An Examination of Changes in Specialists' Posted Price Schedules

by

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ABSTRACT

New York Stock Exchange specialists disseminate information to market participants by displaying price schedules consisting of quoted prices and depths for both the bid and the ask sides of the market. This paper examines how specialists revise these posted price schedules in response to changes in their trading environment. We estimate specialists' quote-revision processes in the context of a simultaneous equations model using four potentially important factors: (1) changes in the limit order book, (2) transactions, (3) competition from regional exchanges, and (4) overall activity in the stock. Our results show that changes in the limit order book have a significant impact on the posted price schedule, while transactions and overall activity are secondary to the limit order book in determining the posted price schedule. In addition, we find evidence that specialists revise their quoted prices and depths in response to different events.

I. Introduction

One distinguishing feature of the New York Stock Exchange (NYSE) system is its reliance on a monopolist specialist for each stock. The specialist is responsible for maintaining the stock's limit order book and for acting as its liquidity provider of last resort. As such, specialists are charged with maintaining a 'fair and orderly market', which amounts to posting and honoring price and depth quotes (hereafter, price schedules) that maintain both price continuity and a 'reasonable' level of depth.

While the price schedule is clearly the specialists' primary tool, very little is known about the process by which the price schedule is revised. Understanding the revision process is a prerequisite to understanding the NYSE market structure. This process is especially important because the posted price schedule is often the only publicly available information about the supply and demand for the stock and, consequently, has the potential to influence investor behavior. Above all, the quote-revision process affects the way in which information is incorporated into the market -- an issue central to the study of finance.

There are a number of reasons why specialists might revise their price schedules. First, the release of new information can change expectations about the value of the asset, leading the specialist to update his quotes.[1] New information about the market for a stock can be conveyed in several ways. First, transactions can convey information to the specialist, since traders buying (selling) the stock may indicate that the current price is below (above) its true value. Similarly, changes in the limit order book due to the placement of an order or to the cancellation of an order can communicate information to the specialist. Most theoretical models have blurred the distinction between orders and transactions by implicitly assuming that every order is executed. Consequently, when orders can be submitted and not executed, it is unclear whether transactions or changes in the limit order book (or both) transmit

[1] The terms "price schedule" and "quotes" will be used interchangeably. When referring to prices only, the term "quoted prices" will be used.

information to the market. Finally, direct corporate announcements also release information about the stock to market participants.[2]

Second, an increase or decrease in competition can provoke a counter-response on the part of the specialist. For the specialist, competition comes in the form of the regional exchanges and of the limit order book. The rules of the NYSE dictate that the specialist is prohibited from taking precedence over a limit order without bettering its price. Consequently, the specialist is forced to compete with the limit order book for order flow. The specialist can choose, however, when to actively compete and when to simply pass the order flow onto the book. In fact, nothing keeps the specialist from posting prices and depths that are *worse* than those on the book, effectively hiding limit orders.[3] As a result, the specialist has flexibility in what he posts, and no automatic updating of the price schedule occurs when the prices or the quantities on the limit order book improve.

Finally, an increase in overall market activity might prompt the specialist to adjust the quoted prices and/or depths to minimize his adverse selection risk. The presence of informed traders in the market creates adverse selection risk for the specialist. This risk is potentially heightened during periods of intense activity, when the probability of an informed trader arriving is high. As a result, activity, consisting not only of transactions but also of newly placed or canceled orders, may induce the specialist to revise his price schedule to combat the increased adverse selection risk.[4]

We estimate specialists' price-schedule-revision processes in the context of a simultaneous equations model, including explanatory variables designed to capture the factors discussed above. The use of a simultaneous equations model directly incorporates the interdependence among the endogenous variables: the bid price, the ask price, the bid depth, and the ask depth. This feature is crucial given the work of Lee, Mucklow, and Ready (1993), Harris (1994), Dupont (1995), and Kavajecz (1996) which

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[2] To the extent that the announcement is unanticipated, we cannot hope to capture its effect. In other words, discrete jumps in the posted prices and depths caused by information shocks that did not filter through the market cannot be explained by our model.

[3] Over the sample period we consider, the NYSE requires only that specialists post representative quotes. Recently enacted NYSE regulations require specialists to reflect the best available prices in their quotes, thereby reducing the potential for hidden limit orders.

shows that quoted prices and quoted depths are often used in conjunction by specialists. The consequences of ignoring this interdependence can be severe. For example, if changes in the bid and the ask prices are related, running an ordinary least squares regression of changes in the bid price on a number of explanatory variables, including changes in the ask price, will result in biased and inconsistent estimates.[5]

We find that changes in the limit order book have a significant impact on the posted price schedule, while transactions and overall activity are secondary to the limit order book both statistically and economically. In addition, the updating process varies with trading volume as well as with the proximity of the specialist's quoted prices to the limit order book. Furthermore, specialists revise the quoted prices and depths in response to different events. While the entire price schedule is revised in response to competition from the limit order book, the depth quotes more often address adverse selection concerns.

The remainder of the paper is organized as follows. Section II relates our study to the existing literature. Section III contains the empirical model. Section IV discusses the data and methodology. Section V presents the results and Section VI concludes.

II. Existing Literature

A great deal of related work has paved the way for the study of specialists' price-schedule-revision processes. Hasbrouck (1988, 1991) and Petersen-Umlauf (1993) use transaction and quote data to better understand what causes quoted prices to change and to analyze the informativeness of trades. Our study builds on this work by examining changes in the posted depths as well as in the posted prices. In addition, we do not limit our study to the effect of transactions, but consider several events with the potential to induce revisions in the price schedule. Focusing solely on prices makes the implicit

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[4] Changes in the specialist's inventory of the stock may also cause him to change his posted price schedule (e.g. Garman (1976)). This possibility is not directly addressed due to the lack of available data.

assumption that specialists actively manage prices but not depths, an assumption which is at odds with the empirical facts.[6] Moreover, fifty-two percent of the quote changes in our sample consist of adjustments made only to the quoted depths and not to the bid or the ask prices. Ignoring changes in depths leads to an incomplete understanding of the quote-revision process. This is particularly true if changes in prices and changes in depths are reactions to different stimuli. For example, if the specialist were using the posted depths to control adverse selection risk rather than using prices, then the effect of adverse selection on the specialists' price schedule would be underestimated. For an illustration of the importance of other (non-transaction) events see Appendix I.

By using order data in conjunction with transaction data to explain changes in quoted prices and depths, Kaniel and Liu (1996) are closest in spirit to our work. Specifically, they investigate whether orders or transactions have a larger impact on the specialist's price schedule by examining whether quote revisions are more likely to follow orders or transactions. The methodology they employ has two limitations. First, the investigation of each component of the price schedule is conducted separately and second, the magnitude of the revision is not addressed. We estimate the relation between the sources of revisions in the posted price schedule and the size of the change in each element (i.e. the bid price, the ask price, the bid depth, and the ask depth) simultaneously. Furthermore, we consider additional sources of revisions in the price schedule as discussed above.

III. Empirical Model

Our simultaneous equations model consists of four equations -- two explaining changes in the quoted prices (the bid price and the ask price) and two explaining changes in the quoted depths (the bid

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[5] The reasoning is as follows. Suppose $\Delta B=b_0+b_1\Delta A+b_2Z+e$ and $\Delta A= c_0+c_1\Delta B+c_2Z+u$. Since ΔA is a function of ΔB, and ΔB is a function of e, ΔA and e are correlated. Consequently, the independent variables and the errors are not independent, causing OLS estimates to be biased and inconsistent.

[6] Lee, Mucklow, and Ready (1993), for example, document an increase in the quoted spread and a decrease in the quoted depths surrounding earnings announcements, which they interpret as evidence that the specialist uses both prices and depths strategically.

depth and the ask depth). The full model is contained in Exhibit I. Exhibit II contains a list of the endogenous and exogenous variables in the model, along with a description of each.

III.1 Endogenous Variables

The four endogenous variables are the change in the bid price in dollars, the change in the ask price in dollars, the change in the bid depth in units of 1,000 shares, and the change in the ask depth in units of 1,000 shares. While many of the existing studies focus on changes in the spread midpoint as a single equation, we instead separate the bid and ask prices into two equations to account for asymmetries in the quote-revision process and for the widening and narrowing of the spread. Although the spread midpoint is often viewed as a proxy for the true value of the stock, specialists do not always set prices symmetrically around this value.[7] Our specification allows the independent variables in the model to affect the bid and the ask prices differently.

We model the interdependence of the endogenous variables in our system as follows (see Figure 1). Changes in the bid price, ΔB, are a function of changes in the ask price, ΔA, and of changes in the bid depth, ΔBD, as well as of other exogenous variables, denoted Z, which will be discussed later (i.e. $\Delta B = f(\Delta A, \Delta BD, Z)$). Changes in the bid depth, ΔBD, are a function of changes in the bid price, ΔB, changes in the ask depth, ΔAD, and of other exogenous variables (i.e. $\Delta BD = g(\Delta B, \Delta AD, Z)$). The ask side is modeled analogously.

Absent direction from theory, the interdependence is based upon a number of empirical and institutional facts. First, a specialist's success in maintaining a "fair and orderly market" is continuously monitored by the exchange. Practically speaking, compliance with this duty amounts to, (i) maintaining a narrow bid-ask spread, (ii) maintaining price continuity and (iii) providing reasonable depth. The effect of a narrow spread coupled with the price continuity requirement explicitly links the bid and ask

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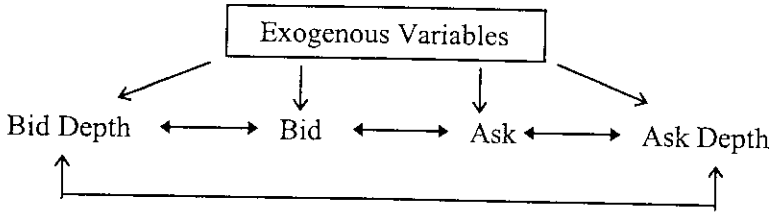
[7] This may be because the specialist manages inventory risk or adverse selection risk by setting more favorable quotes on one side of the market. Jones (1993) provides a theoretical model in which the specialist does not reposition his quotes symmetrically around the true value, but, instead, revises the spread asymmetrically to preclude informed trading.

prices. Consequently, they enter as endogenous variables into each other's equations. Second, the provision for reasonable depth may connect the two depth quotes if the specialist tries to maintain some aggregate level of depth across both sides of the market. Thus, the depth quotes also enter as endogenous variables into each other's equations. Third, studies by Lee, Mucklow and Ready (1993), Harris (1994), Dupont (1995) and Kavajecz (1996) show that the bid (ask) and the bid (ask) depth variables directly affect each other and that prices and depths are often used as substitutes to manage adverse selection and inventory risk. This fact prompts the inclusion of the bid (ask) price as an endogenous variable in the bid (ask) depth equation and vice versa.

Figure 1



III.2 Exogenous Variables

The exogenous variables in the model are chosen to reflect any circumstance that might cause the specialist to revise his posted price schedule. As discussed in the introduction, the exogenous variables we include are: transactions, changes in the limit order book, price changes on regional exchanges, and overall activity.

Transactions are captured with two pairs of variables -- one pair representing transaction volume (BTV and STV) and the other reflecting the transaction size relative to the posted depth (BDPDM and SDPDM). Buy transaction volume, BTV, is defined as the size of the buyer-initiated transaction in units of 1,000 shares. (The sell-side variable is defined analogously.) The distinction between buy and sell transactions is important because buys and sells are likely to affect different sides of the market and, ceteris paribus, may have differential effects on the price schedule. For an example of the potential asymmetry between the effects of purchases and sales see Chan and Lakonishok (1993). The trade size

is also important because it could affect the size or likelihood of a quote revision, and it can be viewed as a measure of the information content of the event.

The depth-exceeded dummy variables, BDPDM and SDPDM, are equal to one when the buy (sell) transaction size exceeds the posted ask (bid) depth and zero otherwise. These variables allow for the possibility that transactions which exceed the quoted size contain more information than others, and, therefore, induce larger quote revisions. Results from Petersen and Umlauf (1993) and Knez and Ready (1996) provide evidence in support of this hypothesis by demonstrating a distinct kink in the quote revision rule for trades larger than the posted depth.

Variables representing changes in the limit order book since the last quote revision can take many forms due to the multidimensionality of the book. We focus on a single price-change and depth-change measure for each side of the market. In particular, we include variables representing changes in the best bid and ask prices on the limit order book since the last quote revision, ΔBBB and ΔBAB, as well as changes in the number of shares on the book at those prices, ΔSBBB and ΔSBAB. These variables reflect the degree to which the liquidity provided by the competing limit order book, as well as the information conveyed by the book, has changed since the last quote revision.

Changes in regional competition are captured through variables which measure the difference between the best prices posted on the regional exchanges and the prices posted on the NYSE. The "better bid on a regional exchange" (BBRE) and "better ask on a regional exchange" (BARE) variables are defined as Bid_{RE} -Bid_{NYSE} and Ask_{NYSE} -Ask_{RE} respectively, where Bid_{RE} (Ask_{RE}) represents the best bid (ask) price on the regional exchanges and Bid_{NYSE} (Ask_{NYSE}) represents the NYSE bid (ask) price. BBRE (BARE) is non-zero only when the best regional bid (ask) represents an improvement over the NYSE quotes and then, again, when the situation reverses itself. Inclusion of the regional variables follows work by Blume and Goldstein (1992) which shows that liquidity provision and price discovery are generated by the regional exchanges, potentially making the regional quotes a significant consideration for the NYSE specialist.

The final pair of explanatory variables reflects the amount of overall activity that has occurred in the market for the stock since the last quote revision (BCLA and ACLA). Since many single events may result in no quote revision, the sequence of events leading up to a quote revision may contain valuable information. The bid-side cumulative lagged activity variable, BCLA, is computed by summing shares from canceled buy orders, from newly placed buy orders, and from sell transactions since the last quote revision, excluding the current event since it is included as a separate variable. Similarly, the ask-side cumulative lagged activity, ACLA, is given by the sum of shares from all canceled sell orders, newly placed sell orders, and buy transactions. An activity variable differs from the change in the number of shares at the best price on the limit order book because it does not involve the netting out of cancellations, orders and transactions, since the number of shares in cancellations, orders, and transactions are all non-negative. Appendix III contains an example of the calculation of the activity variables. We interpret BCLA (ACLA) as an indication of the degree of uncertainty or adverse selection risk on the sell (buy) side of the market. This interpretation emerges from Admati-Pfliederer (1988) and similar models in which informed traders prefer to trade in periods where liquidity traders cluster, thus providing sufficient noise to conceal the informed order flow.[8]

IV. Data and Methodology

We use the TORQ database, which contains order, transaction, and quote data for 144 NYSE stocks from November 1, 1990 to January 31, 1991. All orders submitted through one of the automated routing systems are included in the data, as are all transactions on the NYSE. Both NYSE and regional quotes are also contained in the database.[9]

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[8] It could also be argued that the time elapsed since the last event affects the likelihood and/or size of the quote revision and should be included as an exogenous variable. For example, Engle and Russell (1995) find evidence of transaction clustering for IBM. While our model does not explicitly contain a variable which reflects this, the importance of time is captured through the use of an event window described in detail below.

[9] Orders submitted though an automated routing service consist of approximately 70% of all orders and make up 30-50% of total share volume. See Hasbrouck (1992) for a detailed discussion of the TORQ database.

The TORQ data provide a unique opportunity to examine the relation between the potential sources of revision described above and changes in specialists' posted schedules. In particular, these data have two key features which make such an analysis feasible. First, unlike most data, the TORQ database makes the determination of the true initiator of each transaction possible. When the true initiator is unknown, one of the Lee and Ready (1991) trade classification algorithms must be employed. Odders-White (1997) demonstrates that the Lee and Ready algorithms misclassify approximately 15% of transactions and that the misclassification can bias results. Second, with the TORQ database, estimates of the limit order books can be calculated for the included stocks (see Kavajecz (1997)).

The general methodology employed in building our event database is described below. We begin by collecting newly placed limit order and cancellation records from the TORQ order file. Only order and confirmed cancellation records that affect the best prices on the limit order book or the quantities at those prices are included. Orders and cancellations further away from the market are excluded due to their substantially smaller potential to impact the posted price schedule.

Next, all NYSE quote records are merged with the order and cancellation records. Regional quote records are included only when the best regional bid or ask represents an improvement over the NYSE quotes and then, again, when the situation reverses itself. In other words, the best regional bid and the best regional ask are computed at each regional quote change and only those bettering the NYSE are included in the data set.[10]

The merging of transaction records follows. The transaction records are those used in Odders-White (1997). These records are identical to those in the TORQ transaction file, but have been augmented to contain original order information for each side of the transaction, thus making

[10] The posted depths on the regional exchanges are not included in our analysis because they are typically smaller than the NYSE posted depths. Regional quotes with depths of 100 shares or less are also excluded because market makers are allowed to "trade-through" a 100 share quote. Moreover, these quotes are typically autoquotes and are automatically set to follow a competing market maker's quote. For further discussion of this, see Blume and Goldstein (1992) and Hasbrouck (1995).

determination of the initiator possible. The order, cancellation, quote, and transaction records contained in the data set are then sorted in chronological order to the nearest second.[11]

Since the events which induce quote revisions and the quote revisions themselves do not generally occur simultaneously, we must allow for slight differences in timing. We account for this by collapsing records that are within a window surrounding a quote change into a single event. The window around the quote change varies from one stock to another and is defined as follows. Let Q represent the time at which a quote revision occurs. Then a window of the form [Q-(1)*MED, Q+(1/4)*MED] is computed, where MED is the median time between events and subsequent quote changes in seconds for the chosen stock.[12] The window for each stock has the same functional form, but varies due to differences in the median time between events and quote revisions. Summary statistics on the cross-sectional distribution of the median time between events are shown in Figure 2.

Figure 2

	Mean	Standard Deviation	Min	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile	Max
Median Time between Events (in seconds)	19.97	48.40	0	0	6	9	17	67	486

The final step in the preparation of the data set is the calculation of a sequence of limit order books for each stock. We first estimate the limit order book as of November 1, 1990 (the date at which the data begin). This is done by searching the entire database for execution and cancellation records that refer to orders placed prior to the start of the database. Converting these records into orders gives an estimate of the limit order book at the start of the database. Beginning with this initial limit order book,

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[11] Lee and Ready (1991) document possible problems with the time-stamping of transactions and quote changes which could lead to the misalignment of these records. We choose to align records based on their time stamp with no adjustments because we are dealing with many types of records (not just quotes and transactions), and because we are dealing with time stamps that should be internally consistent. In addition, Odders-White (1997) finds that, for quotes and transactions in the TORQ database, the five-second rule takes effect only 4.4% of the time.

[12] The window extends beyond the quote revision because of the alignment issues discussed above. Consequently, the "post-window" is substantially smaller than the "pre-window." We have also run the model using the two alternative window specifications: [Q-(2)*MED, Q+(1/2)*MED] and [Q-(1/2)*MED, Q+(1/8)*MED]. The results were both qualitatively and quantitatively similar to the results using the original specification. See Appendix I for an example of how records are collapsed using the window.

we sequentially treat each record in the database by appropriately modifying the existing limit order book based on whether the record is a newly placed order, an execution, or a cancellation. Given the sequence of limit order book estimates, changes in the limit order can be computed for each event. The resulting data set is then used in the estimation procedure.

We estimate our simultaneous equations model using the two-stage least squares methodology.[13] We have chosen to use two stage least squares instead of the more efficient three stage least squares to avoid introducing any bias into the coefficient estimates. Recall when conducting three stage least squares, the use of the variance-covariance matrix as a weighting matrix spreads any bias introduced by model misspecification throughout the entire system, contaminating all coefficient estimates.

The following restrictions are imposed on the parameters of our model to achieve identification. The limit order book variables (ΔBBB, ΔSBBB, ΔBAB, ΔSBAB), the activity variables (BCLA and ACLA), and the regional variables (BBRE and BARE) appear only on their respective side of the market. In other words, ΔBBB, ΔSBBB, BCLA, and BBRE appear in the bid price and bid depth equations and ΔBAB, ΔSBAB, ACLA, and BARE appear in the ask price and ask depth equations.[14] These restrictions are natural since each omitted variable directly affects the opposite side of the market only. Indirect effects are still captured through the endogenous variables.

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[13] See Appendix II for a general discussion of simultanous equations models and identification.

[14] The following example outlines why changes in the number of shares at the best bid on the book may affect the posted bid. Suppose the specialist is reflecting the limit order book which has a bid of 20 with a depth of 1000 shares and does not want to offer any additional shares himself. Now suppose that 900 of the shares on the book are canceled, leaving only 100 shares at 20. This may prompt the specialist to move up the book, revising his quote to 20 1/8 and 5000 shares (in an effort to post a "reasonable depth"). The alternative -- posting 100 shares at 20 -- may constitute an unreasonably small depth. Ignoring the effect of the change in the number of shares at the best bid on the posted bid would contaminate the results.

V. Results

V.1 Changes in the Limit Order Book

The results for the full sample are presented in Exhibits III-VI.[15] Each exhibit displays statistics on the distribution of coefficient estimates, the distribution of p-values, and the distribution of R^2 values for the sample of stocks examined. In addition, for each explanatory variable, the exhibits display the percentage of the stocks in the sample having coefficient estimates that are different from zero at the five percent significance level. Exhibits III and IV contain the results for the bid and ask price equations, while the bid and ask depth results are shown in Exhibits V and VI.

The first notable result is the important role played by changes in the limit order book in the revision of all four elements of the posted price schedule. The specialist updates his posted prices primarily in response to changes in the best prices on the limit order book and his posted depths in response to changes in the number of shares at those prices. Changes in the best prices or quantities on the limit order book are statistically significant determinants (at the five percent level) of changes in the posted prices or depths for between 58.7 and 77.6 percent of the stocks in our sample -- percentages far higher than those for the other factors. Although the size of these coefficients varies across stocks, the relation between changes in the book and corresponding changes in the posted price schedule is consistently positive. On average, a one-dollar increase in the best bid (ask) price on the book causes the specialist to increase his posted bid (ask) price by approximately six (five) cents. A 1,000-share increase in the number of shares at the best bid (ask) price on the limit order book leads to a mean increase in the posted bid (ask) depth of 113 (115) shares. Recall that the specialist is not obligated to reflect these changes in the limit order book.

As discussed in the introduction, there are several reasons why the specialist may choose to respond to changes in the limit order book. First, changes in the book due to the placement, cancellation, or execution of an order may convey information to the specialist. Second, the specialist may view a

[15] For the six most frequently-traded stocks (IBM, AT&T, Exxon, Philip Morris, Boeing, and General Electric) we used only one month of data rather than all three months due to the size of the data sets.

change in the book as an increase or decrease in the degree of competition for order flow and react accordingly. For example, suppose the specialist posts a bid price of $20 1/8 when the best bid on the limit order book is $20 because he wants to buy stock for his own inventory. If the best bid on the book increases by an eighth and the specialist still wants to take precedence over the book, he must also increase his posted bid by at least an eighth. On the other hand, suppose the specialist posts a bid price of $20 -- the same as the best bid on the book -- because he wants to pass the order flow onto the existing limit orders. Now if the best bid on the limit order book decreases by an eighth, the specialist must also decrease his bid to avoid posting a better price than the book and, therefore, having to take the other side of subsequent bid-side transactions himself.

We see from the magnitude of the limit order book coefficients that, while changes in the best prices on the limit order book and in the corresponding quantities are important determinants of changes in the posted price schedule, the specialist is not simply hiding behind the limit order book, matching (reflecting one-for-one) each change in the book.[16] In fact, the coefficients are surprisingly small. Even the 90th percentile coefficient reflects a decrease in the posted bid of only $0.15 in response to a $1 decrease in the best bid price on the book. If the specialist reflects the limit order book only a fraction of the time, and the coefficient estimates are averages over the cases in which the specialist does and does not fully reflect changes in the book, then we would expect to see coefficients of this magnitude.

To further investigate this possibility, we separate those changes in the limit order book that the specialist is likely to reflect from those changes to which he is unlikely to react. We do so by conditioning on the proximity of the specialist's quoted prices to the best prices on the limit order book. The idea is that when the specialist is either reflecting or is "close to" the limit order book, he may react more fully to changes in the book than he would when he is providing much of the liquidity himself.

The relevant variables (the changes in the best prices on the book in the price equations and the changes in the quantities on the book in the depth equations) are partitioned into two separate variables

based upon whether the specialist's quoted prices are within an eighth of the best prices on the limit order book (suffix "1") or whether the quoted prices are more than an eighth away from the limit order book prices (suffix "2"). This differentiation allows for the possibility of a kink in the specialist's reaction function. We also include dummy variables that take on the value one whenever the specialist is more than an eighth from the best price on the limit order book, BBBFR and BABFR, which capture any fixed effects of the specialist being "far" away from the book. The results are shown in Exhibits VII through X.

Not surprisingly, the coefficient estimates and p-values for the non-limit order book variables are largely the same as the unconditional results for all four equations. Consequently, the discussion will focus on the limit order book variables. Consistent with our hypothesis, changes in the limit order book that occur when the specialist's posted prices are in close proximity to the book have a much more significant effect (both economically and statistically) than those that occur when the specialist's prices are more than an eighth away from the best prices on the book. The specialist's increased attention to changes in the limit order book when his quoted prices are close to those on the book could be the result of several factors. Competition from the book is likely to play a larger role at these times, the specialist has the ability to pass liquidity onto the book if he chooses, and the information conveyed by the changes in the limit order book may be more relevant to him in these cases.[17]

While the coefficients when the specialist is close to the book (suffix "1") are larger than those when he is farther away (suffix "2"), the magnitude of the coefficients does not approach the benchmark

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[16] If this were the case, we would expect to find a coefficient of 1 on the relevant limit order book variable and of 0 on all other variables. In addition, the R^2 for each equation would be 1 since all changes in the quotes would be perfectly explained by changes in the book.

[17] Recall that the specialist is not required to reflect improvements in the bid or ask prices on the limit order book for a number of reasons. First, during the time period covered by this data, specialists were allowed to hide limit orders if they felt they were not representative of the market. Second, if the specialist is posting a bid (ask) price that is better than the bid (ask) price on the limit order book, then an increase in the best bid (decrease in the best ask) on the book will often result in a price that is still inferior to that of the specialist. (For example, suppose the best ask on the book is $20 and the specialist is posting $19-3/4. If the best ask on the book decreases to $19-7/8, the specialist is still posting a better price and is clearly not obligated to make any adjustments to his quotes.) Changes in the limit order book which the specialist is "required" to reflect (or to hide by posting a price worse than the best price on the limit order book) make up less than 2% of our sample.

value of one in which the specialist simply reflects changes in the book one-for-one. One reason for this is the smoothing behavior undertaken by the specialist. As stated in the introduction, one of the specialist's responsibilities is to maintain a "fair and orderly" market. This includes minimizing price variation. Consequently, the specialist will not fully reflect a change in the limit order book if it would result in a large price jump. In a statistical analysis, we find that the specialist smoothes changes in the prices on the limit order book (meaning he does not change his posted price at all or he changes his posted price by an amount less than the change in the book) roughly 80% of the time.

All of the results for the limit order book variables are consistent with specialists closely monitoring changes in their limit order books and reacting to these changes a significant portion of the time. Although specialists sometimes play a passive role by simply mirroring changes in the limit order book, they more often assume an active role in which they smooth price changes by providing extra liquidity to the market themselves.

V.2 Transactions

Transactions play a secondary role in the quote-revision process, especially for prices. Unlike changes in the limit order book, transactions have different effects on the specialist's posted prices and depths. The specialist updates his posted depths in response to transaction volume, but he revises his posted prices only in response to those transactions whose size exceeds the quoted depth. One feature common to both elements, however, is that buyer-initiated transactions (BTV and BDPDM) affect only the ask side of the market and seller-initiated transactions (STV and SDPDM) affect only the bid side of the market. This is not surprising since most buyer-initiated (seller-initiated) trades take place at, or closer to, the ask (bid) price.

Transactions larger than the posted depth lead to revisions in the quoted prices for roughly one-fourth of the stocks in our sample, while transactions (of any size) result in revised depth quotes for thirty-five to forty percent of the stocks. Large transactions tend to widen the spread and transaction volume tends to reduce the posted depths. These results are consistent with theoretical notions that

informed traders, who are more likely to want to transact at quantities larger than the posted amount, signal an undervalued (overvalued) asset if they are buying (selling).[18]

The transaction variables demonstrate that specialists revise prices and depths in response to different stimuli. The specialist may decrease his depths following a transaction as a protective measure because the transaction conveys some information or because his inventory was affected by taking the other side of the trade.[19] In other words, the posted depths can be thought of as his first line of defense in response to transactions. Only when the transaction exceeds the quoted depth does he also adjust the posted prices. One possible explanation for this is that larger transactions convey more information. Another possibility is that the specialist adjusts prices after a large transaction because the trade exhausted all the liquidity at the previous price. For example, suppose the best bid price on the limit order book is \$20 and there are 900 shares on the book at that price. Also assume that the specialist is posting a bid price of \$20 1/8 and a bid depth of 500 shares. Consider the arrival of a 400-share market sell order. Our results are consistent with the specialist taking the other side of the order and reducing his posted depth. His new quotes, for example, might be 100 shares at \$20 1/8. Now instead suppose the market sell order were for 1,000 shares rather than 400 shares. In this case, the transaction size exceeds the posted depth and the specialist might react by changing both his bid depth and his bid price, say to 400 shares at \$20.

Although transactions generally lead to an increase in the quoted spread and a decrease in the depths, the tails of the distributions of the transaction variables show that the opposite relation actually holds for some stocks. Examination of the distribution of both the coefficients and the p-values in Exhibits III through VI demonstrates that there are clearly differences across stocks. This variation may be due, in part, to differences in trading volume since existing studies suggest that specialists may

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[18] Larger transactions could also result in larger changes to the price schedule when the specialist actively participates in the trade (i.e. if the transaction increases or decreases the specialist's inventory) because these transactions have a larger impact on his inventory. Note that the same argument cannot be made when transactions hit the limit order book because changes in the book are being accounted for by the limit order book variables.

manage frequently-traded stocks differently from infrequently-traded stocks. Consequently, we divide the stocks in our sample into deciles based on average daily trading volume (see Exhibits X through XIV). Due to space constraints, only the results for deciles one (high volume), five, and ten (low volume) are shown.

The results demonstrate a sharp contrast between high, medium and low transaction volume stocks. The transaction variables are extremely important for frequently-traded stocks. After excluding the decile-one results, however, transaction volume has substantially less ability to explain changes in the posted depths.[20] A similar decline in the significance of the transaction variables occurs between deciles five and ten for the posted prices. The limited number of transactions (especially those that exceed the depths) for lower-volume stocks may be one reason for this finding. Alternatively, specialists may manage high-volume stocks more actively than lower-volume stocks due to the fact that high-volume stocks essentially trade in an quote-driven market due to the presence of the trading crowd and low-volume stocks trade in a order-driven market.

V.3 Activity

Activity also has a significant effect on the posted price schedule but, like transactions, activity is secondary to the limit order book. In addition, we find that activity plays a more important role in the revision of the posted depths than of the posted prices.

The relation between activity and adverse selection can be interpreted in two different ways. On the one hand, low activity could signal to the specialist that the *potential* for informed trading is highest since there is currently a consensus about the value of the asset. On the other hand, high activity could signal to the specialist the possible presence of an informed trader attempting to hide among the other market participants, as in Admati and Pfleiderer (1988). The coefficients on the activity variables

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[19] Recall that we have controlled for changes in the limit order book by including the set of limit order book variables. It is, therefore, not the case that the specialist is simply reflecting the decreased number of shares on the book following the execution of a limit order.

support this second interpretation. An increase in activity widens the spread and diminishes both of the depth quotes; a reaction that is consistent with specialists viewing high activity as a proxy for increased adverse selection risk. Our results are consistent with specialists using the posted depths as their primary protection (and prices as secondary protection) against adverse selection.

Examination of Exhibits X through XIV demonstrates that activity is a significant determinant of changes in the posted price schedule for both high and low-volume stocks, especially for the quoted depths. In addition, the median values of the activity coefficients in the price equations are generally increasing (in absolute value) as the average trading volume decreases. One explanation of the importance of the activity variables in lower-volume stocks is the inverse relation between trading frequency and adverse selection proposed by Easley, Kiefer, O'Hara, and Paperman (1996), among others.

Although not shown, we also investigated the importance of activity for cases in which the limit order book is empty on one or both sides of the market. The results demonstrate that the specialist is likely to react to very few factors, with activity playing a slightly more central role than in the general case. The result is consistent with the specialist maintaining a wide spread and low depth quotes such that trade essentially shuts down when the limit order book is absent.

V.4 Other Factors

Although not of primary importance, the results for the other factors in the model are worth noting. The intercept terms show that the specialist is likely to narrow the spread and increase the depths when no activity is taking place (no transactions, no changes in the best prices on the book, etc.). This response is consistent with theories of adverse selection. When the specialist has no need to protect himself against the possibility of informed trading, he posts a narrower spread and wider depth, ceteris paribus.

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[20] The higher statistical significance of variables for high-volume stocks is probably due, in part, to the larger sample sizes for high-volume stocks (since volume and trading frequency are positively correlated).

The intercept terms are much more significant for decile-one stocks than for lower-volume stocks. This may be due in part to the fact that specialists are more willing to narrow the spread on high-volume stocks since they are able to profit from the sheer volume of trade. An active trading crowd can also help to increase liquidity, thereby inducing the specialist to narrow the spread and increase the depths -- a phenomenon that is likely to occur for high-volume rather than low-volume stocks.

We also document a relation between regional prices that are better than the NYSE and the specialist's posted bid and ask prices. Although the regional variables are often significant, the signs of the coefficients are the opposite of what theory would predict. The negative sign of the regional competition coefficients in the bid change equation (overall median = -0.0007) and the positive sign in the ask change equation (overall median = 0.0010) may at first appear counter-intuitive because they suggest that, when the regional quotes are better than the NYSE quotes, the NYSE bid price decreases and the NYSE ask price increases. The signs of the coefficients actually imply, however, that the regional exchanges are typically *following* the NYSE quotes.[21] For example, if the NYSE specialist decreases the bid by an eighth and the regional exchanges follow with a lag, then a positive value of BBRE (the difference between the regional bid and the NYSE bid) will be accompanied by a negative change in the bid. This is consistent with Hasbrouck's (1995) finding that the majority of price discovery occurs at the NYSE and that the regional exchanges follow the NYSE specialist's quotes. The regional competition variables, like many of the explanatory variables in the model, are substantially more important for high-volume stocks, probably because regional exchanges are more likely to quote prices for actively-traded stocks.

The relation hypothesized between the endogenous variables is generally borne out in the results. Not surprisingly, the bid and ask prices are positively correlated, consistent with the specialist maintaining a relatively constant spread. However, note that the coefficients on the bid and ask in the price equations are substantially less than one. The size of the coefficients suggest that specialists do not

[21] For decile 1, 58% of the better regional quotes result from the NYSE moving its prices and the regional exchange(s) responding with a lag.

reposition the spread (move both the bid and ask prices), rather they adjust the price on one side of the market at a time. This "accordion" effect (the spread widens and narrows and then widens again) ensures that specialists maintain price continuity of an eighth. The bid (ask) price and bid (ask) depth are also correlated; however to a lesser extent. The relation between the bid and bid depth (the ask and the ask depth) is generally negative (positive), consistent with the specialist using the prices and depths as substitutes for liquidity provision. Note, however, that for some stocks, the bid and the bid depth (the ask and the ask depth) are positively (negatively) correlated, and for many stocks, the relation is not statistically significant. In addition, the relation between the bid depth and the ask depth is weakly positive but generally not statistically significant.

V.5 Example

V.5.1 Posted Prices

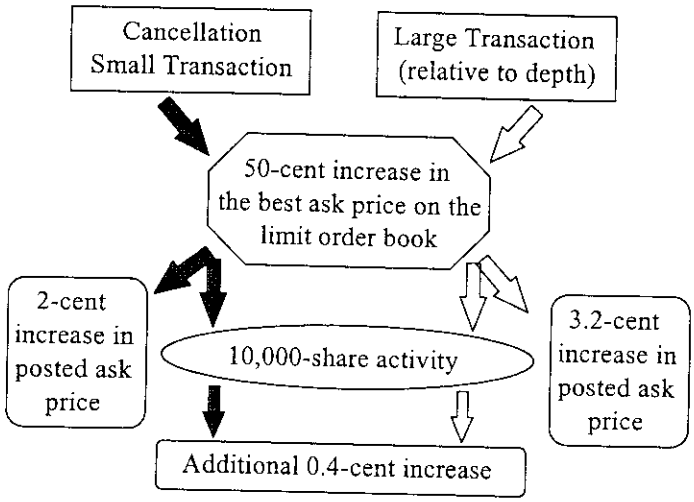
The results demonstrate that specialists update their posted prices primarily in response to changes in the best prices on the limit order book. They also react to increased overall activity and to transactions whose size exceeds the quoted depth, but each of these factors has substantially less impact than the limit order book in both statistical and economic terms.

Figure 3 contains an example which summarizes specialists' median price reaction to various events. First, suppose that either an existing limit order is canceled or a small transaction (meaning its size does not exceed the posted depth) removes a limit order from the book. Further assume that this event results in an increase in the best ask price on the limit order book of fifty cents. The specialist's median response is to increase his posted ask price by two cents. Notice that it is the change in the book that matters here -- not what caused it. The fact that the change in the book was due to cancellation rather than a small transaction (or vice-versa) conveys no additional information to the specialist.

Suppose instead, however, that a transaction whose size exceeded the posted depth was responsible for the change in the limit order book. The specialist distinguishes this case from the others, and reacts by increasing his quoted ask price by 3.2 cents, an increase over fifty percent larger than that

in the first case. If any of these events takes place during a period of high activity, say 10,000 shares, then the specialist increases his ask price by an additional 0.4 cents.

Figure 3



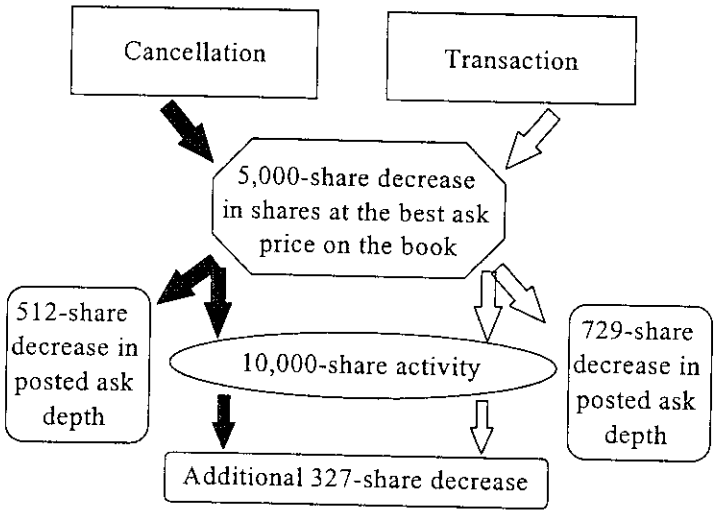
V.5.2 Posted Depths

We also find that specialists update their posted depths primarily in response to changes in the limit order book; however, the secondary influences on the depths differ somewhat from those on the prices. Like prices, the posted depths are revised in response to activity and to transactions, but the specialist changes his depths in response to transaction volume, not only to those transactions which exceed the quoted size. In addition, while still secondary, each of these factors has a larger effect on the quoted depths than on the quoted prices.

An example summarizing specialists' median depth reaction to various events is found in Figure 4. Here, the cause of the change in the limit order book *is* important. If a cancellation results in a 5,000-share decrease in the number of shares at the best ask price on the book, the specialist's median response is to decrease his posted depth by 512 shares. If, on the other hand, the 5,000-share decrease were caused by a transaction, the specialist would react by decreasing the posted depth by 729 shares. When revising the posted depths, the specialist does not care whether or not the transaction size exceeded the quoted depth. If the cancellation or the transaction takes place during a period of high activity, say

10,000 shares, then the specialist decreases his ask depth by an additional 327 shares. This example also demonstrates the larger effect of activity on the posted depths than on the posted prices.

Figure 4



V.6 Model Specification

The accuracy of our model specification can be examined by looking at goodness of fit measures (R^2) and by testing the over-identifying restrictions placed on the model. When considering R^2 values, one must first establish a reasonable benchmark. In some cases, this benchmark represents a "perfect fit" or an R^2 of one. In this study, however, we cannot hope to capture all of the variation in prices and depths with our model because unanticipated information shocks will result in jumps in the price schedule that do not filter through the trading process. Consequently, the R^2 values in Exhibits III through XIV provide some measure of the quality of the model and allow for a relative comparison of the four equations. More importantly, they offer insight into the way in which information is incorporated into the market.

The goodness of fit of our model ranges from roughly zero percent for some stocks to almost sixty percent for others. For the stocks with the larger R^2 values, most of the information appears to be incorporated into the market through the trading process. For those with low R^2's, more information

enters in the form of shocks. In addition, omitted variables may play a larger role for these low-R^2 stocks.

Our model explains more of the variation of posted prices than of posted depths. This could be due to a greater influence of factors missing from the model on the depths. For example, the results are consistent with the specialist responding to changes in his inventory by altering the posted depths or with the presence of floor brokers having a larger impact on depths than on prices. We also find that the model fits better for small and for infrequently-traded stocks than for large or actively-traded stocks. This could be the result of more frequent or severe information shocks for these firms or, again, of a larger influence of omitted variables.

Since each equation in our model contains three endogenous variables and excludes four exogenous variables (see Section IV), the model is over-identified. Tests of the over-identifying restrictions are performed using Basmann's (1960) test. The null hypothesis that the exogenous variables not appearing in the equation have zero coefficients is rejected at the 5% level only four out of a possible 143 times for the bid equation, seven times for the ask equation, eight times for the bid depth equation, and eight times for the ask depth equation.

VI. Conclusion

Understanding the process by which NYSE specialists revise their posted price schedules is a prerequisite to understanding the entire market structure. The process is important because the posted price schedule has the potential to influence investor behavior and because the quote-revision process affects the way in which information is incorporated into the market -- an issue central to the study of finance.

Our findings can be summarized as follows: (1) Changes in the limit order book are the most significant determinant of changes in specialists' posted price schedules. The magnitude of these coefficients is small, however, demonstrating that the specialist is not reflecting changes in the limit order book one-for-one. (2) The activity variables have a significant impact on changes in specialists'

posted price schedule -- particularly for the depth quotes. High levels of activity signal high adverse selection costs. (3) Transaction variables are also important, with transaction volume affecting the posted depths and only those transactions that exceed the quoted depth resulting in changes to the posted prices. When examined decile-by-decile, the results demonstrate that specialists have a tendency to manage high-volume and low-volume stocks differently.

REFERENCES

Admati, Anat R. and Paul Pfleiderer, 1988, A Theory of Intraday Patterns: Volume and Price Variability, Review of Financial Studies 1, 3-40.

Basmann, R. L., 1960, On Finite Sample Distributions of Generalized Classical Linear Identifiability Test Statistics, Econometrica, 939-952.

Blume, Marshall E. and Michael A. Goldstein, 1992, Displayed and Effective Spreads by Market, Rodney L. White Center for Financial Research Working Paper, (December).

Chan Louis K. C. and Josef Lakonishok, 1993, Institutional trades and intraday stock price behavior, Journal of Financial Economics 33, 173-199.

Dupont, Dominique Y. 1995, Market Making, Prices and Quantity Limits, Working Paper Board of Governors of the Federal Reserve System.

Easley, David, Nicholas M. Kiefer, Maureen O'Hara, and Joseph B. Paperman, 1996, Liquidity, Information and Infrequently Traded Stocks, Journal of Finance 51:1405-1436.

Engle, Robert F. and Jeffrey R. Russell, 1995, Autoregressive Conditional Duration: A New Model for Irregularly Spaced Transaction Data, University of California - San Diego working paper.

Garman, Mark, 1976, Market Microstructure, Journal of Financial Economics, 257-275.

Greene, William H., 1990, Econometric Analysis, Macmillan Publishing Company, New York.

Harris, Lawrence E., 1994, Minimum Price Variations, Discrete Bid-Ask Spreads, and Quotation Sizes, Review of Financial Studies, 149-178.

Hasbrouck, Joel, 1988, Trades, Quotes, Inventories, and Information, Journal of Financial Economics 22, 229-252.

Hasbrouck, Joel, 1991, The Summary Informativeness of Stock Trades: An Econometric Analysis, Review of Financial Studies, 571-595.

Hasbrouck, Joel, 1992, Using the TORQ database, NYU working paper.

Hasbrouck, Joel, 1995, One Security, Many Markets: Determining the Contribution to Price Discovery, Journal of Finance, 1175-1199.

Jones, Charles M., 1993, Transaction Costs and Short-Term Return Predictability, University of Michigan working paper.

Kaniel, Ron and Hong Liu, 1996, Are Limit Orders More Important than Transactions and Market Orders in the Quote Updating Process?, Wharton working paper.

Kavajecz, Kenneth A., 1996, The Specialist's Quoted Depth as a Strategic Choice Variable, Rodney L. White Center for Financial Research Working Paper, (July).

Kavajecz, Kenneth A., 1997, A Specialist's Quoted Depth and the Limit Order Book, Rodney L. White Center for Financial Research Working Paper, (June).

Knez, Peter J. and Mark J. Ready, 1996, Estimating the Profits from Trading Strategies. Review of Financial Studies, 1121-1163.

Lee, Charles, M. C, Belinda Mucklow, and Mark J. Ready, 1993, Spreads, Depths, and the Impact of Earnings Information: An Intraday Analysis, Review of Financial Studies, 345-374.

Lee, Charles M. C. and Mark J. Ready, 1991, Inferring Trade Direction from Intraday Data, Journal of Finance, 733-746.

Odders-White, Elizabeth R., 1997, The Significance of Accurate Trade Classification, University of Wisconsin working paper.

Petersen, Mitchell and Steven Umlauf, 1993, Quote Revisions and the Quoted Size: An Empirical Analysis, CRSP working paper no. 312.

Appendix I

The importance of considering depth quotes as well as analyzing other sources of revisions in addition to transactions is highlighted in the following example. Suppose it is 11:07 a.m., and imagine a market in which the bid is 20 and the ask is 20 1/8. The bid and the ask depths are 1000 and 500 shares, respectively, and both sides of the specialist's schedule reflect the liquidity provided by the limit order book. In other words, the specialist is not offering any additional shares beyond those provided by the book. Suppose the following sequence of events takes place. At 11:08, a transaction occurs in which a market buy order for 300 shares is placed and immediately executes at 20 1/8, with a floor broker taking the other side of the transaction. A few minutes later (at 11:13), a limit sell order at 20 1/8 is canceled, eliminating 400 shares on the limit order book at that price. The ask price of 20 1/8 is maintained, however, the ask depth is immediately revised to 100 shares, again reflecting the limit order book.

TIME	BOOK		POSTED QUOTES				BOOK		EVENT
	Best Bid	Shares at Best Bid	Bid	Bid Depth	Ask	Ask Depth	Best Ask	Shares at Best Ask	
11:07:52	20	1000	20	1000	20 1/8	500	20 1/8	500	Quote posted
11:08:35	20	1000	20	1000	20 1/8	500	20 1/8	500	300 shr buy trans. at 20 1/8
11:13:21	20	1000	20	1000	20 1/8	500	20 1/8	100	400 shr sell order canceled
11:13:25	20	1000	20	1000	20 1/8	100	20 1/8	100	Quote posted

The above example illustrates the importance of examining *all* events. The change in the quoted depth was induced not by the transaction, but rather, by the change in the limit order book due to the cancellation. Consequently, an analysis of transactions and prices alone could misstate the effect of transactions on quotes.

The following example of how records are collapsed using the event window refer to the above table. Recall that the cancellation and the quote revision occur at 11:13:21 and 11:13:25, respectively.

Suppose the window for this stock begins eight seconds before and ends two seconds after a quote revision. These two records would be collapsed into one event. Specifically, the variable values for this event would be:

Variable	Value	Variable	Value	Variable	Value	Variable	Value
ΔB	0	BTV	0	BCLA	0.3	ΔBBB	0
ΔA	0	STV	0	ACLA	0	ΔBAB	0
ΔBD	0	BDPDM	0	BBRE	*	ΔSBBB	0
ΔAD	-0.4	SDPDM	0	BARE	*	ΔSBAB	-0.4
* Unknown given the information above							

Had the quote revision in the example taken place at 11:14:01 rather than at 11:13:25, then the cancellation and the quote would have remained two separate records.

Appendix II
Simultaneous Equations Models

Simultaneous equations models consist of systems of equations that capture the interdependence among the variables in the model. The structural form of the contains endogenous variables on the left hand side and both endogenous and exogenous variables on the right hand side of the equations. The typical notation for the structural form equations is the result of collecting terms on the left hand side as follows:

$$Y\beta + Z\Gamma = \varepsilon$$

where Y and Z are matrices of endogenous and exogenous variables, respectively.

Simultaneous equations models can sometimes be solved by indirect least squares using the reduced form of the model, which consists of the endogenous variables written as functions of exogenous variables only:

$$Y = Z\Pi + e$$

where $\Pi = -\Gamma\beta^{-1}$ and $e = \varepsilon\beta^{-1}$. Ordinary least squares regressions can then be run for each equation separately to estimate Π and Σ_e, the variance-covariance matrix for the reduced-form error terms. Provided the system is identified, the parameters of the original structural form model can be recovered from the reduced form estimates. In practice, however, two or three-stage least squares estimators are typically used to estimate the structural form parameters directly because the indirect least squares methodology cannot be applied to over-identified systems.[22] We employ the two-stage least squares methodology.

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[22] Alternative approaches include limited-information maximum likelihood (LIML) and full-information maximum likelihood (FIML) estimators. See Greene (1990) for a detailed discussion of the theory and estimation of simultaneous equations models.

The steps in this process are as follows:

(1) Predict the set of right-hand side variables for each equation, $X_i = [Y_i | Z_i]$, using Z only, thereby creating instruments for the endogenous variables. The result is:

$$\hat{X}_i = P_Z X_i, \quad \text{where } P_Z = Z(Z'Z)^{-1}Z'.$$

(2) Regress Y_i on the instruments, $\hat{X}_i$ (which includes the exogenous variables, Z_i) using ordinary least squares:

$$\hat{\beta}_{i,2SLS} = (X_i' P_Z X_i)^{-1} X_i' P_Z Y_i.$$

There are two conditions that must be satisfied in order for the model to be identified -- the order condition and the rank condition. The order condition is a necessary but not sufficient condition which states that the number of excluded exogenous variables in each equation must be at least as great as the number of included endogenous variables on the right hand side of the equation. The necessary *and* sufficient rank condition dictates that the submatrix of reduced form coefficients corresponding to the excluded exogenous variables have rank greater than or equal to the number of included endogenous variables on the right hand side.

Appendix III

The following table demonstrates the way in which the activity variables are computed.

Event	Size of Newly-placed Order (in 1,000 shares)		Size of Canceled Order (in 1,000 shares)		Size of Transaction (in 1,000 shares)		BCLA (in 1,000 shares)	ACLA (in 1,000 shares)
	Buy (BCLA)	Sell (ACLA)	Buy (BCLA)	Sell (ACLA)	Buy (ACLA)	Sell (BCLA)		
Quote	-	-	-	-	-	-	0	0
Cancellation	-	-	3.2	-	-	-	0	0
Order	-	4.5	-	-	-	-	3.2	0
Transaction	-	-	-	-	2.4	-	3.2	4.5
Transaction	-	-	-	-	-	1.0	3.2	6.9
Order	5.1	-	-	-	-	-	4.2	6.9
Quote	-	-	-	-	-	-	9.3	6.9

Exhibit I

The Model

The model we estimate is as follows:

$$\begin{bmatrix} \Delta B \\ \Delta A \\ \Delta BD \\ \Delta AD \end{bmatrix} = \begin{bmatrix} a_0 & 0 & a_2 & a_3 & 0 & a_5 & a_6 & a_7 & a_8 & a_9 & 0 & a_{11} & 0 & a_{13} & 0 & a_{15} & 0 \\ b_0 & b_1 & 0 & 0 & b_4 & b_5 & b_6 & b_7 & b_8 & 0 & b_{10} & 0 & b_{12} & 0 & b_{14} & 0 & b_{16} \\ c_0 & c_1 & 0 & 0 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 & 0 & c_{11} & 0 & c_{13} & 0 & c_{15} & 0 \\ d_0 & 0 & d_2 & d_3 & 0 & d_5 & d_6 & d_7 & d_8 & 0 & d_{10} & 0 & d_{12} & 0 & d_{14} & 0 & d_{16} \end{bmatrix} \begin{bmatrix} 1 \\ \Delta B \\ \Delta A \\ \Delta BD \\ \Delta AD \\ \text{BTV} \\ \text{STV} \\ \text{BDPDM} \\ \text{SDPDM} \\ \Delta\text{BBB} \\ \Delta\text{BAB} \\ \Delta\text{SBBB} \\ \Delta\text{SBAB} \\ \text{BCLA} \\ \text{ACLA} \\ \text{BBRE} \\ \text{BARE} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \end{bmatrix}$$

Notes: A description of each variable is included in Exhibit II. Endogenous variables are in italics. Zeros indicate identifying restrictions placed on the model which are discussed in Section III.2.

Exhibit II

Variable Definitions

Variable	Description
ΔB	Change in the bid in dollars
ΔA	Change in the ask in dollars
ΔBD	Change in the bid depth in shares
ΔAD	Change in the ask in shares
BTV	Buy transaction volume = the size in shares of the buy transaction (=0 for non-transaction records)
STV	Sell transaction volume = the size in shares of the sell transaction (=0 for non-transaction records)
BDPDM	Buy depth-exceeded dummy (for buy transaction events only) = 1 if buy transaction volume exceeds the posted ask depth (0 otherwise)
SDPDM	Sell depth-exceeded dummy (for sell transaction events only) = 1 if sell transaction volume exceeds the posted bid depth (0 otherwise)
BCLA	Bid-side cumulative lagged activity = the sum of all shares from newly placed buy orders, canceled buy orders, and sell transactions since the last quote revision (excluding the current event volume)
ACLA	Ask-side cumulative lagged activity = the sum of all shares from newly placed sell orders, canceled sell orders, and buy transactions since the last quote revision (excluding the current event volume)
ΔBBB	Change in the best bid on the (limit order) book in dollars since the last quote revision
ΔBAB	Change in the best ask on the (limit order) book in dollars since the last quote revision
ΔSBBB	Change in the number of shares at the best bid on the book in shares since the last quote revision
ΔSBAB	Change in the number of shares at the best ask on the book in shares since the last quote revision
BBRE	Better bid on regional exchange = Bid_{RE} -Bid_{NYSE} in dollars
BARE	Better ask on regional exchange = Ask_{NYSE}-Ask_{RE} in dollars

Notes: Endogenous variables are in italics.

Exhibit III
Unconditional Model Results
Bid Price Equation

Variable	Mean	10%	25%	Median	75%	90%	Signif
Intercept	0.0029	-0.0006	0.0004	0.0016	0.0033	0.0056	
	(0.3770)	(0.0004)	(0.0295)	(0.2831)	(0.7224)	(0.8537)	28.0%
ΔB							
ΔA	0.2830	0.0273	0.1227	0.2274	0.3811	0.5089	
	(0.2947)	(0.0000)	(0.0111)	(0.1682)	(0.5106)	(0.8506)	38.5%
ΔBD	-0.0145	-0.0508	-0.0218	-0.0049	0.0002	0.0139	
	(0.5056)	(0.0578)	(0.2336)	(0.4957)	(0.7880)	(0.9228)	7.7%
ΔAD							
BTV	-0.0004	-0.0020	-0.0005	-0.0001	0.0001	0.0010	
	(0.6920)	(0.2340)	(0.5651)	(0.7656)	(0.9036)	(0.9714)	2.8%
STV	-0.0006	-0.0031	-0.0010	-0.0001	0.0003	0.0016	
	(0.5796)	(0.0791)	(0.2993)	(0.6420)	(0.8637)	(0.9556)	7.7%
BDPDM	-0.0039	-0.0089	-0.0043	0.0000	0.0028	0.0094	
	(0.6915)	(0.2340)	(0.5651)	(0.7656)	(0.9311)	(0.9706)	1.4%
SDPDM	-0.0171	-0.0426	-0.0322	-0.0147	-0.0011	0.0105	
	(0.4239)	(0.0003)	(0.0498)	(0.3957)	(0.8108)	(0.9203)	25.2%
BCLA	-0.0039	-0.0033	-0.0011	-0.0002	0.0001	0.0008	
	(0.4174)	(0.0049)	(0.1073)	(0.4125)	(0.7054)	(0.8637)	18.9%
ACLA							
ΔBBB	0.0614	0.0063	0.0141	0.0405	0.0938	0.1503	
	(0.1634)	(0.0000)	(0.0000)	(0.0003)	(0.2210)	(0.6838)	67.8%
ΔBAB							
ΔSBBB	0.0009	-0.0025	-0.0004	0.0001	0.0016	0.0054	
	(0.5515)	(0.0823)	(0.2999)	(0.5313)	(0.8444)	(0.9387)	4.9%
ΔSBAB							
BBRE	-0.1260	-0.5040	-0.1762	-0.0007	0.0000	0.0001	
	(0.4791)	(0.0000)	(0.0121)	(0.5673)	(0.8925)	(0.9664)	28.7%
BARE							
R^2	0.0849	0.0033	0.0193	0.0557	0.1143	0.1830	

Notes:

(i) The variable groups are from top to bottom: intercept, endogenous, transactions, activity, limit order book and regional. Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of coefficients (top row) and the distribution of p-values (bottom row, in parentheses).

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

Exhibit IV
Unconditional Model Results
Ask Price Equation

Variable	Mean	10%	25%	Median	75%	90%	Signif
Intercept	-0.0031	-0.0055	-0.0026	-0.0014	-0.0004	0.0011	
	(0.4527)	(0.0058)	(0.1551)	(0.4599)	(0.7104)	(0.8663)	17.5%
ΔB	0.2964	0.0259	0.1043	0.2536	0.3970	0.5812	
	(0.3014)	(0.0000)	(0.0056)	(0.1760)	(0.5197)	(0.8574)	38.5%
ΔA							
ΔBD							
ΔAD	0.0018	-0.0389	-0.0074	0.0036	0.0221	0.0506	
	(0.5031)	(0.0615)	(0.2498)	(0.5336)	(0.7839)	(0.8723)	9.1%
BTV	0.0018	-0.0019	-0.0002	0.0004	0.0024	0.0068	
	(0.5498)	(0.0580)	(0.2349)	(0.5988)	(0.8403)	(0.9413)	9.8%
STV	0.0004	-0.0007	-0.0002	0.0000	0.0004	0.0015	
	(0.7081)	(0.3411)	(0.5647)	(0.7656)	(0.9209)	(0.9791)	2.1%
BDPDM	0.0216	-0.0121	-0.0015	0.0121	0.0291	0.0480	
	(0.4527)	(0.0001)	(0.0818)	(0.4843)	(0.8062)	(0.9254)	23.1%
SDPDM	0.0017	-0.0141	-0.0044	0.0006	0.0055	0.0131	
	(0.6547)	(0.2121)	(0.4623)	(0.7192)	(0.8982)	(0.9663)	2.8%
BCLA							
ACLA	0.0031	-0.0021	-0.0002	0.0004	0.0016	0.0056	
	(0.3992)	(0.0016)	(0.0289)	(0.4169)	(0.7254)	(0.8676)	27.3%
ΔBBB							
ΔBAB	0.0479	0.0031	0.0134	0.0351	0.0647	0.1200	
	(0.1925)	(0.0000)	(0.0000)	(0.0126)	(0.2666)	(0.7612)	58.7%
ΔSBBB							
ΔSBAB	0.0010	-0.0040	-0.0017	-0.0002	0.0010	0.0067	
	(0.5391)	(0.1335)	(0.2956)	(0.5647)	(0.8002)	(0.8915)	7.7%
BBRE							
BARE	0.0940	0.0000	0.0001	0.0010	0.0149	0.4996	
	(0.4571)	(0.0000)	(0.0520)	(0.4547)	(0.8702)	(0.9641)	22.4%
R^2	0.0699	0.0035	0.0127	0.0398	0.0809	0.1784	

Notes:

(i) The variable groups are from top to bottom: intercept, endogenous, transactions, activity, limit order book and regional. Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of coefficients (top row) and the distribution of p-values (bottom row, in parentheses).

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

Exhibit V
Unconditional Model Results
Bid Depth Equation

Variable	Mean	10%	25%	Median	75%	90%	Signif
Intercept	0.0537	-0.0408	0.0042	0.0399	0.1122	0.2248	
	(0.4911)	(0.0322)	(0.1697)	(0.4950)	(0.7748)	(0.8898)	12.6%
ΔB	-13.241	-116.89	-39.653	-11.040	-1.8643	11.4025	
	(0.4116)	(0.0045)	(0.0844)	(0.4010)	(0.7011)	(0.8543)	21.7%
ΔA							
ΔBD							
ΔAD	0.1372	-0.1176	-0.0265	0.0509	0.1611	0.4775	
	(0.5284)	(0.0973)	(0.2972)	(0.5780)	(0.7731)	(0.8792)	6.3%
BTV	-0.0011	-0.0470	-0.0140	0.0003	0.0155	0.0576	
	(0.6800)	(0.2160)	(0.4876)	(0.7681)	(0.9113)	(0.9740)	2.8%
STV	-0.0518	-0.1893	-0.0766	-0.0273	0.0018	0.0418	
	(0.4186)	(0.0000)	(0.0029)	(0.3247)	(0.8292)	(0.9463)	35.0%
BDPDM	-0.2019	-0.6488	-0.3265	-0.0886	0.0431	0.2079	
	(0.6714)	(0.1864)	(0.4553)	(0.8029)	(0.9208)	(0.9682)	2.8%
SDPDM	0.8544	-0.4091	-0.1398	0.1782	0.7167	2.5764	
	(0.5408)	(0.0041)	(0.2069)	(0.6187)	(0.8459)	(0.9278)	12.6%
BCLA	-0.0094	-0.0892	-0.0370	-0.0148	0.0094	0.0638	
	(0.3145)	(0.0002)	(0.0174)	(0.1696)	(0.6018)	(0.8388)	32.2%
ACLA							
ΔBBB	3.9576	-0.2229	0.0892	0.5066	3.4305	13.5576	
	(0.3975)	(0.0035)	(0.0913)	(0.4108)	(0.6805)	(0.8494)	18.9%
ΔBAB							
ΔSBBB	0.1126	0.0184	0.0480	0.0998	0.1537	0.2163	
	(0.1579)	(0.0000)	(0.0000)	(0.0000)	(0.1495)	(0.7020)	69.2%
ΔSBAB							
BBRE	0.5302	-12.152	-0.1701	0.0000	0.0110	0.5859	
	(0.6462)	(0.0852)	(0.3826)	(0.7180)	(0.9377)	(0.9802)	6.3%
BARE							
R^2	0.0451	0.0038	0.0085	0.0229	0.0563	0.1048	

Notes:

(i) The variable groups are from top to bottom: intercept, endogenous, transactions, activity, limit order book and regional. Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of coefficients (top row) and the distribution of p-values (bottom row, in parentheses).

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

Exhibit VI
Unconditional Model Results
Ask Depth Equation

Variable	Mean	10%	25%	Median	75%	90%	Signif
Intercept	0.0910	-0.0125	0.0221	0.0588	0.1172	0.2661	
	(0.3780)	(0.0033)	(0.0877)	(0.3210)	(0.6190)	(0.8515)	21.7%
ΔB							
ΔA	17.7789	-9.3639	-0.4528	9.2011	25.6725	68.9013	
	(0.4285)	(0.0096)	(0.0991)	(0.4042)	(0.7408)	(0.8996)	17.5%
ΔBD	0.0412	-0.1814	-0.0500	0.0188	0.0147	0.3429	
	(0.5910)	(0.1434)	(0.3303)	(0.6521)	(0.8486)	(0.9591)	4.9%
ΔAD							
BTV	-0.0738	-0.2824	-0.1254	-0.0433	-0.0011	0.0386	
	(0.3721)	(0.0000)	(0.0009)	(0.2033)	(0.7237)	(0.9116)	39.9%
STV	-0.0033	-0.0424	-0.0141	-0.0026	0.0088	0.0277	
	(0.6681)	(0.1912)	(0.4457)	(0.7900)	(0.9135)	(0.9649)	3.5%
BDPDM	0.7006	-0.7046	-0.1204	0.1419	0.5577	1.8287	
	(0.5078)	(0.0148)	(0.1524)	(0.5745)	(0.8237)	(0.9085)	17.5%
SDPDM	-0.1316	-0.7749	-0.2206	-0.0008	0.0732	0.2991	
	(0.6571)	(0.2080)	(0.4147)	(0.7227)	(0.9089)	(0.9752)	2.8%
BCLA							
ACLA	-0.0322	-0.1421	-0.0870	-0.0327	-0.0080	0.0230	
	(0.2487)	(0.0000)	(0.0007)	(0.0953)	(0.4945)	(0.7103)	44.8%
ΔBBB							
ΔBAB	-3.6149	-7.9270	-2.1638	-0.4520	-0.0775	0.1007	
	(0.3582)	(0.0022)	(0.0315)	(0.2496)	(0.6789)	(0.8763)	26.6%
ΔSBBB							
ΔSBAB	0.1150	0.0342	0.0547	0.1023	0.1679	0.2547	
	(0.0954)	(0.0000)	(0.0000)	(0.0000)	(0.0371)	(0.3615)	77.6%
BBRE							
BARE	0.7103	-3.9762	-0.0590	-0.0035	0.0032	0.2002	
	(0.6617)	(0.1285)	(0.4616)	(0.7513)	(0.9149)	(0.9664)	7.0%
R^2	0.0460	0.0050	0.0104	0.0249	0.0511	0.1131	

Notes:

(i) The variable groups are from top to bottom: intercept, endogenous, transactions, activity, limit order book and regional. Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of coefficients (top row) and the distribution of p-values (bottom row, in parentheses).

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

Exhibit VII
Conditional Results Based on Proximity to the Book
Bid Price Equation

Variable	Mean	10%	25%	Median	75%	90%	Signif
Intercept	0.0019	-0.0012	0.0001	0.0012	0.0026	0.0048	
	(0.3345)	(0.0000)	(0.0310)	(0.2231)	(0.5823)	(0.8764)	29.4%
ΔA	0.3356	0.0497	0.1495	0.2866	0.4326	0.6597	
	(0.1857)	(0.0000)	(0.0000)	(0.0264)	(0.3176)	(0.7567)	55.9%
ΔBD	-0.0053	-0.0234	-0.0100	-0.0026	0.0023	0.0114	
	(0.4400)	(0.0242)	(0.1251)	(0.4535)	(0.6970)	(0.8979)	15.4%
BTV	-0.0002	-0.0017	-0.0004	0.0000	0.0002	0.0012	
	(0.6607)	(0.2272)	(0.5027)	(0.7335)	(0.8843)	(0.9457)	4.2%
STV	-0.0004	-0.0028	-0.0006	0.0000	0.0003	0.0017	
	(0.5506)	(0.0506)	(0.2802)	(0.6089)	(0.8234)	(0.9517)	9.8%
BDPDM	-0.0056	-0.0074	-0.0034	-0.0004	0.0031	0.0085	
	(0.6305)	(0.1098)	(0.4110)	(0.7038)	(0.9061)	(0.9686)	4.9%
SDPDM	-0.0196	-0.0412	-0.0330	-0.0168	-0.0031	0.0019	
	(0.3459)	(0.0000)	(0.0020)	(0.1619)	(0.7364)	(0.9042)	42.7%
BCLA	-0.0014	-0.0031	-0.0011	-0.0002	0.0000	0.0006	
	(0.3431)	(0.0011)	(0.0411)	(0.2825)	(0.6198)	(0.7897)	26.6%
ΔBBB1	0.0671	0.0091	0.0183	0.0460	0.0997	0.1734	
	(0.0942)	(0.0000)	(0.0000)	(0.0000)	(0.0588)	(0.3047)	74.8%
ΔBBB2	0.0927	0.0000	0.0029	0.0226	0.0725	0.2146	
	(0.2345)	(0.0000)	(0.0047)	(0.0863)	(0.4687)	(0.6866)	38.5%
BBBFR	0.0211	-0.0131	-0.0014	0.0042	0.0263	0.0615	
	(0.4150)	(0.0023)	(0.0546)	(0.3861)	(0.7006)	(0.9251)	22.4%
ΔSBBB	0.0007	-0.0020	-0.0005	0.0001	0.0007	0.0029	
	(0.4889)	(0.0387)	(0.1850)	(0.4886)	(0.7753)	(0.9450)	11.9%
BBRE	-0.1271	-0.5247	-0.2520	-0.0006	0.0000	0.0001	
	(0.4466)	(0.0000)	(0.0011)	(0.3993)	(0.8602)	(0.9578)	30.1%
R^2	0.1048	0.0087	0.0371	0.0795	0.1415	0.2333	

Notes:

(i) Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of coefficients and the distribution of p-values.

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

Exhibit VIII
Conditional Results Based on Proximity to the Book
Ask Price Equation

Variable	Mean	10%	25%	Median	75%	90%	Signif
Intercept	-0.0027	-0.0033	-0.0024	-0.0010	0.0000	0.0011	
	(0.4380)	(0.0007)	(0.1011)	(0.4599)	(0.6915)	(0.8824)	22.4%
ΔB	0.3178	0.0404	0.1280	0.2570	0.4441	0.6141	
	(0.2010)	(0.0000)	(0.0001)	(0.0251)	(0.3251)	(0.7432)	53.1%
ΔAD	0.0022	-0.0187	-0.0044	0.0015	0.0106	0.0211	
	(0.4479)	(0.0309)	(0.1525)	(0.4064)	(0.7741)	(0.9190)	14.7%
BTV	0.0016	-0.0017	-0.0002	0.0002	0.0009	0.0047	
	(0.5347)	(0.0225)	(0.2470)	(0.6055)	(0.8293)	(0.9242)	12.6%
STV	0.0000	-0.0012	-0.0003	0.0000	0.0003	0.0012	
	(0.6647)	(0.2027)	(0.4584)	(0.7426)	(0.8931)	(0.9589)	2.8%
BDPDM	0.0226	-0.0062	0.0003	0.0138	0.0291	0.0452	
	(0.3764)	(0.0000)	(0.0031)	(0.3507)	(0.7135)	(0.9083)	36.4%
SDPDM	0.0021	-0.0093	-0.0031	0.0010	0.0045	0.0099	
	(0.6107)	(0.1545)	(0.3889)	(0.6754)	(0.8734)	(0.9593)	3.5%
ACLA	0.0024	-0.0008	0.0000	0.0004	0.0013	0.0031	
	(0.3390)	(0.0001)	(0.0067)	(0.2419)	(0.6427)	(0.8429)	34.3%
ΔBAB1	0.0517	0.0041	0.0151	0.0383	0.0766	0.1262	
	(0.1165)	(0.0000)	(0.0000)	(0.0001)	(0.0678)	(0.4682)	72.0%
ΔBAB2	0.0598	-0.0024	0.0006	0.0167	0.0514	0.1207	
	(0.3065)	(0.0001)	(0.0045)	(0.1001)	(0.5712)	(0.8481)	37.8%
BABFR	-0.0130	-0.0355	-0.0113	-0.0011	0.0064	0.0166	
	(0.4824)	(0.0051)	(0.1987)	(0.5081)	(0.8002)	(0.9200)	12.6%
ΔSBAB	0.0010	-0.0024	-0.0008	0.0000	0.0008	0.0035	
	(0.4843)	(0.0357)	(0.1803)	(0.5118)	(0.7523)	(0.9160)	11.9%
BARE	0.0820	0.0000	0.0001	0.0010	0.0165	0.4983	
	(0.4044)	(0.0000)	(0.0202)	(0.3131)	(0.8004)	(0.9522)	27.3%
R^2	0.0887	0.0076	0.0276	0.0617	0.1135	0.1906	

Notes:

(i) Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of coefficients and the distribution of p-values.

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

Exhibit IX
Conditional Results Based on Proximity to the Book
Bid Depth Equation

Variable	Mean	10%	25%	Median	75%	90%	Signif
Intercept	0.0532	-0.0280	0.0053	0.0403	0.0982	0.1792	
	(0.4462)	(0.0200)	(0.1273)	(0.4943)	(0.7365)	(0.8823)	17.5%
ΔB	-11.656	-105.77	-29.570	-8.3120	-0.3148	4.1651	
	(0.3900)	(0.0036)	(0.0701)	(0.3440)	(0.7002)	(0.9027)	20.3%
ΔAD	0.1146	-0.0940	-0.0112	0.0458	0.1932	0.4259	
	(0.4982)	(0.0632)	(0.2296)	(0.4975)	(0.7837)	(0.9350)	7.7%
BTV	-0.0017	-0.0365	-0.0135	-0.0008	0.0141	0.0498	
	(0.6703)	(0.2286)	(0.4856)	(0.7599)	(0.9059)	(0.9579)	4.2%
STV	-0.0502	-0.1840	-0.0794	-0.0230	0.0023	0.0446	
	(0.3958)	(0.0000)	(0.0020)	(0.3015)	(0.7856)	(0.9493)	37.1%
BDPDM	-0.2103	-0.7764	-0.3252	-0.0849	0.0121	0.1056	
	(0.6434)	(0.1435)	(0.4027)	(0.7491)	(0.9047)	(0.9698)	4.2%
SDPDM	0.9251	-0.3368	-0.0838	0.1693	0.9006	2.4525	
	(0.4697)	(0.0008)	(0.0973)	(0.4761)	(0.8252)	(0.9291)	21.0%
BCLA	-0.0171	-0.0822	-0.0379	-0.0186	0.0019	0.0539	
	(0.2704)	(0.0000)	(0.0121)	(0.0852)	(0.5563)	(0.7733)	42.0%
ΔBBB	4.8172	-0.0877	0.0220	0.5845	3.1529	17.9610	
	(0.4187)	(0.0121)	(0.1069)	(0.4133)	(0.7316)	(0.8620)	16.1%
BBBFR	0.3917	-0.6112	-0.2964	-0.0163	0.1613	1.1061	
	(0.4659)	(0.0130)	(0.1568)	(0.4916)	(0.7465)	(0.8930)	13.3%
ΔSBBB1	0.1187	0.0275	0.0554	0.1108	0.1678	0.2128	
	(0.1120)	(0.0000)	(0.0000)	(0.0000)	(0.0325)	(0.5929)	77.6%
ΔSBBB2	0.1617	-0.0963	-0.0135	0.0161	0.0830	0.2547	
	(0.4849)	(0.0192)	(0.1269)	(0.5293)	(0.7980)	(0.9161)	16.8%
BBRE	1.9123	-8.5034	-0.0436	0.0000	0.0244	2.5535	
	(0.6366)	(0.0828)	(0.3756)	(0.7512)	(0.9421)	(0.9775)	6.3%
R^2	0.0536	0.0062	0.0115	0.0289	0.0785	0.1147	

Notes:

(i) Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of coefficients and the distribution of p-values.

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

Exhibit X
Conditional Results Based on Proximity to the Book
Ask Depth Equation

Variable	Mean	10%	25%	Median	75%	90%	Signif
Intercept	0.0797	-0.0135	0.0252	0.0673	0.1220	0.2082	
	(0.3177)	(0.0047)	(0.0489)	(0.2182)	(0.5317)	(0.8597)	25.2%
ΔA	9.6054	-4.6417	0.0926	5.2027	22.2956	49.3821	
	(0.4049)	(0.0042)	(0.0916)	(0.3344)	(0.6716)	(0.9011)	22.4%
ΔBD	0.0288	-0.1409	-0.0314	0.0245	0.1076	0.2142	
	(0.5405)	(0.0963)	(0.2732)	(0.5208)	(0.8507)	(0.9563)	6.3%
BTV	-0.0660	-0.2804	-0.1076	-0.0385	0.0016	0.0240	
	(0.3617)	(0.0000)	(0.0005)	(0.1561)	(0.7511)	(0.9214)	42.0%
STV	-0.0065	-0.0374	-0.0204	-0.0033	0.0067	0.0253	
	(0.6445)	(0.1885)	(0.3871)	(0.7454)	(0.9040)	(0.9706)	4.9%
BDPDM	0.8833	-0.2121	-0.0302	0.1903	0.6740	2.4229	
	(0.4801)	(0.0061)	(0.0826)	(0.5473)	(0.7813)	(0.9412)	21.7%
SDPDM	-0.1102	-0.6614	-0.2466	-0.0248	0.0572	0.2296	
	(0.6449)	(0.1769)	(0.3719)	(0.7422)	(0.9232)	(0.9718)	4.9%
ACLA	-0.0297	-0.1203	-0.0686	-0.0332	-0.0058	0.0374	
	(0.2112)	(0.0000)	(0.0004)	(0.0412)	(0.3366)	(0.7287)	51.7%
ΔBAB	-3.3481	-6.1300	-1.8475	-0.3661	-0.0437	0.0984	
	(0.3553)	(0.0077)	(0.0419)	(0.2579)	(0.6154)	(0.8615)	27.3%
BABFR	-0.0308	-0.5754	-0.3094	-0.0523	0.0676	0.4135	
	(0.5354)	(0.0477)	(0.2096)	(0.6021)	(0.8138)	(0.9446)	9.1%
ΔSBAB1	0.1227	0.0438	0.0655	0.1134	0.1767	0.2489	
	(0.0578)	(0.0000)	(0.0000)	(0.0000)	(0.0075)	(0.2228)	85.3%
ΔSBAB2	0.1084	-0.0300	0.0000	0.0308	0.1059	0.2580	
	(0.4820)	(0.0303)	(0.2531)	(0.5051)	(0.7386)	(0.9085)	12.6%
BARE	0.9845	-1.4313	-0.0278	-0.0019	0.0093	1.2392	
	(0.6546)	(0.1347)	(0.3891)	(0.7734)	(0.9281)	(0.9721)	8.4%
R^2	0.0522	0.0073	0.0143	0.0287	0.0631	0.1161	

Notes:

(i) Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of coefficients and the distribution of p-values.

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

Exhibit XI
Results Conditional on Trading Volume Deciles
Bid Price Equation

Variable	Decile	Mean β	Mean p-val	10% β	10% p-val	Median β	Median p-val	90% β	90% p-val	% Signif
Intercept	1	0.0014	0.1376	0.0001	0.0000	0.0019	0.0000	0.0050	0.7428	73.3
	5	0.0020	0.4188	0.0002	0.0011	0.0013	0.4696	0.0040	0.7749	21.4
	10	0.0144	0.5196	-0.0005	0.1430	0.0062	0.5930	0.0394	0.7920	7.7
ΔA	1	0.2646	0.1488	0.0802	0.0000	0.1718	0.0297	0.6554	0.4190	60.0
	5	0.3872	0.2554	0.0819	0.0000	0.2942	0.0766	0.8977	0.7558	50.0
	10	0.1010	0.4770	-0.5635	0.0111	0.1745	0.5284	0.5089	0.9397	15.4
ΔBD	1	0.0056	0.3851	-0.0249	0.0035	-0.0015	0.3031	0.0616	0.8156	20.0
	5	-0.0214	0.3944	-0.0666	0.0820	-0.0121	0.3488	0.0021	0.7860	7.1
	10	-0.0662	0.6721	-0.9287	0.2097	-0.0090	0.7880	0.5806	0.8968	0.0
BTV	1	0.0002	0.4430	-0.0002	0.0352	0.0000	0.4758	0.0014	0.8522	13.3
	5	-0.0003	0.6747	-0.0009	0.0818	-0.0003	0.8190	0.0000	0.9570	0.0
	10	-0.0040	0.8571	-0.0140	0.6940	-0.0024	0.9161	0.0010	0.9761	0.0
STV	1	0.0015	0.3410	-0.0007	0.0025	-0.0002	0.2763	0.0024	0.8533	26.7
	5	-0.0001	0.6921	-0.0015	0.2250	0.0000	0.7955	0.0004	0.9719	0.0
	10	0.0023	0.7454	-0.0150	0.5632	-0.0009	0.7969	0.0057	0.9057	0.0
BDPDM	1	-0.0001	0.4721	-0.0049	0.0767	0.0002	0.5318	0.0089	0.9402	6.7
	5	0.0014	0.6850	-0.0069	0.1774	0.0008	0.7460	0.0098	0.9706	0.0
	10	-0.0506	0.8155	-0.0761	0.5137	-0.0043	0.9044	0.0046	0.9718	0.0
SDPDM	1	-0.0544	0.3065	-0.1101	0.0000	-0.0352	0.1092	-0.0015	0.8743	33.3
	5	-0.0194	0.3840	-0.0347	0.0000	-0.0127	0.3186	0.0000	0.9959	21.4
	10	-0.0018	0.7945	-0.0239	0.6079	-0.0071	0.8625	0.0133	0.9263	0.0
BCLA	1	-0.0003	0.2675	-0.0011	0.0023	0.0000	0.1187	0.0002	0.8158	33.3
	5	-0.0010	0.3000	-0.0041	0.0050	-0.0004	0.2014	0.0003	0.7493	35.7
	10	-0.0358	0.5778	-0.1565	0.3585	-0.0010	0.5672	0.0037	0.8221	0.0
ΔBBB	1	0.0383	0.1667	0.0017	0.0000	0.0379	0.0000	0.0825	0.7119	66.7
	5	0.0300	0.1715	0.0046	0.0000	0.0209	0.0001	0.0825	0.6570	64.3
	10	0.0936	0.3835	0.0122	0.0000	0.0653	0.0959	0.2017	0.9874	46.2
ΔSBBB	1	-0.0003	0.3685	-0.0037	0.0683	0.0001	0.4048	0.0018	0.8168	6.7
	5	0.0011	0.5652	-0.0007	0.2307	0.0000	0.5666	0.0032	0.8803	7.1
	10	0.0052	0.6288	-0.0206	0.2460	0.0013	0.7288	0.0387	0.9684	0.0
BBRE	1	-0.4640	0.0704	-0.6589	0.0000	-0.4986	0.0000	-0.0084	0.0379	93.3
	5	-0.0219	0.6238	-0.0853	0.0072	-0.0002	0.6974	0.0005	0.9837	21.4
	10	-0.1279	0.4991	-0.6252	0.0038	0.0000	0.5910	0.0000	0.9816	15.4
R^2	1	0.1033		0.0015		0.1098		0.2161		
	5	0.1198		0.0140		0.0539		0.3568		
	10	0.1105		0.0027		0.0774		0.3149		

Notes:

(i) Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of the coefficients and the p-values.

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

(iv) Decile 1 (10) contains stocks with the highest (lowest) average daily trading volume.

Exhibit XII
Results Conditional on Trading Volume Deciles
Ask Price Equation

Variable	Decile	Mean β	Mean p-val	10% β	10% p-val	Median β	Median p-val	90% β	90% p-val	% Signif
Intercept	1	0.0002	0.2060	-0.0034	0.0000	-0.0010	0.0161	0.0003	0.7238	60.0
	5	-0.0008	0.6150	-0.0026	0.2351	-0.0004	0.6549	0.0010	0.9795	0.0
	10	-0.0193	0.6065	-0.0247	0.4012	-0.0022	0.5966	0.0019	0.8698	0.0
ΔB	1	0.2113	0.2018	0.0134	0.0000	0.1540	0.0013	0.3955	0.7279	60.0
	5	0.4030	0.2036	0.1956	0.0000	0.2619	0.0555	1.0388	0.5014	50.0
	10	0.4947	0.3455	-0.0792	0.0197	0.3511	0.2474	1.1281	0.8463	15.4
ΔAD	1	0.0048	0.3712	-0.0081	0.0058	0.0015	0.2890	0.0133	0.8680	26.7
	5	0.0121	0.5355	-0.0214	0.3205	0.0112	0.5135	0.0390	0.8420	7.1
	10	-0.0340	0.6736	-0.3031	0.4652	-0.0064	0.6432	0.2341	0.8776	0.0
BTV	1	0.0002	0.3692	-0.0008	0.0021	0.0003	0.3689	0.0013	0.8502	33.3
	5	0.0014	0.6505	-0.0015	0.1564	0.0000	0.7624	0.0058	0.9901	0.0
	10	0.0001	0.7439	-0.0284	0.5586	-0.0038	0.7738	0.0094	0.8914	0.0
STV	1	-0.0001	0.5157	-0.0002	0.0990	0.0000	0.5428	0.0002	0.8832	6.7
	5	0.0001	0.7768	-0.0007	0.3794	0.0000	0.8640	0.0010	0.9927	0.0
	10	0.0024	0.8125	-0.0068	0.5620	0.0005	0.8675	0.0135	0.9879	0.0
BDPDM	1	0.0304	0.3455	0.0017	0.0000	0.0181	0.2074	0.0980	0.8303	26.7
	5	0.0145	0.4854	-0.0031	0.0000	0.0067	0.5373	0.0516	0.9523	35.7
	10	0.0803	0.6970	-0.0223	0.3442	-0.0019	0.8001	0.0717	0.9460	7.7
SDPDM	1	0.0013	0.5371	-0.0063	0.0222	0.0015	0.5008	0.0066	0.9494	13.3
	5	-0.0017	0.6839	-0.0109	0.2431	0.0000	0.7328	0.0054	0.9489	0.0
	10	0.0164	0.8673	-0.0117	0.6145	-0.0003	0.9022	0.1132	0.9902	0.0
ACLA	1	-0.0004	0.1998	-0.0007	0.0000	0.0001	0.0104	0.0007	0.5142	60.0
	5	0.0010	0.5002	-0.0010	0.1329	0.0004	0.5090	0.0034	0.8176	7.1
	10	0.0280	0.4369	-0.0041	0.0746	0.0330	0.4488	0.0895	0.7781	7.7
ΔBAB	1	0.0408	0.1594	0.0124	0.0000	0.0397	0.0000	0.0752	0.4915	66.7
	5	0.0159	0.1859	-0.0063	0.0000	0.0138	0.0258	0.0526	0.5435	57.1
	10	0.0334	0.3514	0.0031	0.0042	0.0208	0.2326	0.0686	0.8827	30.8
ΔSBAB	1	-0.0002	0.3959	-0.0010	0.0198	-0.0002	0.3607	0.0010	0.8771	26.7
	5	-0.0007	0.5772	-0.0036	0.0214	-0.0003	0.6949	0.0024	0.8782	14.3
	10	0.0144	0.5565	-0.0770	0.2316	0.0077	0.5280	0.0768	0.8539	0.0
BARE	1	0.2825	0.1175	0.0005	0.0000	0.0856	0.0006	0.6394	0.2996	66.7
	5	-0.0169	0.6113	-0.0005	0.3693	0.0003	0.6257	0.0051	0.9660	7.1
	10	0.0808	0.6896	0.0000	0.0167	0.0000	0.8105	0.0574	0.9695	7.7
R^2	1	0.0687		0.0029		0.0248		0.1550		
	5	0.0675		0.0090		0.0355		0.2536		
	10	0.0751		0.0054		0.0460		0.1557		

Notes:

(i) Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of the coefficients and the p-values.

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

(iv) Decile 1 (10) contains stocks with the highest (lowest) average daily trading volume.

Exhibit XIII
Results Conditional on Trading Volume Deciles
Bid Depth Equation

Variable	Decile	Mean β	Mean p-val	10% β	10% p-val	Median β	Median p-val	90% β	90% p-val	% Signif
Intercept	1	0.1826	0.2720	0.0228	0.0001	0.1274	0.1614	0.3686	0.7528	40.0
	5	0.0029	0.5914	-0.1896	0.2836	0.0142	0.6470	0.2489	0.8681	7.1
	10	-0.0120	0.6700	-0.2441	0.3932	-0.0152	0.6942	0.2248	0.8630	0.0
ΔB	1	-85.458	0.2199	-159.06	0.0003	-59.734	0.1731	3.1201	0.5012	40.0
	5	-9.1221	0.3790	-39.653	0.0258	-14.532	0.3421	-2.6566	0.7373	14.3
	10	-6.8758	0.5390	-49.696	0.1269	-0.8924	0.5729	31.9552	0.8633	7.7
ΔAD	1	0.0281	0.4612	-0.0890	0.0625	0.0151	0.3430	0.1236	0.9197	6.7
	5	0.2141	0.5038	-0.1812	0.1503	0.0881	0.5270	0.5383	0.8413	0.0
	10	0.3730	0.5265	-1.0267	0.1318	0.1307	0.4737	1.5077	0.8792	7.7
BTV	1	-0.0068	0.4400	-0.0277	0.0143	-0.0057	0.3595	0.0111	0.8437	13.3
	5	0.0275	0.7708	-0.0079	0.2228	-0.0008	0.8827	0.0783	0.9745	0.0
	10	-0.0377	0.8059	-0.1497	0.6042	-0.0096	0.8636	0.0552	0.9851	0.0
STV	1	-0.1031	0.0005	-0.1893	0.0000	-0.0974	0.0000	-0.0283	0.0002	100.0
	5	-0.0339	0.6093	-0.0674	0.0315	-0.0019	0.6974	0.0093	0.9655	21.4
	10	0.0479	0.7315	-0.0479	0.3727	0.0171	0.8457	0.1644	0.9204	0.0
BDPDM	1	-0.1116	0.5032	-1.4799	0.0646	-0.0270	0.6013	1.5029	0.8596	0.0
	5	-0.3821	0.6946	-0.4130	0.1191	-0.0786	0.7677	0.0483	0.9943	7.1
	10	-0.0650	0.8339	-0.3613	0.5979	-0.0892	0.9208	0.1575	0.9637	0.0
SDPDM	1	3.2848	0.2042	0.3088	0.0000	1.5188	0.2234	5.9405	0.4996	40.0
	5	0.4248	0.5213	-0.6832	0.0091	-0.0940	0.6287	2.5764	0.8783	14.3
	10	-0.3207	0.8163	-0.9081	0.6187	-0.0866	0.8402	0.1370	0.9430	0.0
BCLA	1	-0.0290	0.0616	-0.0370	0.0000	-0.0214	0.0153	-0.0035	0.1943	60.0
	5	-0.0389	0.3232	-0.1386	0.0123	-0.0121	0.2149	0.0154	0.8022	28.6
	10	0.1280	0.6238	-0.0191	0.0803	0.0321	0.7309	0.5502	0.9379	7.7
ΔBBB	1	3.1861	0.3294	-0.0933	0.0000	2.3539	0.3655	7.8037	0.7486	33.3
	5	10.8054	0.3976	-0.0033	0.0392	0.2871	0.3260	23.0776	0.8321	21.4
	10	0.1221	0.5537	-0.7730	0.1185	0.0419	0.6058	5.6226	0.9716	7.7
ΔSBBB	1	0.0652	0.0009	0.0435	0.0000	0.0667	0.0000	0.0823	0.0050	100.0
	5	0.0758	0.1884	0.0071	0.0000	0.0766	0.0296	0.1482	0.8864	64.3
	10	0.1372	0.3675	-0.0301	0.0008	0.1309	0.2791	0.3579	0.9284	23.1
BBRE	1	-17.241	0.3139	-67.275	0.0022	-9.3581	0.0852	14.3840	0.8773	33.3
	5	25.0085	0.7033	-13.884	0.3328	-0.0008	0.7300	0.0578	0.9871	7.1
	10	0.7153	0.7781	-1.7986	0.4365	0.0000	0.8750	0.0099	0.9613	0.0
R^2	1	0.0260		0.0019		0.0150		0.0802		
	5	0.0232		0.0015		0.0115		0.0761		
	10	0.0371		0.0069		0.0307		0.0704		

Notes:

(i) Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of the coefficients and the p-values.

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

(iv) Decile 1 (10) contains stocks with the highest (lowest) average daily trading volume.

Exhibit XIV
Results Conditional on Trading Volume Deciles
Ask Depth Equation

Variable	Decile	Mean β	Mean p-val	10% β	10% p-val	Median β	Median p-val	90% β	90% p-val	% Signif
Intercept	1	0.2599	0.2054	-0.0125	0.0000	0.1443	0.0012	0.6408	0.6297	60.0
	5	-0.0175	0.3999	-0.0535	0.1926	0.0301	0.2866	0.1182	0.7466	7.1
	10	0.0383	0.5058	-0.0755	0.1104	-0.0097	0.4579	0.0936	0.8002	7.7
ΔA	1	120.482	0.2072	-65.079	0.0000	47.222	0.1440	570.486	0.5537	40.0
	5	10.8202	0.5091	-3.2328	0.1230	7.8240	0.4848	24.5809	0.9335	0.0
	10	7.3449	0.5740	-2.2579	0.2180	0.0533	0.4758	34.7708	0.9102	0.0
ΔBD	1	0.0508	0.5691	-0.0963	0.0473	0.0180	0.6529	0.2752	0.9274	13.3
	5	-0.1000	0.5622	-0.2414	0.1590	-0.0011	0.5331	0.5368	0.9769	7.1
	10	0.1478	0.4519	-0.4398	0.0705	0.0147	0.3590	0.7778	0.8632	7.7
BTV	1	-0.1426	0.0247	-0.3002	0.0000	-0.1265	0.0000	-0.0249	0.0055	93.3
	5	-0.0404	0.4947	-0.0922	0.0040	-0.0100	0.5878	-0.0217	0.9116	28.6
	10	0.0387	0.6665	-0.1352	0.4828	0.0254	0.7172	0.1538	0.9125	7.7
STV	1	-0.0071	0.4418	-0.0424	0.0769	-0.0081	0.4325	0.0210	0.8869	6.7
	5	-0.0014	0.7371	-0.0137	0.4780	-0.0017	0.7901	0.0146	0.9791	0.0
	10	0.0334	0.7634	-0.0256	0.4837	0.0109	0.8536	0.1605	0.9401	0.0
BDPDM	1	2.5480	0.2034	-1.5138	0.0000	2.2297	0.0313	9.4155	0.7467	60.0
	5	0.1761	0.6088	-0.5636	0.2954	0.1254	0.5926	0.7825	0.9545	0.0
	10	-0.1873	0.7355	-1.2872	0.5023	-0.0207	0.7885	0.2955	0.9116	0.0
SDPDM	1	-0.5786	0.4868	-2.1121	0.1184	-0.4675	0.5037	0.4641	0.8489	0.0
	5	0.0273	0.7556	-0.2086	0.5273	0.0464	0.7880	0.2537	0.9331	0.0
	10	-0.0479	0.7713	-0.5583	0.4147	0.0115	0.8758	0.0854	0.9271	0.0
ACLA	1	-0.0609	0.1215	-0.1625	0.0000	-0.0306	0.0001	-0.0010	0.5370	73.3
	5	-0.0393	0.2923	-0.1169	0.0003	-0.0290	0.0595	0.0171	0.8197	50.0
	10	-0.0068	0.2753	-0.4493	0.0004	-0.0173	0.1528	0.3791	0.7026	38.5
ΔBAB	1	-6.0733	0.3079	-24.806	0.0000	-1.5895	0.0512	0.1007	0.8866	46.7
	5	-0.7040	0.4305	-1.0697	0.0263	-0.1523	0.3927	0.7058	0.8763	14.3
	10	-0.9359	0.5121	-5.4238	0.1806	-0.0775	0.4628	0.0217	0.9624	0.0
ΔSBAB	1	0.9046	0.0235	0.0585	0.0000	0.0747	0.0000	0.1487	0.0163	93.3
	5	0.1036	0.1866	0.0131	0.0000	0.0946	0.0108	0.1936	0.4905	64.3
	10	0.1603	0.2453	0.0217	0.0003	0.1639	0.1084	0.2653	0.5840	38.5
BARE	1	-22.176	0.4246	-19.744	0.0013	-0.1226	0.6008	20.0890	0.7674	26.7
	5	-0.7472	0.8006	-3.9762	0.4081	-0.0012	0.8779	0.0187	0.9828	0.0
	10	0.0289	0.9059	-0.0227	0.6928	0.0000	0.9349	0.0057	0.9914	0.0
R^2	1	0.0196		0.0024		0.0119		0.0498		
	5	0.0225		0.0034		0.0173		0.0536		
	10	0.0732		0.0043		0.0511		0.2209		

Notes:

(i) Quantities are denominated in units of 1,000 shares. Prices are denominated in dollars. For a more complete explanation of the variable definitions see Exhibit II.

(ii) For each explanatory variable, information is provided on the distribution of the coefficients and the p-values.

(iii) The last column labeled Signif. reports the percentage of stocks in the sample having coefficient estimates that are significant at the 5% level.

(iv) Decile 1 (10) contains stocks with the highest (lowest) average daily trading volume.