10012 (Saar: suite 9-93, 212-998-0318, gsaar@stern.nyu.edu; Yu: suite 9-180, 212-998-0345, lyu@stern.nyu.edu). We wish to thank Yakov Amihud, Cecilia Caglio, Robert Engle, Luca Filippa, Thierry Foucault, Joel Hasbrouck, Larry Harris, Craig Holden, Robert Jennings, Charles Jones, Ronald Jordan, Timothy McCormick, Barbara Rindi, Patrik Sandas, James Shapiro, Chester Spatt, Daniel Weaver, and seminar (or conference) participants at Bocconi University, Iowa State University, the New York Stock Exchange, the Securities and Exchange Commission, Southern Methodist University, SUNY at Buffalo, Texas A&M University, Tilburg University, University of Georgia, University of Kentucky, the NBER Market Microstructure Group meetings, and the Western Finance Association meetings for helpful comments. This research began while Boehmer was a Director of Research and Saar was a Visiting Research Economist at the New York Stock Exchange. The opinions expressed in this paper do not necessarily reflect those of the members or directors of the NYSE.

Lifting the Veil:
An Analysis of Pre-Trade Transparency at the NYSE

Abstract

This paper investigates an important feature of market design: pre-trade transparency, defined as the availability of information about pending trading interest in the market. We look at how NYSE's introduction of OpenBook, which enables traders off the exchange floor to observe depth in the limit order book in real time, affects the trading strategies of investors and specialists, informational efficiency, and liquidity. We find that traders attempt to manage the exposure of their limit orders: the cancellation rate increases, time-to-cancellation declines, and smaller orders are submitted. Traders seem to prefer to manage the trading process themselves using the new OpenBook information rather than delegate the task to floor brokers. We show that specialists' participation rate in trading declines and the depth they add to the quote is reduced, consistent with a loss of their information advantage or with being "crowded out" by active limit order strategies. We detect some improvement in the informational efficiency of prices, and provide evidence that displayed liquidity in the book increases and the execution costs of trades decline following the introduction of OpenBook. These results suggest that an increase in pre-trade transparency improves market quality.

1 INTRODUCTION

The proliferation of new exchanges and trading platforms in the U.S. and abroad brings to the forefront many issues in market design. Should a market have at its core an electronic limit order book? What possible roles can market makers play? What information should market participants observe on order flow and prices? These issues have implications for investor trading strategies, specialist behavior, market liquidity, the informational efficiency of prices, and ultimately investor welfare. We investigate a key feature of market design: transparency, or the ability of market participants to observe information in the trading process.

Our focus is on a particular form of transparency: the ability of market participants to observe the pending trading interests of other participants, or in other words, the content of the limit order book. Knowledge about buying and selling interest can be used both to refine one's inference about the value of a security, and to strategically plan the execution of a trading goal to minimize transaction costs. We use the introduction of OpenBook by the NYSE to investigate the impact of an increase in the extent of public information about the content of the limit order book.

OpenBook, introduced in January 2002, allows traders off the NYSE floor to observe depth in the book in real time at each price level for all securities. Before the introduction of OpenBook, only the best bid and offer (representing orders in the book, floor broker interest, and the specialist's own trading desires) had been disseminated. OpenBook increased transparency by adding information about depth in the book at all price levels. Our objective in this study is to examine how publicly revealing information about the limit order book affects investor trading strategies, the way prices evolve in response to order flow, and the resulting state of liquidity in the market.

The literature on transparency differentiates pre-trade transparency, or the availability of information about quotes and trading interest, from post-trade transparency, or information about executed trades.[1] Even in the realm of pre-trade transparency, which is our subject of investigation, most papers look at the influence of quote information in a multiple-dealer market (e.g., Bloomfield and O'Hara, 1999; Flood, *et al.*, 1999) or use the availability of information to characterize different market structures (e.g., Madhavan, 1992; Biais, 1993; Pagano and Röell, 1996).[2]

In recent years there has been a growing theoretical and empirical literature about limit order books. The tradeoffs in using limit orders and the nature of equilibrium in limit order markets were the focus of several theoretical models (e.g., Cohen, Maier, Schwartz, and Whitcomb (1981), Glosten (1994), Seppi (1997), Parlour (1998), and Foucault (1999)).[3] Two papers, Madhavan, Porter, and Weaver (2000) and Baruch (2002), specifically construct models to address the question of how revealing more or less information about the content of a limit order book affects the market. We rely on the theoretical predictions from these two papers to guide our investigation into the impact of limit order book transparency on informational efficiency and liquidity.

In organizing our empirical investigation, we have found it useful to think about the consequences of changes in pre-trade transparency first in terms of direct effects on the trading strategies of market participants and then on the resulting equilibrium state of informational efficiency and liquidity. Harris (1996) provides a discussion of the risks associated with the

---

[1] For investigations of post-trade transparency see Chowhdry and Nanda (1991), Naik, Neuberger, and Viswanathan (1994), Franks and Schaefer (1995), Madhavan (1995), Lyons (1996), and Bloomfield and O'Hara (1999).

[2] Madhavan (1996) investigates the role of information about order flow, but focuses on the availability of information about traders' motives (i.e., whether liquidity traders can be identified) and therefore can be viewed more as a model of anonymity in financial markets. See also Rindi (2002).

[3] Recent empirical work on limit order markets includes Biais, Hillion, and Spatt (1995), Handa and Schwartz (1996), Ahn, Bae, and Chan (2001), Sandas (2001), and Hasbrouck and Saar (2001).

exposure of limit orders. The first risk is that a trader may reveal to the market private information about the value of the security, allowing other traders to trade on it. A second risk is that exposed limit orders can be used to construct trading strategies aimed explicitly at taking advantage of these limit orders (e.g., "pennying" or front-running the limit orders). Harris details strategies that limit-order traders can use to manage the exposure of their orders. They may break up their orders, submitting smaller limit orders. This would reduce the first risk, as market observers may be more reluctant to make an inference about the value of the security on the basis of a small order. Traders may also cancel and resubmit limit orders more often. This would reduce the second risk, as it would frustrate front-running strategies. Finally, traders may use agents closer to the trading process (floor brokers at the NYSE) to manage order exposure, rather than submitting limit orders to the book themselves.

We look at the cancellation of limit orders after OpenBook is introduced, and find a higher cancellation rate and shorter time-to-cancellation of limit orders in the book. We also find smaller limit orders after the change in transparency. This evidence is consistent with the idea that traders attempt to manage the exposure of their orders, in line with Harris's reasoning. However, we do not observe a shift from trading using limit orders in the book to trading with the help of floor brokers. Instead, the volume executed by floor brokers declines compared to that executed against limit orders in the book. Why may that be happening? OpenBook enables traders not just to observe information about demand and supply away from the quote, but also to see how their own actions affect the book. This "visibility effect" may make self-management of orders more appealing to traders, in a manner analogous to the attraction of active traders in Nasdaq stocks to electronic communications networks. Such an effect could dominate the argument Harris (1996) makes for employing agents, and explain our finding.

We also investigate the trading of one particular type of market professionals—NYSE specialists—who both maintain the limit order book and trade for their own account (make a market in the stocks). An open limit order book may affect specialists in a couple of ways. First, if investors become reluctant to provide liquidity with limit orders, specialists may need to increase their participation in the trading process in their capacity as liquidity providers of last resort. Second, opening the book may reduce the information advantage that specialists have about future price movements.[4] This may make proprietary trading riskier for the specialists, reducing their incentive to trade.

We find that the specialist participation rate in trades declines following the introduction of OpenBook. We also find that they reduce the depth they add to the quote (together with floor brokers) beyond what is in the limit order book. These changes in trading strategies are consistent with an increase in the risk of proprietary trading on the part of specialists due to loss of their information advantage. Because public limit orders have priority over the specialists' proprietary trading, these changes are also consistent with a "crowding out" effect due to more active limit order strategies employed by investors. Finally, a reduced contribution of the floor to the quoted depth may be due to the shift we observe from floor trades to limit orders that are sent to the book electronically.

Changing strategies of market participants can alter characteristics of the market environment that are important to investors, such as liquidity and informational efficiency. Several arguments have been made in the literature about the impact of pre-trade transparency on these market characteristics. Glosten (1999) presents an informal argument stating that increased transparency should lead to greater commonality of information, and that this tends to reduce the extent of adverse selection. His argument implies that greater transparency should result in more efficient prices (information gets out more quickly) and narrower spreads (less need to protect against informed traders). Baruch (2002) examines who benefits from an open limit order book in a static model where market orders are submitted by liquidity traders and a strategic informed

---

[4] On whether the limit order book provides information about future price movements, see Harris and Panchapagesan (1999), Corwin and Lipson (2000), Irvine, Benston, and Kandel (2000), Kaniel and Liu (2001), and Coppejans and Domowitz (2002).

trader, while liquidity is supplied by limit order traders and a specialist. Two implications of his model are that opening the book (i) improves liquidity in the sense that the price impact of market orders is smaller, and (ii) improves the informational efficiency of prices. Therefore, both Glosten and Baruch conclude that greater transparency is a win-win situation.

A different view is expressed by Madhavan, Porter, and Weaver (2000). They present a static model with multiple informed and uninformed traders who use market orders and liquidity traders who use limit orders. In their model, greater transparency leads to wider spreads, less depth, and higher volatility. Therefore, opening the book reduces liquidity, contrary to the predictions of Baruch (2002) and Glosten (1999). Madhavan *et al.* also conduct an empirical investigation of the Toronto Stock Exchange's decision to disseminate information about depth at the top four price levels in the book (in addition to the best bid and offer) in April 1990. Since they do not have the detailed order-level data that we have, they are unable to provide evidence about investor strategies or depth in the book, but they do show that spreads are wider after the event and that volatility is higher, both consistent with their theoretical predictions.[5]

Our results contrast with the Toronto Stock Exchange findings and provide support for the view that greater pre-trade transparency is a win-win situation. To examine whether greater pre-trade transparency indeed makes prices more efficient, we use a variance decomposition methodology proposed by Hasbrouck (1993) and find smaller deviations of transaction prices from the efficient (random walk) price. We also document a slight reduction in the absolute value of first-order return autocorrelations calculated from quote midpoints. These findings are consistent with more efficient prices following the introduction of OpenBook that are less subject to overshooting and reversal.

---

[5] While we did not find other empirical work that investigates limit order book transparency, two experimental studies touch upon the issue. Friedman (1993) finds that showing the entire book (as opposed to only the best bid and offer) reduces the bid-ask spread in the market, but does not significantly alter the informational efficiency of prices. Gerke, Arneth, Bosch, and Syha (1997) compare open and closed book environments, and find lower volatility in the transparent setting but no statistically significant differences in spreads.

We then examine two measures of liquidity about which we have predictions from the theoretical models: depth in the book and effective spreads (or the price impact of trades). Displayed liquidity in the limit order book increases somewhat following the introduction of OpenBook. Results on effective spreads confirm that execution costs decline. Our analysis of the change in liquidity around the event uses several econometric models to implement controls and account for potential estimation problems, and the results are robust to the different specifications we use.

While we believe that the effects we document are associated with the increase in transparency that accompanied the introduction of OpenBook, we fully acknowledge that this is an investigation of a single event and therefore our statistical ability to attribute changes to the event is limited. This issue is a recurring theme in empirical analysis of financial implications of regulatory changes (see, for example, Schwert (1981)). We believe that the question of how changes in market design affect market quality is important enough to warrant a careful investigation of this particular event. Furthermore, we do address the concern that the changes we document are due to a secular trend in the variables rather than the introduction of OpenBook. We look at changes in these variables before the event and conclude that the effects we document do not reflect a trend that existed in the market.

Amihud and Mendelson (1986) claim that liquidity affects expected returns in that investors require higher expected returns to compensate them for higher transaction costs. Since we document a reduction in effective spreads, a natural hypothesis is that prices increase to reflect lower future expected returns. While we cannot perform a "classic" event study of returns since there is no definite announcement date for OpenBook, we examine abnormal returns around the implementation date of the service. We show that abnormal returns are cross-sectionally negatively related to changes in effective spreads around the event, which is consistent with possible price effects of improved liquidity.

Overall, we find that greater transparency of the limit order book benefits investors. This finding is important for several reasons. First, the theoretical literature provides conflicting predictions on how liquidity would change when opening the book, and our findings about liquidity are contrary to those documented when the Toronto Stock Exchange started revealing information about demand in the book. Second, the Securities and Exchange Commission (SEC) has repeatedly emphasized the need for increased pre-trade transparency. Our research is the first empirical study to provide support for such a policy. Third, our results show that market design exerts influence not just on trading strategies but also on equilibrium liquidity and the informational efficiency of prices. As such, research on market design can help exchanges and regulators improve the functioning of financial markets.

The rest of this paper proceeds as follows. Section 2 provides details on the OpenBook initiative at the NYSE, describes the event periods, and presents the sample and the data sources used in the investigation. Section 3 presents the results of our tests concerning the trading strategies of investors, the participation of specialists, informational efficiency, and liquidity. Section 4 is a conclusion.

2 RESEARCH DESIGN

2.1 OpenBook

Whether or not to make public the content of the limit order book maintained by specialists at the NYSE has been the subject of discussion for over a decade. In 1991, the NYSE received the approval of the SEC for a program that would have provided snapshots of the book to member firms three times a day. In June of that year, the NYSE announced that it would not implement the system, citing lack of interest among member firms. In 1998, the NYSE announced it was considering providing information about the limit order book for prices two ticks below and above the best bid and offer. In October 2000, the NYSE again announced intentions to reveal more on the book as part of an initiative called Network NYSE. The implementation was scheduled for the second quarter of 2001, but was postponed. In 2001, the NYSE filed with the SEC for approval of a service called OpenBook that gives information about depth in the book to subscribers, either directly from the NYSE or through data vendors such as Reuters and Bloomberg.

The NYSE's request was approved by the SEC on December 7, 2001, and the OpenBook service was introduced on January 24, 2002, for all NYSE securities simultaneously. OpenBook operates between 7:30am and 4:30pm. It is available for all NYSE-traded securities and shows the aggregate limit order volume available in the NYSE Display Book system at each price point.[6] The information about depth is updated every ten seconds throughout the day. Since the NYSE charges a fee for the service, we can get a sense of the extent to which this new information is being disseminated. OpenBook had approximately 2,700 subscribers when the service was introduced. This number grew to about 6,000 during the first four months of operation in a steady fashion.

2.2 Event Periods

It is difficult to pinpoint the announcement date for OpenBook. Several times during the last few years the idea was announced but never materialized. Therefore, it is not clear whether the announcement in October 2000, when the NYSE's press release mentioned OpenBook as part of the Network NYSE initiative, had much credibility. Only when the SEC approved the service in December 2001 could the NYSE in fact implement the service (though some people might have anticipated it). In contrast, there is no such uncertainty about the implementation date of OpenBook: the service was made available to the public on January 24, 2002. Fortunately, it is the implementation date that matters most for our purpose. While prices may change in anticipation of an event, trading strategies that require information about limit orders in the book cannot be implemented without this information. Therefore, the effects we wish to investigate are best examined around the implementation date.

[6] OpenBook does not show orders with special handling instructions such as CAP (or percentage) orders. Also, OpenBook does not provide any order execution capabilities. It is merely an information dissemination system.

We are interested in identifying the permanent effects of the change in pre-trade transparency. For that purpose we need to examine two periods in which the market is in equilibrium with respect to traders' use of order flow information, one before the event and one after the event. We choose two weeks (ten trading days) for the length of each period. We believe this choice strikes a balance between our desire to employ more data for the statistical tests on the one hand and both the stability of the estimates and the complexity of handling NYSE order-level data on the other.

The NYSE did not make other changes to its trading platform around the time OpenBook was introduced. Decimalization was completed a year earlier (January 2001), and Direct+ (an initiative that provides automatic execution against the quote for small orders) was implement in April 2001. Primex, a Nasdaq facility for trading NYSE stocks, began operating on December 2001. It was used primarily by wholesalers such as Madoff Securities and did not seem to attract much volume beyond what these wholesalers were doing already. We believe that staying close to January 24 in our choice of a pre-event period is preferable. Since traders cannot use the information in OpenBook prior to January 24, there is no need to eliminate a long window before the event in order to obtain the steady state of traders' strategies. We choose the full two trading weeks prior to the introduction week as the pre-event period (January 7 through January 18).

The choice of an appropriate post-event period is more complex. While traders were able to see limit order book information beginning January 24, learning how to use this information likely took some time. This is true both for traders who want to use it just to optimize the execution of their orders and for traders who plan to use it to design profitable trading strategies. Furthermore, once such strategies are in place, other traders (e.g., mutual funds' trading desks) may experience poorer execution of their limit orders. This would prompt more traders to change their strategies until a new equilibrium emerges. How long it takes for such a process is hard to say. It could take days, weeks, or months, depending on the sophistication of the traders and profit opportunities.

Also, the number of subscribers increased in the months following the introduction of OpenBook, which could affect the adjustment of the market to the new pre-trade transparency regime.

One approach to choosing a post-event equilibrium period would be to take a period rather far from the event itself. While this may be useful in assuring that the changes observed are permanent, it then becomes more difficult to attribute them to the event as more time has passed. Another approach is to choose a rather long post-event period. This has the disadvantage that the variables of interest may not be stationary during the period of adjustment.

We therefore choose a third approach that we hope overcomes these problems. As with the pre-event period, we use two weeks as the length of a post-event period to capture a reasonably stationary snapshot of the trading environment. However, to allow for adjustment to an equilibrium state, and to examine this adjustment, we use four post-event periods rather than one. We take the first two full weeks of trading of each month following the introduction of OpenBook: February 4-15, March 4-15, April 1-12, and May 6-17. This enables us to examine how the new equilibrium emerges over time.

2.3 Sample and Data

The universe of stocks considered for this study includes all common stocks of domestic issuers traded on the NYSE. We eliminate firms that did not trade continuously between January and May of 2002, firms with more than one class of traded shares, closed-end funds, and investment trusts. This results in a population of 1,332 stocks. We then sort by median dollar volume in the last quarter of 2001 and choose a stratified sample of 400 securities that can also be divided into four 100-stock groups according to the intensity of trading.[7] In the presentation of our findings, if the picture is very similar across groups we present only the results for the entire

[7] We also verified that our sample stocks did not experience stock splits or undergo mergers during the sample period.

sample to simplify the exposition. Whenever the results differ for stocks with different trading intensity, we present the results for the four groups separately.

Table 1 provides summary statistics for the entire sample and for each of the four trading-intensity groups. We present summary statistics for the pre-event period and the four post-event periods. The table testifies to the heterogeneous nature of the sample, ranging from a median average daily volume of 59.43 million dollars for the most actively traded group in the pre-event period to a median of $370,000 for the least actively traded group. All variables—volume, quoted spread, depth, effective spread, and price—change in the expected manner when moving from the most active stocks to the least active stocks. For the most (least) actively traded stocks, median quoted spread is 4.4 (8.9) cents, and median quoted depth (summing both the bid and ask sides) is 3,445 (1,607) shares. We also observe that prices are higher for the most actively traded stocks in the sample, $42.74, as compared with $11.15 for stocks in the least actively traded group.

The data source used for the summary statistics in Table 1 is the TAQ database distributed by the New York Stock Exchange. We use these data to analyze effective spreads and informational efficiency.[8] To study the relation between liquidity changes and returns, we use daily distribution- and split-adjusted returns from FactSet and CRSP.

The rest of our analysis is based on NYSE order-level data provided in the System Order Data (SOD) and Consolidated Equity Audit Trail Data (CAUD) files.[9] In general, the SOD file

---

[8] The variables we analyze are calculated using NYSE trades and quotes. We apply various filters to clean the data. We only use trades for which TAQ's CORR field is equal to either zero or one, and for which the COND field is either blank or equal to B, J, K, or S. We eliminate trades with non-positive prices. We also exclude a trade if its price is greater (less) than 150% (50%) of the price of the previous trade. We eliminate quotes for which TAQ's MODE field is equal to 4, 5, 7, 8, 9, 11, 13, 14, 15, 16, 17, 19, 20, 27, 28, or 29. We exclude quotes with non-positive ask or bid prices, or where the bid is higher than the ask. We require that the difference between the bid and the ask be smaller than 25% of the quote midpoint. We also eliminate a quote if the bid or the ask is greater (less) than 150% (50%) of the bid or ask of the previous quote. When signing trades, we use an additional filter that requires the difference between the price and the prevailing quote-midpoint to be less than $8.

[9] A reduced version of these files was the basis for the TORQ database organized by Joel Hasbrouck in 1991. A description appears in Hasbrouck (1992).

includes detailed information on all orders that arrive at the NYSE via the SuperDot system or that are entered by the specialist into the Display Book system (which powers the limit order book). SOD contains about 99% of the orders, representing 75% of NYSE volume, and follows orders from arrival through execution or cancellation. Together with the LOFOPEN file, which describes the exact state of the limit order book every day before the opening of trading, SOD allows us to precisely reconstruct the limit order book on the NYSE at any time. It also enables us to examine how investors change their order submission strategies, and to determine how much depth specialists and floor brokers add to the quote beyond what is in the limit order book.

The CAUD files contain detailed execution information on both electronic and manual orders (the latter handled by floor brokers). This enables us to determine the participation rate of specialists in the trading process and the portions of trading volume that originate from either floor brokers or electronic limit orders.

3 RESULTS

Our analysis of the change in pre-trade transparency induced by OpenBook closely follows the exposition of the arguments in the introduction. First, we look at how market participants change their trading strategies as a result of the event. We examine both traders' use of limit orders and specialists' participation in trading and liquidity provision. Second, we examine how these strategies affect the informational efficiency of prices by looking at the deviations of transaction prices from the efficient price and the autocorrelations of quote-midpoint returns. Third, we look at liquidity provision in the book and execution costs for NYSE trades. We then examine the question whether our results could be explained by a secular trend in the variables we analyze. Finally, we explore the relation between liquidity changes and returns around the implementation of OpenBook.

3.1 Trading Strategies

For the statistical analysis of trading strategies we use non-parametric univariate tests.[10] For each period, we compute stock-specific means for all variables. We then report the median across stocks of pairwise differences between each post-event period and the pre-event period, and the *p*-value from a Wilcoxon test against the two-sided hypothesis that the median is equal to zero. We therefore investigate the total effects of the introduction of OpenBook on strategies, without making an attempt to disentangle which changes represent *direct* effects of the event and which changes are *indirect* effects attributable to changes in other variables. We begin by looking at the conjectures from Harris (1996) that traders will react to the risk in order exposure by changing their behavior: canceling and resubmitting limit orders more frequently (shortening the time they are publicly displayed in the book), breaking limit orders into smaller sizes, and making greater use of agents such as floor brokers.

Table 2 examines the cancellation of limit orders. The results are presented for the overall sample, because the four groups behave in a similar fashion. The first line in Panel A shows an increase in the cancellation rate of limit orders (number of limit orders cancelled divided by the number submitted). The median differences between the post- and pre-event periods are positive, and increase monotonically with time. The median change from January to February is 0.68% (though not statistically significant), reaching 4.75% between January and May (and highly statistically significant). The second line in Panel A presents the time-to-cancellation (in seconds) of limit orders that are cancelled. It declines following the event, and declines further with time. Compared to January, time-to-cancellation is 12.77 seconds shorter in February and 50.58 seconds shorter in May. On a pre-event median value of 290 seconds, the decline in time-to-cancellation seems to be quite large (17.4%).

[10] Many of the variables we investigate do not necessarily fit the normality assumption needed for a t-test.

A limitation of the above analysis of time-to-cancellation and the cancellation rate is that it ignores censoring (i.e., limit orders that are executed or expire and therefore cannot be cancelled). We use survival (or duration) analysis to estimate two models that take censoring into account (see Hasbrouck and Saar, 2002, and Lo, MacKinlay, and Zhang, 2002). First, we use an accelerated failure time model that assumes time-to-cancellation follows a Weibull distribution. The logarithm of time-to-cancellation of limit orders is modeled as a linear function of an intercept, a dummy variable that takes the value 1 after the introduction of OpenBook, and the distance of the limit order from the relevant quote side (the bid for limit buy orders and the ask for limit sell orders) divided by the quote midpoint. The standardized distance from the quote is included as a covariate since it is presumably an important determinant of the probability of both execution and cancellation. The duration model is estimated separately for each stock using all limit orders in the 20-day pre- and post-event periods.

To aid in interpretation of the coefficients, we report in Table 2 the transformation $e^{\text{coefficient}} - 1$ that provides the percentage change in expected time-to-cancellation between the pre- and post-event periods. The first line in Panel B presents the cross-sectional median of the transformed coefficients on the event dummy variable and the number of the statistically significant coefficients (at the 5% level). In all four post-event periods, the Wilcoxon test is highly significant and over 394 (of 400) coefficients in the individual stock regressions are statistically significant. For the February post-event period, expected time-to-cancellation of limit orders declined by 10.47%. The decline continues over the sample period and reaches 24.29% by May.

We also report the results of semiparametric Cox regressions (see Cox, 1972), where the logarithm of the hazard rate is modeled as a linear function of an intercept, a dummy variable for the event, and the distance from the quote. While both the Cox model and the Weibull model belong to the class of proportional hazard models, the Cox model does not require that we choose a particular probability distribution for time-to-cancellation. The transformation $e^{\text{coefficient}} - 1$ presented in the second line in Panel B can be interpreted as the percentage change in the estimated cancellation rate of limit orders between the pre- and post-event periods (controlling for the distance from the quote). The results indicate that the cancellation rate increases in a gradual manner: from 6.57% in February to 17.24% in May. The increase in cancellation rate is highly statistically significant in all four periods.

Panel A of Table 3 continues our investigation of changes in the trading strategies of investors following the introduction of OpenBook. The first line shows median pairwise differences in the size of limit orders between the post- and pre-event periods. For all four post-event periods, the median changes are negative and statistically different from zero. The magnitude of the changes increases with time after the event. The difference in the size of a typical limit order of the same stock between February and January is −29.5 shares, reaching −68.4 in May. On a pre-event median limit order size of 543 shares, this represents a decline of 12.6%.

The second line in Panel A presents the changes in floor-broker activity relative to electronic limit-order activity. The ratio we compute is the sum of the number of shares bought and sold by floor brokers divided by the sum of the number of shares bought and sold by limit orders in the book. We document a decline in floor activity relative to limit orders in the book, ranging from −0.014 in February to −0.05 in May (the differences in the last three post-event periods are statistically different from zero).[11] On a pre-event median ratio of 0.52, the magnitude of the decline is almost 10%.

The results are consistent with heightened limit-order exposure management: smaller limit orders are submitted, limit orders are cancelled more often, and limit orders are left for a shorter time in the book. The new ability to see depth in the book seems to make self-management of the trading process more attractive. The shift we document from floor trading to electronic limit orders may indicate that the benefit associated with active trading strategies employed by the traders

[11] Separate analysis shows that floor broker activity relative to total volume goes down after the introduction of OpenBook (and the change is statistically significant in three out of the four periods), and electronic limit order activity relative to total volume increases significantly in all four post-event periods.

themselves using OpenBook outweighs the cost of displaying trading interests. The trend in median differences of the variables over the four post-event periods is consistent with the idea that traders learn over time about the new service, learn how to use the information in OpenBook, and adjust their trading strategies accordingly.[12]

The change in pre-trade transparency and the change in the behavior of traders can cause NYSE specialists, who make a market in the stocks, to alter their behavior. We use the CAUD files to examine specialist participation in the trading process. The participation rate is defined as the number of shares bought and sold by the specialist over the total number of shares bought and sold. The first line in Panel B of Table 3 shows that the specialist participation rate declines in the post-event periods. While the median difference between the first post-event period and the pre-event period is not statistically distinguishable from zero, the median differences for the three other post-event periods are negative and highly statistically significant.[13]

The bid-ask quote disseminated by the NYSE is determined by the specialist. The depth quoted at the bid and ask prices, however, can just reflect the depth available at the best prices in the book. Alternatively, the specialist can add depth to the quote reflecting interest of floor brokers or his own interest (in his capacity as a dealer). The second line in Panel B describes the dollar value that specialists (potentially reflecting floor broker trading interest) add to the quoted depth beyond what is in the limit order book. To create this variable, we use the LOFOPEN and SOD files to reconstruct the book and compare the best prices and depths in the book to the quote disseminated by the specialist every five minutes throughout the trading day. We compute the value of the specialist contribution to the quoted depth beyond what is in the limit order book for each five-minute snapshot, average over all snapshots, and compute the differences between the

---

[12] The adjustment takes time because not all traders would learn at the same speed, and also because predatory trading strategies based on the information in OpenBook take time to develop. Time may be further required for institutional traders to learn about the risks in leaving their limit orders on the book in the new environment.

[13] Similar results are obtained when the participation rate is defined in terms of number of orders rather than number of shares.

post- and pre-event periods for each stock. The specialists' contribution declines monotonically over the four post-event periods, from a median difference of −\$1,164.76 to −\$2,599.81 (three of the four differences are statistically different from zero).

These results—less participation by the specialists in trading and committing to a smaller quoted depth—are consistent with an increase in the risk associated with the specialists' proprietary trading due the loss of their information advantage. They are also consistent with a "crowding out" effect, in that more active management of public limit orders (which have priority over the proprietary trading of specialists) is limiting the ability of specialists to participate in the trading process. Finally, the reduced depth added by the specialists and floor brokers is also consistent with the shift from floor to electronic limit orders that we have documented.

3.2 Information and Prices

Both Glosten (1999) and Baruch (2002) predict that improved transparency would lead to increased informational efficiency of prices. We implement two tests of this hypothesis. The first test is based on the variance decomposition procedure in Hasbrouck (1993). Using information about transaction prices and trade size, Hasbrouck proposes a vector autoregression model to separate the efficient (random walk) price from deviations introduced by the trading process (e.g., short-term fluctuations in prices due to inventory control or order imbalances in the market). More specifically, the variance of log transaction prices, $V(p)$, is decomposed into the variance of the efficient price and the variance of the deviations induced by the trading process, $V(s)$. Because the expected value of the deviations is assumed by the procedure to be zero, the variance is a measure of their magnitude.

To control for possible changes in the overall variability of prices around the event that can cause a change in the magnitude of the deviations, we divide $V(s)$ by $V(p)$ to normalize the measure.[14] This ratio, *VR(s/p)*, reflects the proportion of deviations from the efficient price in the total variability of the transaction price process. If OpenBook allows traders to better time their trading activity to both take advantage of displayed liquidity and provide liquidity in periods of market stress, the proportion of deviations from the efficient price should be smaller after the event. The first line in Table 4 shows median changes between the pre- and post-event periods for *VR(s/p)* (expressing the ratio in percentage terms). While the changes are not significantly different from zero in the February and March post-event periods, they become negative and highly significant in the April and May post-event periods.

Another test of informational efficiency can be formulated by assuming that the quote midpoint is the market's best estimate of the equilibrium value of the stock at every point in time. A more efficient quote-midpoint process would be closer to a random walk and therefore exhibit less autocorrelation (both positive and negative). The second and third lines in Table 4 show changes in the absolute value of the 30-minute and 60-minute first-order quote-midpoint return autocorrelation. For the 30-minute process, we divide the trading day into half-hour intervals and compute the returns from the prevailing quote midpoints at the beginning and end of each interval (a similar construction is used for the 60-minute process). We examine the absolute value of the correlation coefficients because we would like to test how close the return process is to a random walk, which is characterized by zero autocorrelations.

We find that the direction of changes in autocorrelation is consistent with more efficient prices, but the results are rather weak. While the median changes are negative in all post-event periods, only two of the numbers are statistically different from zero. One of the two statistically

---

[14] It is reasonable to assume that the magnitude of the deviations is positively related to the efficient price variance. The methodology allows for such a correlation. If the efficient price variance of some stocks changes over the sample period, this change may affect the estimated deviations even if OpenBook had no impact on their magnitude. By using the ratio we partially overcome this potential problem. If the variance of the deviations is approximately proportional to the efficient price variance, then a change in the efficient price variance will not affect the ratio and would allow a clean inference about the effect of OpenBook.

significant changes, however, is in the March post-event period that does not exhibit a statistically significant change in *VR(s/p)*. The results of these two tests together point to some improvement in informational efficiency under the new pre-trade transparency regime.

3.3 Liquidity

What we would like to examine in this section is how the changing strategies of investors and specialists aggregate to create a new state of liquidity provision in the market. This analysis has special significance since the theoretical arguments we have surveyed disagree on this point—Madhavan, Porter, and Weaver (2000) claim that greater transparency would cause liquidity to deteriorate while Glosten (1999) and Baruch (2002) claim that it would improve liquidity. In particular, Madhavan, *et al.* show that depth in the book would decrease and spreads (or the price impact of trades) would increase when the book is opened. Baruch (2002) provides the opposite prediction about spreads, claiming that the price impact of trades would decrease with greater transparency.

To evaluate the predictions from these models, we look at both depth in the book and effective spreads. We record snapshots of total depth in the limit order book for each stock every five minutes. We then construct our depth measure by averaging these snapshots for each period. The effective spread measure is computed by averaging the distance between the transaction price and the prevailing quote midpoint for all transactions in a period. Because there is much evidence that liquidity is affected by attributes such as volume, we use several parametric approaches to examine the change in liquidity conditional on three control variables. The controls are the average daily dollar volume, intra-day volatility expressed as the average daily range of transaction prices (high minus low), and the average transaction price of the stock (to control for price level effects).

The first econometric specification assumes that the liquidity measure for stock i in period τ (where $\tau \in \{\text{pre, post}\}$), $L_{i,\tau}$, can be expressed as the sum of a stock-specific mean (μ_i), an event effect (α), a set of control variables, and an error term (η):

$$L_{i\tau} = \mu_i + \alpha\delta_\tau + \beta_1 AvgVol_{i\tau} + \beta_2 HiLow_{i\tau} + \beta_3 AvgPrc_{i\tau} + \eta_{i\tau}$$

where δ_τ is an indicator variable that takes the value zero in the pre-event period and one in the post-event period, *AvgVol* represents dollar volume, *HiLow* is intra-day volatility, and *AvgPrc* is the price. By assuming that the errors are uncorrelated across securities and over the two periods (although we do not require them to be identically distributed), we can examine differences between the post- and pre-event periods and eliminate the firm-specific mean:

$$\Delta L_i = \alpha + \beta_1 \Delta AvgVol_i + \beta_2 \Delta HiLow_i + \beta_3 \Delta AvgPrc_i + \varepsilon_i$$

where Δ denotes a difference between the post- and pre-event periods.

We estimate the equation above using OLS and compute test statistics based on White's heteroskedasticity-consistent standard errors. The first line in Panel A of Table 5 presents the intercepts and *p*-values from the regressions using the change to depth in the book (in round lots) as the liquidity variable. The intercepts for all four post-event periods are positive, and two of the four are statistically significant at the 5% level, indicating some increase in book depth in the post-event period. The second line in Panel A presents the results using effective spreads (in cents) as the dependent variable. All coefficients are negative, and they increase in magnitude over time from –0.1046 in February to –0.8001 in May (where the last three post-event periods are statistically significant). Since effective spreads measure the cost of trading and volume measures the quantity of trading, it can be argued that a single-equation specification regressing effective spreads on volume suffers from an endogeneity problem. We examined this potential problem using a simultaneous-equation model of spreads and volume, and the results were similar to those from the single-equation specification.[15]

---

[15] The specification of the simultaneous-equation model we used is:

$$\Delta ESpread¢_i = \alpha + \beta_1 \Delta AvgVol_i + \beta_2 \Delta HiLow_i + \beta_3 \Delta AvgPrc_i + \beta_4 \Delta StdInv_i + \varepsilon_i$$

$$\Delta AvgVol_i = \beta_5 + \beta_6 \Delta ESpread¢_i + \beta_7 \Delta HiLow_i + \beta_8 \Delta AvgPrc_i + \beta_9 \Delta SysVol_i + \nu_i$$

Since the event happens to all stocks at the same time, it is possible that the error terms are correlated across stocks. This would cause the standard errors of the intercepts to be biased, but the OLS coefficients would still be consistent. To examine the robustness of our results to this potential problem, we compute daily values of the variables (e.g., ten daily averages of effective spreads indexed by *t* rather than an average over the entire period), and estimate the following equation pooling all the stocks in our sample:

$$L_{it} = Intercept + \Sigma_{k=1}^{n} (\beta_k Day^k_{it}) + \gamma_1 Vol_{it} + \gamma_2 HL_{it} + \gamma_3 Prc_{it} + \varepsilon_{it}$$

where the dummy variables Day^k_{it} ($k = 1, \ldots, n$) take the value one for the k-th day in the n-day post-event period and zero otherwise, *Vol* is the daily dollar volume, *HL* is the daily range of transaction prices, and *Prc* is the daily average transaction price of the stock. We estimate the model in two ways: (i) for the pre-event period combined with each of the post-event periods (resulting in 10 coefficients of the daily post-event dummy variables), and (ii) for the entire sample period of 50 pre-event and post-event days (resulting in 40 coefficients of the daily post-event dummy variables).

Panel B of Table 5 reports the median of the coefficients on the post-event dummy variables and the *p*-value (in parentheses) of a Wilcoxon signed rank test against the hypothesis of a zero median. The idea behind the test is similar in spirit to the one underlying the Fama and MacBeth (1973) specification. The OLS coefficients on the dummy variables are consistent even with cross-correlated errors, and therefore a test that uses time-series variation in the coefficients is not affected by this potential problem. Three of the four post-event periods show a significant

---

where $\Delta StdInv$ is the standard deviation of daily inventory closing positions of specialists (from the NYSE's SPETS file), and $\Delta SysVol$ is the systematic component of dollar volume. The systematic component is obtained from a market model of dollar volume using one year of daily data ending before the beginning of the pre-event period, with an equally-weighted portfolio of all common domestic NYSE stocks as a proxy for the market (see Lo and Wang, 2000, and Llorente, Michaely, Saar, and Wang, 2002, on the issue of a market model for volume). The simultaneous-equation model was estimated both using two-stage least squares and three-stage least squares. For all post-event periods, the magnitudes of the intercepts from the effective spreads equation and their statistical significance were almost identical to those reported in Table 5, and are therefore omitted for brevity.

increase in book depth after the introduction of OpenBook, and so does the regression over all periods together. Similarly, there is a highly significant decline in effective spreads in three of the four post-event periods and in the regression for the entire sample period.[16]

The fact that the results are qualitatively similar using the different econometric specifications indicates that our findings are rather robust. We conclude that both "ex-ante" liquidity (displayed trading interest in the book) and "ex-post" liquidity (effective spreads) increase following the introduction of OpenBook.

3.4 Could the Results Just Reflect a Trend?

In the introduction we noted that our study of changes in pre-trade transparency uses a single event: the introduction of OpenBook. As such, we rely on the cross-section of stocks to provide us with statistical significance for the changes we document. In principle, it is possible that these changes reflect a trend that existed in the market even before the introduction of OpenBook.

To examine this issue, we would like to look at the variables prior to the introduction of OpenBook. We therefore proceed to take another 10-day period, August 27 to September 10, 2001, and test the differences in the variables from this period to the January pre-event period. Our choice of a "robustness" period was driven by three considerations. First, we wanted the interval of time between the robustness period and the January pre-event period to be similar to the interval between one of the post-event periods and the pre-event period so that we could compare the magnitude of the changes. Second, we wanted to avoid looking at the variables in the immediate

---

[16] We implemented yet another procedure to examine robustness to the potential problem of cross-correlated errors by computing cross-sectional daily averages of each variable and using OLS to estimate the following time-series model:

$$CSL_t = Intercept + \Sigma_{k=1}^{4} (\beta_k D^k_t) + \gamma_1 CSVol_t + \gamma_2 CSHL_t + \gamma_3 CSPrc_t + \varepsilon_t$$

where the dummy variables D^k_t (k = 1, 2, 3, 4) take the value of one for the k-th post-event period and zero otherwise, *CSVol* is the cross-sectional average of daily dollar volume, *CSHL* is the cross-sectional average of intra-day volatility, and *CSPrc* is the daily mean transaction price averaged across stocks. All four coefficients were positive and statistically significant in the depth regression, and two of the four were negative and significant in the effective spreads regression.

aftermath of September 11, 2001 due to the unusual market conditions that prevailed. Third, we did not want to take a period too close to January 2001 in order not to pick up the effects of changes in the minimum tick size. The August 27-September 10 period seems like a reasonable choice that balances these considerations (and the time interval between this period and January 2002 is similar to the one between the pre-event period and the May post-event period).

Table 6 shows the changes from the robustness period to the pre-event period for all the variables we investigated in sections 3.1, 3.2, and 3.3. In general, the magnitude of the changes is much smaller than those we find following the introduction of OpenBook, and their sign is often in the opposite direction. Panel A reports the results on trading strategies. The cancellation rate of limit orders decreased prior to OpenBook, time-to-cancellation increased, and limit order size increased. These are statistically significant changes, but they go in the opposite direction to the results we document after the introduction of OpenBook. There is no statistically significant change prior to OpenBook in the floor-to-limit ratio, the specialist participation rate, or the contribution of the specialists to the depth of the quote. In contrast, we find significant changes in these variables form January to the May post-event period. It therefore seems unlikely that the changes in trading strategies following the introduction of OpenBook are simply a manifestation of a trend.

Panel B of Table 6 presents the results of changes in the informational efficiency variables. None of the changes is statistically significant (and they are all positive as opposed to the negative changes we document following the introduction of OpenBook).

Panels C and D contain the analysis of liquidity. We observe that depth in the book declines from the robustness period to the pre-event period, and so our finding in section 3.3 of an increase in depth does not reflect a trend that existed prior to the introduction of OpenBook. Effective spreads seem to decline, but the results are rather weak. The intercept from the regression of changes in spreads is weakly significant but much smaller in magnitude than the results we document over a similar time interval from January to May (Table 5, Panel A). The spread effect is not statistically significant prior to the introduction of OpenBook in the multivariate regression at the daily frequency that we implement to mitigate the effect of cross-correlated errors. It therefore seems that the pronounced change in liquidity that we observe after the introduction of OpenBook cannot be solely attributed to a trend.

3.5 Liquidity Changes and Returns

It has long been claimed that liquidity affects required returns (see, for example, Amihud and Mendelson, 1986). The usual argument is that investors require higher expected returns to compensate them for higher execution costs. If liquidity improves following the introduction of OpenBook, prices of stocks should rise to reflect the lower expected returns that investors will require of the stocks. Easley and O'Hara (2002) tie expected returns directly to the state of private and public information in the market. If OpenBook causes a shift from private to public information, their model would predict that prices should rise to reflect lower required returns.

While event studies of returns are common in the finance literature, the hypothesis we aim to test differs from the usual case. First, most event studies of returns focus on the announcement date. If investors know how the event is going to impact prices, the effect should occur on the announcement rather than on the implementation. As we noted in section 2.2, the announcement date of the event is difficult to determine. The second difference from the traditional framework is that tests of cumulative abnormal returns following events are usually meant to detect a change on a certain day that occurs as a direct result of the event itself (see the discussion in Brown and Warner, 1985). Here, we have a hypothesis about the relation between liquidity (or price discovery) and returns. While prices could potentially discount expected changes in liquidity immediately after the event, we doubt there was a consensus at that time on how, if at all, liquidity would change as a result of the new pre-trade transparency regime.[17] The changes in liquidity that

[17] Note that the lack of consensus extended to academia as even the theoretical models on the effects of opening the book had conflicting predictions.

we have documented occur over a period of time after the event. The change in returns could therefore also occur over time and not on a specific day immediately after the event. In light of the above issues, we fully acknowledge that any evidence we present on the behavior of returns around the implementation of OpenBook would only be suggestive. Nonetheless, it may be interesting to look at the relation between the changes in liquidity we documented and returns.

We compute a cumulative abnormal return (CAR) measure by summing daily abnormal returns from January 24 (the introduction of OpenBook) to the end of each post-event period. The daily abnormal returns are the residuals of a market model estimated over the period January 2, 2001, through November 30, 2001, with the value-weighted portfolio of Nasdaq National Market and Amex stocks as a proxy for the market. We use Nasdaq and Amex stocks since all NYSE stocks experience the introduction of OpenBook at the same time, not just our sample.

The cross-sectional median CARs are positive and highly statistically significant in all post-event periods. It seems as if cumulative abnormal returns increase over the first three months after the introduction of OpenBook, from 2% in February to 10% in April, and then level off. We examined the robustness of this result to the choice of benchmark by looking at CARs created from the residuals of a three-factor model that includes, in addition to the market proxy, the returns on JP Morgan's Commodity Futures Index and the JP Morgan U.S. Government Bond Index. The CARs from the 3-factor model were very similar to those from the market model.[18]

The considerations we discussed above make it difficult to unequivocally attribute these abnormal returns to the changes in liquidity. One can also wonder whether the improvement we document in effective spreads is large enough to generate such large abnormal returns. Although the changes in the true state of liquidity may be more pronounced than what we capture with a

[18] A potential econometric problem with the above analysis is that, because of the clustering in event time, errors in the market models of the individual stocks may be cross-correlated. We therefore estimated a pooled OLS regression with dummy variables for the post-event period days and used time-series variation in the consistent estimates of coefficients on the dummy variables to construct a test that is robust to cross-correlated errors. The result of significant abnormal returns was robust to this specification.

measure such as effective spreads, attribution of abnormal returns in the period after the introduction of OpenBook to the gradual changes in liquidity is difficult. Instead, we use the cross-sectional nature of our sample to ask a simple question: Are the changes in effective spreads negatively related to the CARs? If part of the abnormal return is due to liquidity changes, stocks that experience a greater decrease in effective spreads around the introduction of OpenBook should have larger CARs.

We therefore estimate the following cross-sectional relationship between changes in relative effective spreads between the pre- and post-event periods and cumulative abnormal returns from the beginning of the pre-event period to the end of each post-event period:

$$CAR_i = \alpha + \beta \Delta ESpread_i + \varepsilon_i$$

Table 7 presents the results of the cross-sectional OLS regressions for each post-event period. We present the results for each trading-intensity group separately because the slope coefficients are rather different in size for the four groups. It is clear from the table that a negative relationship between changes in effective spreads and cumulative abnormal returns holds around the event. All 16 slope coefficients (four groups, four post-event periods) are negative and statistically different from zero. The coefficients are monotonically decreasing across trading-intensity groups.[19] We believe this is due to the systematic difference in magnitudes of the effective spreads of the groups (as evident in Table 1). These negative and significant slope coefficients suggest that those stocks experiencing a greater decrease in effective spreads around the event also exhibit a greater increase in prices in a manner consistent with Amihud and Mendelson (1986).

4 CONCLUSIONS

The structure of securities markets in the U.S. and around the world is undergoing many changes. Various competing market structures were introduced into U.S. equity trading by

[19] Using dollar effective spreads results in similar findings.

Alternative Trading Systems, and the SEC has been instrumental in providing the conditions that helped these new trading platforms to flourish. In particular, the SEC has been pushing for greater pre-trade transparency by mandating certain display requirements for limit orders (affecting both market makers and Alternative Trading Systems organized as electronic limit order books). The insistence of the SEC on pre-trade transparency stems from its conviction that transparency improves not just price discovery, but also the fairness, competitiveness, and attractiveness of U.S. markets (see the SEC's Market 2000 study).

So far, however, there has been no consensus in the academic literature on whether greater pre-trade transparency in the sense of disclosing more information about limit orders in the book is beneficial to the market. As previously mentioned, the theoretical model in Madhavan, Porter, and Weaver (2000) implies that greater pre-trade transparency harms liquidity, and the empirical portion of their study that investigates an increase in pre-trade transparency implemented by the Toronto Stock Exchange in 1990 finds support for this prediction. Against this context, our results provide empirical support, for the first time, to the view that improved pre-trade transparency of a limit order book is beneficial. Our focus on the largest market in the world and the quality of the order-level data we use make our findings even more significant in the debate among academics and policy makers.

We find that investors do change their strategies in response to the change in market design: they submit smaller limit orders and cancel limit orders in the book more quickly and more often. These findings are consistent with a more active management of trading strategies in the face of greater risk of order exposure. Additionally, we find that traders shift activity away from floor brokers toward electronically submitted limit orders. This may indicate that OpenBook enables traders to implement more complex strategies themselves, and therefore reduces their need to delegate that responsibility to floor brokers. We also find that NYSE specialists change their behavior in that they trade less and, together with floor brokers, add less depth to the quote. These changes can reflect the increased risk in proprietary trading without the help of privileged information about the book, a crowding out effect that results from increased competition provided by active limit order trading, and a shift in investor strategies from using floor brokers to limit orders submitted electronically via SuperDot.

The equilibrium effects on the state of the market, both in terms of liquidity and informational efficiency, seem to suggest that increased transparency is a win-win situation. We find some improvement in informational efficiency following the introduction of OpenBook, consistent with the view that greater pre-trade transparency is beneficial for the price discovery process. Displayed liquidity in the book increases and execution costs decline. One potential explanation for the difference between our results and the findings from the change implemented by the Toronto Stock Exchange in 1990 lies in developments over the past decade in information processing, order handling, and trading technologies. The ability of buy side traders to utilize information about the limit order book to improve their trading strategies is much greater today, which may be the reason we see emergence of an equilibrium where liquidity improves.

Beyond providing support to the SEC's beliefs about the importance of transparency to the quality of U.S. markets, our analysis provides evidence that market design has substantial implications for investors. The OpenBook experience shows how provision of additional information can help investors manage their trading needs, and our analysis suggests that it resulted in improved market quality.

The introduction of OpenBook provides hope that even markets that are considered highly liquid and active, such as the NYSE, can improve by changing features of market design to meet investor and regulator demands. NYSE material stresses that OpenBook was designed to increase transparency in a decimal trading environment. Because the idea of publicly distributing information about the book has been around for many years, implementation at this time indeed seems to have been in response to the change in the tick size. In a sense, one regulatory change in market design (the smaller tick size) caused the NYSE to implement another change in market design (improved pre-trade transparency). The current securities trading environment is characterized by both frequent regulatory interventions and competitive pressures. The experience with OpenBook suggests that markets can and should respond to changes in their environment by modifying the design of their trading systems to better meet investor needs.

REFERENCES

Ahn, H. J., Bae, K. H., Chan, K., 2001, Limit orders, depth and volatility: Evidence from then Stock Exchange of Hong Kong. Journal of Finance 56, 767-788.

Amihud, Y., Mendelson, H., 1986, Asset pricing and the bid ask spread. Journal of Financial Economics 17, 223-249.

Baruch, S., 2002, Who benefits from an open limit-order book? Unpublished working paper. University of Utah.

Biais, B., 1993, Price formation and equilibrium liquidity in fragmented and centralized markets. Journal of Finance 48, 157-185.

Biais, B., Hillion, P., Spatt, C., 1995, An empirical analysis of the limit order book and the order flow in the Paris Bourse. Journal of Finance 50, 1655-1689.

Bloomfield, R., O'Hara, M., 1999, Market transparency: Who wins and who loses? Review of Financial Studies 12, 5-35.

Brown, S. J., Warner, J. B., 1985, Using daily stock returns: The case of event studies. Journal of Financial Economics 14, 3-31.

Chowhdry, B., Nanda, V., 1991, Multimarket trading and market liquidity. Review of Financial Studies 4, 483-511.

Cohen, K. J., Maier, S. F., Schwartz, R. A., Whitcomb, D. K., 1981, Transaction costs, order placement strategy, and existence of the bid-ask spread. Journal of Political Economy 89, 287-305.

Coppejans, M., Domowitz, I., 2002, An empirical analysis of trades, orders, and cancellations in a limit order market. Unpublished working paper. Duke University.

Corwin, S. A., Lipson, M. L., 2000, Order flow and liquidity around NYSE trading halts. Journal of Finance 55, 1771-1800.

Cox, D. R., 1972. Regression models and life tables. Journal of the Royal Statistical Society B34, 187-220.

Easley, D., O'Hara, M., 2002, Information and the cost of capital. Unpublished working paper. Johnson Graduate School of Management, Cornell University.

Fama, E. F., MacBeth, J. D., 1973, Risk, return, and equilibrium: Empirical tests. Journal of Political Economy 81, 607-636.

Flood, M. D., Huisman, R., Koedijk, K. G., Mahieu, R. J., 1999, Quote disclosure and price discovery in multiple-dealer financial markets. Review of Financial Studies 12, 37-59.

Foucault, T., 1999, Order flow composition and trading costs in a dynamic limit order market. Journal of Financial Markets 2, 99-134.

Franks, J. R., Schaefer, S. M., 1995, Equity market transparency on the London Stock Exchange. Journal of Applied Corporate Finance 8, 70-77.

Friedman, D., 1993, Privileged traders and asset market efficiency: A laboratory study. Journal of Financial and Quantitative Analysis 28, 515-534.

Gerke, W., Arneth, S., Bosch R., Syha, C., 1997, Open and closed order book and its effect on liquidity and volatility – market microstructure of stock exchanges in experiments and in the "Neuer Market." Unpublished working paper. Universität Erlangen-Nürnberg.

Glosten, L. R., 1999, Introductory comments: Bloomfield and O'Hara, and Flood, Huisman, Koedijk, and Mahieu. Review of Financial Studies 12, 1-3.

Handa, P. and R. Schwartz, 1996, Limit order trading. Journal of Finance, 51, 1835-1862.

Harris, L. E., 1996, Does a large minimum price variation encourage order exposure? Unpublished working paper. University of Southern California.

Harris, L. E., Panchapagesan, V., 1999, The information-content of the limit order book: Evidence from NYSE specialist actions. Unpublished working paper. University of Southern California.

Hasbrouck, J., 1992, Using the TORQ database. Unpublished working paper. New York University.

Hasbrouck, J., 1993, Assessing the quality of a security market: A new approach to transaction-cost measurement. Review of Financial Studies 6, 191-212.

Hasbrouck, J., Saar, G., 2002. Limit orders and volatility in a hybrid market: The Island ECN. Unpublished working paper. New York University.

Irvine, P., Benston, G., Kandel, E., 2000, Liquidity beyond the inside spread: Measuring and using information in the limit order book. Unpublished working paper. Emory University.

Kaniel, R., Liu, H., 2001, So what orders do informed traders use? Unpublished working paper. University of Texas at Austin.

Llorente G., Michaely, R., Saar, G., Wang, J., 2002. Dynamic volume-return relation of individual stocks. Review of Financial Studies 15, 1005-1047.

Lo, A. W., MacKinlay, A. C., Zhang, J., 2002. Econometric models of limit-order executions. Journal of Financial Economics 65, 31-72.

Lo, A. W., Wang, J., 2000. Trading volume: Definitions, data analysis, and implications of portfolio theory. Review of Financial Studies 13, 257-300.

Lyons, R. K., 1996, Optimal transparency in a dealer market with an application to foreign exchange. Journal of Financial Intermediation 5, 225-254.

Madhavan, A. N., 1992, Trading mechanisms in securities markets. Journal of Finance 47, 607-642.

Madhavan, A. N., 1995, Consolidation, fragmentation, and the disclosure of trading information. Review of Financial Studies 8, 579-603.

Madhavan, A. N., 1996, Security prices and market transparency. Journal of Financial Intermediation 5, 255-283.

Madhavan, A. N., Porter, D., Weaver, D., 2000, Should securities markets be transparent? Unpublished working paper. University of Southern California.

Naik, N. Y., Neuberger, A., Viswanathan, S., 1994, Disclosure regulation in competitive dealership markets: Analysis of the London Stock Exchange. Unpublished working paper. London Business School.

Pagano, M., Röell, A., 1996, Transparency and liquidity: A comparison of auction and dealer markets with informed trading. Journal of Finance 51, 579-611.

Parlour, C., 1998, Price dynamics in limit order markets. Review of Financial Studies 11, 789-816.

Rindi, B., 2002, Transparency, liquidity and price formation. Unpublished working paper. Bocconi University.

Sandas, P., 2001, Adverse selection and competitive market making: empirical evidence from a limit order market. Review of Financial Studies 14, 705-734.

Schwert, G. W., 1981, Using financial data to measure effects of regulation. Journal of Law and Economics 24, 121-158.

SEC, 1994, Market 2000: An examination of current equity market developments (Division of Market Regulation, United States Securities and Exchange Commission, Washington, D.C.).

Seppi, D. J., 1997, Liquidity provision with limit orders and a strategic specialist. Review of Financial Studies 10, 103-150.

Table 1
Sample Summary Statistics

The universe of stocks for the study consists of all domestic common stocks listed on the NYSE, excluding firms with multiple classes of shares traded, closed-end funds, and investment trusts. We sort the stocks according to median dollar volume in the last quarter of 2001 and divide the universe into four quartiles. From each quartile we choose a stratified sample of 100 stocks, creating a final sample of 400 stocks. The table presents summary statistics for the five periods used in the study: the pre-event period (January 7–18) and the four post-event periods: February 4–15, March 4–15, April 1–12, and May 6–17. From the TAQ database, AvgVol is the average daily number of shares traded; QSpread is the average quoted spread calculated in dollar terms and in percentage terms (the bid-ask spread divided by the quote midpoint); QDepth is the average total quoted depth (sum of the depths on the bid and ask sides) measured in dollars and in number of shares; ESpread is the average effective spread (the transaction price minus the midquote) in dollars and percentage terms (scaled by the quote midpoint); and AvgPrc is the average transaction price of the stock.

		AvgVol (in million $)		**AvgVol** (in 100s)		**QSpread** (in cents)		**QSpread** (in %)		**QDepth** (in $1000)		**QDepth** (in 100s)		**ESpread** (in cents)		**ESpread** (in %)		**AvgPrc** (in $)	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Entire Sample	Jan.	31.70	5.69	8,498.44	2,372.30	7.6	6.2	0.439	0.250	77.69	60.04	30.62	23.34	5.0	4.0	0.296	0.156	30.25	25.49
	Feb.	31.59	5.89	9,419.32	2,131.70	7.5	6.3	0.458	0.254	76.60	58.76	31.38	23.90	5.0	4.3	0.313	0.160	29.77	24.87
	Mar.	35.16	6.68	9,305.33	2,505.20	7.1	6.0	0.406	0.228	76.35	57.87	29.37	22.11	4.8	3.9	0.270	0.145	31.64	26.37
	Apr.	30.43	6.11	7,675.17	2,254.15	6.8	5.7	0.378	0.207	70.91	53.84	26.44	20.35	4.5	3.7	0.248	0.133	32.14	27.04
	May	30.53	5.78	8,225.61	2,290.75	6.6	5.6	0.372	0.194	73.29	53.80	26.91	20.31	4.4	3.6	0.239	0.126	32.31	27.81
Group 1 (most active stocks)	Jan.	109.80	59.43	26,433.18	14,941.40	4.9	4.4	0.119	0.108	159.94	131.84	40.56	34.45	3.2	3.0	0.079	0.070	45.86	42.74
	Feb.	108.78	60.61	29,888.36	14,868.15	5.1	4.6	0.130	0.115	152.89	124.74	41.45	29.80	3.4	3.1	0.087	0.077	44.94	41.25
	Mar.	120.85	67.28	29,056.45	17,172.45	4.7	4.3	0.114	0.098	156.88	130.14	39.90	33.13	3.2	2.9	0.077	0.066	47.73	43.19
	Apr.	104.20	57.70	23,608.54	13,764.15	4.4	3.9	0.106	0.090	143.92	123.43	36.86	28.14	2.9	2.6	0.070	0.059	47.82	43.91
	May	102.63	60.53	24,815.17	17,110.85	4.3	4.0	0.109	0.092	153.54	130.90	40.61	29.49	2.9	2.6	0.073	0.062	47.13	42.23
Group 2	Jan.	13.25	11.03	5,345.64	3,443.70	6.0	5.6	0.208	0.192	77.85	70.19	28.55	24.37	3.8	3.5	0.133	0.121	32.08	31.21
	Feb.	13.80	11.98	5,523.12	3,954.65	5.9	5.7	0.214	0.190	78.09	77.67	30.18	23.31	3.8	3.6	0.138	0.122	31.94	31.39
	Mar.	15.18	13.12	5,498.91	4,198.90	5.7	5.3	0.191	0.169	76.02	70.95	27.07	22.94	3.7	3.4	0.125	0.109	33.87	33.64
	Apr.	13.14	12.10	4,604.03	3,705.15	5.2	4.9	0.175	0.167	70.77	68.94	24.24	20.48	3.3	3.1	0.111	0.105	34.12	32.80
	May	14.72	11.24	5,440.99	3,549.60	5.0	4.8	0.173	0.145	70.48	69.80	24.52	20.62	3.2	3.1	0.112	0.094	34.45	33.51
Group 3	Jan.	3.26	2.72	1,638.28	1,217.05	9.3	7.0	0.355	0.300	49.08	42.68	23.87	18.65	5.9	4.5	0.229	0.194	28.25	23.61
	Feb.	3.18	2.36	1,614.53	1,165.90	8.8	7.3	0.372	0.306	52.47	44.86	26.89	19.61	5.9	4.6	0.242	0.195	27.61	23.13
	Mar.	3.91	3.19	1,937.55	1,333.00	8.6	6.6	0.324	0.270	48.35	44.98	22.51	17.42	5.7	4.4	0.208	0.175	29.37	24.81
	Apr.	3.70	2.84	1,743.91	1,078.30	8.4	6.4	0.302	0.249	45.86	43.16	19.95	15.81	5.5	4.2	0.195	0.156	30.33	25.03
	May	3.78	2.92	1,646.25	1,212.00	8.2	6.2	0.296	0.236	44.95	39.08	19.51	15.00	5.5	3.9	0.189	0.153	30.70	25.78
Group 4 (least active stocks)	Jan.	0.48	0.37	576.64	326.60	10.3	8.9	1.076	0.833	23.90	19.08	29.49	16.07	7.2	6.3	0.744	0.568	14.82	11.15
	Feb.	0.59	0.43	651.26	361.60	10.0	9.5	1.118	0.849	22.94	19.78	27.01	17.10	7.1	6.4	0.786	0.589	14.59	10.89
	Mar.	0.72	0.54	728.39	445.45	9.6	8.8	0.995	0.751	24.15	20.84	28.00	14.53	6.6	5.9	0.669	0.508	15.57	11.18
	Apr.	0.69	0.58	744.21	432.65	9.4	8.9	0.930	0.689	23.09	19.65	24.70	14.02	6.5	6.1	0.617	0.459	16.30	12.51
	May	1.00	0.61	1,000.03	394.40	8.8	8.2	0.909	0.591	24.19	19.57	23.00	14.19	5.9	5.2	0.582	0.382	16.94	13.07

Table 2
Analysis of Limit Order Cancellation

This table presents the analysis of changes in limit order cancellation strategies following the introduction of OpenBook. The pre-event period is January 7–18 (**Jan**), and the post-event periods are February 4–15 (**Feb**), March 4–15 (**Mar**), April 1–12 (**Apr**), and May 6–17 (**May**) (each contains 10 trading days). In Panel A, ΔCancRate is the change in cancellation rate defined as the ratio of the number of cancelled limit orders to the number of limit orders submitted, and ΔTimeCanc is the change in the number of seconds between submission and cancellation of limit orders. We report the cross-sectional median change and the *p*-value (in parentheses) of a Wilcoxon signed rank test against the hypothesis of a zero median. Panel B presents the results of the duration analysis of time-to-cancellation. For each stock in the sample, we use a parametric approach assuming a Weibull distribution for time-to-cancellation (T):

$$Log\ T_{it} = \alpha_i + \beta_i I_{it} + \gamma_i\ Distance\ from\ quote_{it} + \varepsilon_{it}$$

and a nonparametric analysis applying the Cox (1972) model of the hazard rate ($h(t)$) :

$$Log\ h_{it}(t) = \alpha_i(t) + \beta_i I_{it} + \gamma_i\ Distance\ from\ quote_{it} + \varepsilon_{it}$$

In both models, I is a dummy variable that takes the value of one for post-event observations and 0 for pre-event observations. Distance from the relevant quote sides (i.e., bid for sells and ask for buys), standardized by the quote midpoint, is used as a covariate. We report the median of $e^{\beta} - 1$ (where the coefficients on the dummy variables are estimated separately for each stock), the number of βs significant at the 5% level, and the *p*-value (in parentheses) of a Wilcoxon signed rank test against the hypothesis of a zero median. ** indicates significance at the 1% level and * indicates significance at the 5% level (both against a two-sided alternative).

Panel A: Analysis of Limit Order Cancellation

	Feb-Jan		**Mar-Jan**		**Apr-Jan**		**May-Jan**	
Variable	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)
ΔCancRate	0.0068	(0.1009)	0.0259**	(0.0000)	0.0466**	(0.0000)	0.0475**	(0.0000)
ΔTimeCanc	-12.765*	(0.0190)	-25.095**	(0.0000)	-39.902**	(0.0000)	-50.584**	(0.0000)

Panel B: Duration Analysis

	Feb-Jan			**Mar-Jan**			**Apr-Jan**			**May-Jan**		
$e^{\beta} - 1$	**Median**	# of significant out of 400	(*p*-value of Wilcoxon test)	**Median**	# of significant out of 400	(*p*-value of Wilcoxon test)	**Median**	# of significant out of 400	(*p*-value of Wilcoxon test)	**Median**	# of significant out of 400	(*p*-value of Wilcoxon test)
Weibull	-0.1047**	394	(0.0000)	-0.1497**	393	(0.0000)	-0.2234**	398	(0.0000)	-0.2429**	398	(0.0000)
Cox	0.0657**	397	(0.0000)	0.1059**	398	(0.0000)	0.1700**	397	(0.0000)	0.1724**	399	(0.0000)

Table 3

Analysis of Trading Strategies

This table presents analysis of changes in trading strategies of investors and specialists following the introduction of OpenBook. The pre-event period is January 7–18 (**Jan**), and the post-event periods are February 4–15 (**Feb**), March 4–15 (**Mar**), April 1–12 (**Apr**), and May 6–17 (**May**) (each contains 10 trading days). In Panel A, ΔLimitSize is the change in the average size of limit orders between the pre- and post-event periods in shares, and ΔFloor/Lmt is the change in the ratio of the number of shares executed by floor brokers to the number of shares executed using limit orders in the book. Panel B demonstrates the changes in specialist behavior. ΔSpecRate measures changes in the specialists' participation rate in terms of number of shares, and ΔSpecDepth is the change in the specialists' total commitment (in dollars) on the bid and ask sides of the quoted depth. For all variables, the table reports the cross-sectional median and the *p*-value (in parentheses) of a Wilcoxon signed rank test against the hypothesis of a zero median. ** indicates significance at the 1% level and * indicates significance at the 5% level (both against a two-sided alternative).

Panel A: Differences in Trading Strategies of Investors between Post- and Pre-Event Periods

	Feb-Jan		**Mar-Jan**		**Apr-Jan**		**May-Jan**	
Variable	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)
ΔLimitSize	-29.513**	(0.0003)	-31.515**	(0.0000)	-55.763**	(0.0000)	-68.423**	(0.0000)
ΔFloor/Lmt	-0.0135	(0.2100)	-0.0323**	(0.0022)	-0.0438**	(0.0001)	-0.0495**	(0.0000)

Panel B: Differences in NYSE Specialists' Behavior between Post- and Pre-Event Periods

	Feb-Jan		**Mar-Jan**		**Apr-Jan**		**May-Jan**	
Variable	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)
ΔSpecRate	0.0003	(0.5876)	-0.0069**	(0.0001)	-0.0050**	(0.0019)	-0.0088**	(0.0000)
ΔSpecDepth	-1164.76*	(0.0200)	-1320.08	(0.1300)	-2972.83**	(0.0000)	-2599.81**	(0.0000)

Table 4
Analysis of Informational Efficiency

This table presents an analysis of information and prices around the introduction of OpenBook. The pre-event period is January 7–18 (**Jan**), and the post-event periods are February 4–15 (**Feb**), March 4–15 (**Mar**), April 1–12 (**Apr**), and May 6–17 (**May**) (each contains 10 trading days). We use two types of tests to examine changes in the informational efficiency of prices. The first test uses a variable constructed from the variance decomposition procedure in Hasbrouck (1993). ΔVR (*s/p*) is the change in the ratio (in percentage terms) of the variance of the discrepancies between log transaction prices and the efficient (random walk) price divided by the variance of log transaction prices (to normalize the measure). The second test looks at the change in the absolute value of first-order autocorrelations of quote-midpoint returns. We divide the trading day into 30-minute intervals for Δ | Corr30 | and 60-minute intervals for Δ | Corr60 |, and compute the returns from prevailing quote midpoints at the beginning and end of each interval. For all variables, the table reports the cross-sectional median and the *p*-value (in parentheses) of a Wilcoxon signed rank test against the hypothesis of a zero median. ** indicates significance at the 1% level and * indicates significance at the 5% level (both against a two-sided alternative).

	Feb-Jan		**Mar-Jan**		**Apr-Jan**		**May-Jan**	
Variable	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)	**Median**	(*p*-value of Wilcoxon test)
ΔVR (*s/p*)	-0.00047	(0.5294)	0.00043	(0.4390)	-0.00567**	(0.0000)	-0.00691**	(0.0000)
Δ| Corr30 |	-0.00343	(0.5868)	-0.01181*	(0.0384)	-0.00355	(0.5384)	-0.00100	(0.7996)
Δ| Corr60 |	-0.00370	(0.2498)	-0.00590	(0.1393)	-0.01424	(0.0906)	-0.01749*	(0.0251)

Table 5
Analysis of Liquidity

This table presents results of analyses of liquidity changes around the introduction of OpenBook controlling for changes in volume, volatility, and price level. The pre-event period is January 7–18 (**Jan**), and the post-event periods are February 4–15 (**Feb**), March 4–15 (**Mar**), April 1–12 (**Apr**), and May 6–17 (**May**) (each contains 10 trading days). We use two liquidity measures: ΔDepth is the change to the total depth in the book in round lots, and ΔESpread¢ is the change in effective spreads in cents. In Panel A, we report the results of OLS regressions of changes in the liquidity measures on changes in the control variables:

$$\Delta L_i = \alpha + \beta_1 \Delta AvgVol_i + \beta_2 \Delta HiLow_i + \beta_3 \Delta AvgPrc_i + \varepsilon_i$$

where ΔAvgVol is the difference in average daily dollar volume, ΔHiLow is the difference in intra-day volatility (average daily range of transaction prices), and ΔAvgPrc is the difference in the average transaction price of the stock. All differences are between the post- and pre-event periods. We run the regressions separately for each post-event period. We report the intercepts from the eight regressions, the *p*-values calculated using White's heteroskedasticity-consistent standard errors, and the adjusted R^2 of the regressions. For the analysis in Panel B we use daily data to estimate (by OLS) the following relation:

$$L_{it} = \text{Intercept} + \Sigma_{k=1}^{n} (\beta_k Day^k_{it}) + \gamma_1 Vol_{it} + \gamma_2 HL_{it} + \gamma_3 Prc_{it} + \varepsilon_{it}$$

where dummy variable Day^k_{it} ($k = 1, \ldots, n$) takes the value of one for the *k*-th day in the *n*-day post-event period and zero otherwise, Vol is the average daily dollar volume, HL is the daily price range, and Prc is the daily average transaction price of the stock. We estimate the model for each post-event period separately and for a pooled 40-day post-event period. We report the median of the dummy variables' coefficients (β_ks) and the *p*-value (in parentheses) of a Wilcoxon signed rank test against the hypothesis of a zero median. For all parameters, ** indicates significance at the 1% level and * indicates significance at the 5% level (both against a two-sided alternative).

Panel A: Differences in Liquidity Variables in a Cross-Sectional Multivariate Regression (400 Observations)

	Feb-Jan			**Mar-Jan**			**Apr-Jan**			**May-Jan**		
Variable	α	(*p*-value of t-statistic)	Adj R^2 (in %)	α	(*p*-value of t-statistic)	Adj R^2 (in %)	α	(*p*-value of t-statistic)	Adj R^2 (in %)	α	(*p*-value of t-statistic)	Adj R^2 (in %)
ΔDepth	4586.35	(0.1398)	5.18	10734.64*	(0.0299)	5.27	11713.03*	(0.0298)	6.28	9006.07	(0.1347)	1.59
ΔESpread¢	-0.1046	(0.1848)	11.64	-0.2817**	(0.0066)	1.70	-0.6257**	(0.0000)	7.16	-0.8001**	(0.0000)	11.07

Panel B: Analysis of Liquidity Changes Estimated from Multivariate Regressions at the Daily Frequency

	Feb (8000 Obs.)		**Mar** (8000 Obs.)		**Apr** (8000 Obs.)		**May** (8000 Obs.)		**All Periods** (20000 Obs.)	
Variable	**Median β** (n=10)	(*p*-value of Wilcoxon test)	**Median β** (n=10)	(*p*-value of Wilcoxon test)	**Median β** (n=10)	(*p*-value of Wilcoxon test)	**Median β** (n=10)	(*p*-value of Wilcoxon test)	**Median β** (n=40)	(*p*-value of Wilcoxon test)
Depth	1404.45*	(0.0249)	317.71	(0.6103)	1198.40*	(0.0144)	1569.02**	(0.0080)	1211.95**	(0.0000)
ESpread¢	-0.0087	(0.9188)	-0.4048**	(0.0059)	-0.8600**	(0.0059)	-1.1311**	(0.0059)	-0.6562**	(0.0000)

Table 6
Investigating the Possibility of a Trend

This table presents results of changes in trading strategies, informational efficiency, and liquidity in the months before the event. These results can be used to judge whether there is a secular trend in the variables we analyze in Tables 2-5. We examine the differences in these variables between the 10-day periods of August 30 - September 10, 2001 (**Sep01**) and the pre-event period of January 7–18, 2002 (**Jan02**). In Panel A, ΔCancRate is the change in cancellation rate defined as the ratio of the number of cancelled limit orders to the number of limit orders submitted, ΔTimeCanc is the change in the number of seconds between submission and cancellation of limit orders, ΔLimitSize is the change in the average size of limit orders in shares, ΔFloor/Lmt is the change in the ratio of the number of shares executed by floor brokers to the number of shares executed using limit orders in the book, ΔSpecRate measures the change in the specialists' participation rate in terms of number of shares, and ΔSpecDepth is the change in the specialists' total commitment (in dollars) on the bid and ask sides of the quoted depth. In Panel B, ΔVR (*s/p*) is the change in the ratio (in percentage terms) of the variance of the discrepancies between log transaction prices and the efficient (random walk) price divided by the variance of log transaction prices (to normalize the measure), Δ | Corr30 | and Δ | Corr60 | measure the changes in the absolute value of first-order autocorrelations of quote-midpoint returns using 30-minute and 60-minute returns, respectively. For all variables in Panels A and B, the table reports the cross-sectional median and the *p*-value (in parentheses) of a Wilcoxon signed rank test against the hypothesis of a zero median. Panels C and D present the results of the analysis of changes in liquidity variables. Descriptions of the regressions in these panels are detailed in the text of Table 5. ** indicates significance at the 1% level and * indicates significance at the 5% level (both against a two-sided alternative).

Panel A: Differences in Trading Strategies **Jan02-Sep01**

Variable	**Median**	(*p*-value of Wilcoxon test)
ΔCancRate	-0.0229**	(0.0000)
ΔTimeCanc	20.620**	(0.0000)
ΔLimitSize	49.902**	(0.0000)
ΔFloor/Lmt	-0.0058	(0.2321)
ΔSpecRate	-0.0017	(0.1969)
ΔSpecDepth	964.30	(0.6400)

Panel B: Differences in Informational Efficiency **Jan02-Sep01**

Variable	**Median**	(*p*-value of Wilcoxon test)
Δ VR (*s/p*)	0.00003	(0.4783)
Δ| Corr30 |	0.00031	(0.9891)
Δ| Corr60 |	0.01918	(0.0845)

Panel C: Differences in Liquidity Variables in a Cross-Sectional Multivariate Regression **Jan02-Sep01**

Variable	***α***	(*p*-value of *t*-statistic)	Adj R^2 (in %)
ΔDepth	-1683.49**	(0.0014)	11.75
ΔESpread¢	-0.3238*	(0.0291)	3.43

Panel D: Analysis of Liquidity Changes Estimated from Multivariate Regressions at the Daily Frequency **Jan02-Sep01**

Variable	**Median *β*** (n=10)	(*p*-value of Wilcoxon test)
Depth	-2799.40**	(0.0059)
ESpread¢	-0.2965	(0.1029)

Table 7

Analysis of Liquidity Changes and Cumulative Abnormal Returns

This table presents an analysis of the relation between liquidity changes and cumulative abnormal returns around the introduction of OpenBook. The pre-event period is January 7–18 (**Jan**), and the post-event periods are February 4–15 (**Feb**), March 4–15 (**Mar**), April 1–12 (**Apr**), and May 6–17 (**May**) (each contains 10 trading days). We compute daily abnormal returns as residuals from factor models estimated using daily returns from January 2 through November 30, 2001. We use two model specifications: i) a market model with a value-weighted Nasdaq and Amex portfolio as the market proxy, and ii) a three-factor model that includes the market proxy, the return on JP Morgan's Commodity Futures Index, and the return on JP Morgan's US Government Bond Index. We construct a cumulative abnormal return (CAR) measure by summing the daily abnormal returns up to the end of each post-event period. We report the results of OLS regressions of the cumulative abnormal returns between the beginning of the pre-event period and the end of each post-event period on changes in relative effective spreads (ΔESpread):

$$CAR_i = \alpha + \beta \, \Delta ESpread_i + \varepsilon_i$$

We run the regressions separately for each of the four 100-stock trading intensity groups (based on median dollar volume in the last quarter of 2001) and for each post-event period. ** indicates significance at the 1% level and * indicates significance at the 5% level (both against a two-sided alternative).

	Feb			Mar			Apr			May		
	α (*p*-value)	β (*p*-value)	Adj R^2 (in %)	α (*p*-value)	β (*p*-value)	Adj R^2 (in %)	α (*p*-value)	β (*p*-value)	Adj R^2 (in %)	α (*p*-value)	β (*p*-value)	Adj R^2 (in %)
Group 1 (most active stocks)	0.033** (0.004)	-4.731** (0.000)	50.68	-0.001 (0.926)	-3.322** (0.000)	31.26	-0.017 (0.305)	-3.962** (0.000)	22.75	-0.021 (0.221)	-4.545** (0.000)	36.08
Group 2	-0.003 (0.770)	-2.619** (0.000)	32.90	-0.015 (0.290)	-2.061** (0.000)	15.53	0.013 (0.520)	-1.344* (0.022)	4.27	-0.036 (0.127)	-2.489** (0.000)	16.84
Group 3	-0.014 (0.172)	-0.374* (0.035)	3.49	0.001 (0.940)	-0.647* (0.014)	5.04	0.022 (0.293)	-1.245** (0.000)	14.69	-0.029 (0.243)	-1.247** (0.000)	14.61
Group 4 (least active stocks)	0.002 (0.910)	-0.219** (0.000)	14.80	-0.005 (0.807)	-0.419** (0.000)	35.72	0.037 (0.090)	-0.501** (0.000)	38.56	-0.036 (0.195)	-0.618** (0.000)	46.15