THE JOURNAL OF FINANCE • VOL. LV, NO. 4 • AUGUST 2000

Friction

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ABSTRACT

The sources of trading friction are studied, and simple, robust empirical measures of friction are provided. Seven distinct measures of trading friction are computed from transactions data for 1,706 NYSE/AMSE stocks and 2,184 Nasdaq stocks. The measures provide insights into the magnitude of trading costs, the importance of informational versus real frictions, and the role of market structure. The degree to which the various measures are associated with each other and with trading characteristics of stocks is examined.

THIRTY YEARS AGO, friction in financial markets was largely ignored in the theory of finance. The then modern finance paradigm rested on the abstractions of frictionless and efficient markets–useful abstractions but abstractions nevertheless. In the ensuing 30 years, study of the microstructure of markets has become an important research area, a result of the availability of transaction data, regulatory interest in markets, and theoretical development in the field of asymmetric information.

My objective is to review our understanding of friction and to look for simple and robust empirical regularities in the measurement of trading friction. What is friction? What are its sources? How is trading friction measured? What is the magnitude of friction by alternative measures? To what extent are different measures of friction correlated? How are alternative friction measures related to characteristics of markets and of securities?

This effort is important, I believe, not only because it consolidates some of the empirical research in microstructure but also because it provides evidence about the different sources of friction and their relation. If we are to relate friction to asset pricing, it is important to understand how friction may be measured. If we wish to improve markets, we must understand the sources of friction in markets.

I. What Is Friction?

Friction in financial markets measures the difficulty with which an asset is traded. Friction could be measured by how long it takes optimally to trade a given amount of an asset (Lippman and McCall (1986)). Alternatively, friction

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1999

can be measured by the price concession needed for an immediate transaction (Demsetz, (1968)). The two approaches converge because the immediate price concession can be viewed as the payment required by another trader, such as a dealer, to buy (or sell) the asset immediately and then dispose of (acquire) the asset according to the optimal policy. I will follow the approach of Demsetz (1968), which is to view friction as the price concession paid for immediacy.

A. The Price of Immediacy

Suppliers of immediacy, such as market makers, are passive traders who stand ready to trade at prices they quote. The demanders of immediacy are active traders who place market orders to trade immediately. Immediate sales are usually made at the bid price, and immediate purchases are usually made at the ask price. The spread between the bid and the ask is one measure of friction. Stoll (1978a) models the source of that spread in the spirit of Demsetz. The cross-sectional relation of spreads to firms' trading characteristics, of the type suggested by Demsetz, is strong and has changed little over time.

Consider the following cross-sectional regression:

$$s = a_0 + a_1 \log V + a_2\sigma^2 + a_3 \log MV + a_4 \log P + a_5 \log N + e \qquad (1)$$

where s is the stock's proportional quoted half-spread defined as 1/2 (ask price − bid price)/P, V is daily dollar volume, σ^2 is the return variance, MV is the stock's market value, P is the stock's closing price, N is the number of trades per day, and e is the error term.[1] The rationale for these variables is based primarily on order processing and inventory considerations. Increases in volume, number of trades, and firm size increase the probability of locating a counterparty, thereby reducing the risk of accepting inventory. The stock's return variance measures the risk of adverse price change of a stock put into inventory.[2] Price controls for the effect of discreteness and is an additional proxy for risk in that low price stocks tend to be riskier.

Table I presents the results of a regression of the form (1) for 1,706 NYSE/AMSE and 2,184 Nasdaq stocks. To reduce errors associated with a single day, averages of each underlying variable are taken across the days in each month before calculating the proportional spread or taking the logarithm. Three months—December 1997, January 1998, and February 1998—are considered. Details of the data procedures are described later in this paper. The results are highly significant and consistent across the months. Over 60 percent of the cross-sectional variance in spreads is explained. The results are consistent with empirical findings of Demsetz (1968), Tinic (1972), Tinic

[1]The relation (1) is only one of several possible formulations. For example, one could take the dollar spread as the dependent variable. Similarly, the independent variables can be expressed in alternative ways. The fundamental variables—share volume, return variance, price, number of trades, and market value—almost always are strongly significant in each formulation.

[2]Stoll (1978a) and Ho and Stoll (1981) show that the variance rather than the systematic risk of a stock is relevant because a supplier of immediacy is not diversified with respect to the unwanted inventory.

Table I

Relation of Quoted Proportional Half-Spread to Trading Characteristics of Stocks

The dependent variable is the proportional half-spread defined as the average half-spread for the month divided by the average closing price. V is average daily dollar volume of trading in the month. σ^2 is variance of stock's daily return in the prior year. MV is stock's market value at the end of November 1997. P is average closing price in the month. N is average number of trades per day in the month.

	December 1997		January 1998		February 1998	
	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value
			Panel A: NYSE/AMSE			
Intercept	0.0207	25.86	0.0206	23.74	0.0202	26.39
Log V	−0.0010	−9.35	−0.0011	−9.77	−0.0010	−10.41
σ^2	1.5467	16.74	1.6562	17.12	1.4533	16.81
Log MV	0.0003	3.56	0.0004	4.67	0.0003	4.68
Log P	−0.0024	−21.15	−0.0025	−21.29	−0.0023	−22.00
Log N	0.0003	2.63	0.0003	1.96	0.0003	2.13
Adj R^2	0.7731		0.7763		0.7914	
Observations	1,706		1,706		1,706	
			Panel B: Nasdaq			
Intercept	0.0384	24.48	0.0379	23.50	0.0352	23.49
Log V	−0.0012	−5.95	−0.0016	−7.94	−0.0014	−7.73
σ^2	0.4908	7.56	0.4850	7.15	0.3511	5.60
Log MV	−0.0003	−2.18	0.0001	0.81	0.0001	1.14
Log P	−0.0020	−9.51	−0.0016	−7.57	−0.0020	−10.00
Log N	−0.0011	−5.60	−0.0011	−4.98	−0.0009	−4.63
Adj R^2	0.6467		0.6588		0.6688	
Observations	2,184		2,184		2,184	

and West (1974), Benston and Hagerman (1974), Branch and Freed (1977), Stoll (1978b), and others. As a matter of empirical regularity, quoted proportional spreads are negatively related to measures of trading activity, such as volume, negatively related to the stock price, and positively related to a stock's volatility. There are some differences by exchange. Nasdaq spreads are higher after controlling for firms' characteristics, and the number of trades and market value play different roles in the two markets.

The first point to be made is that the empirical relation (1) is very strong, particularly with respect to an activity variable such as volume. Few empirical relations in finance are this strong.

B. Real versus Informational Friction

The second point is that we have not reached agreement on the sources of this strong empirical relation. Early writers such as Demsetz assumed the spread reflected payment for services provided by suppliers of immediacy to overcome friction. First, the supply of immediacy, like any business activity, requires real economic resources—labor and capital—to route orders, to execute trades, and to clear and settle trades. These resources must be paid for. Second, suppliers of immediacy assume unwanted inventory risk for which compensation must be provided. A third factor, market power, has long been recognized as a potential source of the spread: dealers with market power will increase the spread relative to their costs. Trading friction, in this approach, is the real resources used up (or extracted as monopoly rents) to accomplish trades. Theoretical papers underlying the real friction view of the spread include Garman (1976), Stoll (1978a), Amihud and Mendelson (1980), Cohen et al. (1981), Ho and Stoll (1981, 1983), and Laux (1995).

Later views of friction relied on informational arguments as in Copeland and Galai (1983), Glosten and Milgrom (1985), and Kyle (1985). Under this view, the spread is the value of the information lost to more timely or better informed traders. The spread does not reflect the cost of real resources required to supply immediacy. Instead, the spread is a measure of the redistribution of wealth from some traders to others. Using the term "friction" for this source of the spread is perhaps a misnomer, as the market mechanism itself is frictionless. The spread exists to provide protection against losses. Under the informational view of the spread, the cross-sectional relation, (1), reflects informational differences across stocks.

The informational view of the spread has two intellectual branches that are often not properly distinguished. One branch views the spread as the value of the free trading option offered by those posting quotes. Because posting and removing quotes takes time, suppliers of immediacy provide free options to speedy traders who can "pick off" quotes if new information warrants a different price from the quoted price. If new information arrives before quotes can be adjusted, the person placing the quote—the limit order investor or the dealer—loses. The spread exists to compensate suppliers of immediacy for the option they grant to the rest of the market. The work of Copeland and Galai (1983) is in this spirit.

The second and more prevalent informational branch assumes the presence of asymmetric information. A supplier of immediacy faces the danger that a bid or ask will be accepted by someone with superior—or adverse—information. Informed traders buy at the ask if they have information justifying a higher price, and they sell at the bid if they have information justifying a lower price. When the information becomes known, informed traders gain at the expense of suppliers of immediacy. The equilibrium spread must at least cover such losses. As Bagehot (1971) first noted, if suppliers of immediacy are to avoid losses, uninformed traders must pay a spread sufficient to compensate suppliers of immediacy for losses to informed investors. The optimal strategy in the presence of information asymmetry and the behavior of prices has been the focus of many important theoretical papers, including Kyle (1985), Easley and O'Hara (1987), Admati and Pfleiderer (1988), and Glosten (1994).

Understanding the sources of the spread is important for policy. If the source of the spread is real friction, improvements in trading systems can narrow the spread. If the source is monopoly rents, increased competition will narrow the spread. If the source is differential delays for some traders vis-à-vis others, improvements in speed and greater parity of traders will reduce spreads. If the source is private information, improvements in disclosure will reduce spreads.

Understanding the source of friction is important for asset pricing.[3] Real frictions must be reflected in lower asset prices so that the return on an asset is sufficient to offset the real cost of trading the asset, adjusted for the holding period. The effect of informational friction on asset prices is less clear because informational friction affects only the distribution of wealth. If informational friction is to have an asset pricing effect, asset prices must depend on uncertainty regarding the distribution of wealth in the economy. Yet, asset pricing models generally take a representative agent approach and do not account for this uncertainty.

Although the potential sources of the spread—whether real frictions or informational frictions—are well understood, measurement of the sources of friction is difficult. How much of the quoted spread is the result of real friction? How much the result of informational friction? Is the cross-sectional relation (1) the result of real or of informational factors? One way of distinguishing the sources of the spread is by examining a stock's short-term price changes in comparison to its spread. Roll (1984) provides a framework for doing this. Important papers that examine the relation between the static quoted spread measure and dynamic friction measures include Hasbrouck (1988, 1991), Glosten and Harris (1988), Choi, Salandro, and Shastri (1988), Stoll (1989), George, Kaul, and Nimalendran (1991), Madhavan and Smidt (1991), Huang and Stoll (1994, 1997), Lin, Sanger, and Booth (1995), and Madhavan, Richardson. and Roomans (1997). Real frictions must be compensated for by trading gains, which are earned from the bid-ask bounce. If, on average, the trade price bounces back to its earlier level after a trade, profits are earned, and one can infer that the spread reflects real frictions such as order-processing costs. Informational trading results in permanent price changes. If there is no bid-ask bounce in transaction prices, one can infer that the spread entirely reflects information factors.

My objective in this paper is to specify alternative empirical measures of friction and examine their magnitude and relation. Some measures, such as the quoted spread, are total measures of friction, including real and informational components. Others reflect primarily real friction. Others reflect primarily informational friction. I examine these measures and compare how they are related to each other and to trading characteristics such as specified in equation (1).

[3] Stoll and Whaley (1983) show that the small firm effect can be explained by transaction costs. Amihud and Mendelson (1986) model the relation of real friction and asset prices. Brennan and Subrahmanyam (1996), Brennan, Chordia, and Subrahmanyam (1998), and Easley, Hvidkjaer and O'Hara (1999) consider the asset pricing effects of different friction measures.

II. A Model of the Spread and Price Change

How should one measure trading friction? The quoted spread is a measure of what a market order must pay when seeking immediate execution. It is a static measure in the sense that it is measured at a moment in time. Another approach is to measure the temporary price change associated with trading. For example, what is the price impact associated with a trade, or how much does the price bounce back after a trade? Such approaches are dynamic—they depend on price changes through time. In fact, suppliers of immediacy earn revenues only dynamically—from favorable changes in the prices of their positions. Conversely, demanders of immediacy pay costs only dynamically—from adverse realized price changes.

To help understand alternative friction measures and their relation, I use the model of Huang and Stoll (1997, p. 1015, eq. (25)) that relates the price change after a trade to the spread:

$$\Delta P_{t+1} = \frac{S}{2}\left[Q_{t+1} - Q_t + \beta Q_t + \alpha(Q_t - Q_t^*)\right] + e_{t+1}, \tag{2}$$

where

ΔP_{t+1} = price change from the trade at t to the trade at $t + 1$,
Q_t = trade indicator variable, taking the value 1 if the trade at time t is at the ask and -1 if the trade is at the bid,
Q_t^* = market's expectation of the trade indicator at time t based on the information available after the trade at $t - 1$ but before the trade at t,
S = spread defined as the ask price less the bid price,
β = fraction of the spread due to inventory costs,
α = fraction of the spread due to adverse information, and
e_{t+1} = serially uncorrelated public information shock.

Under this model, a stock's price change after a trade is related to the spread, S, and to new public information, e_{t+1}. The spread, S, is observable. The fraction β of the spread reflects inventory costs. The fraction α of the spread reflects adverse information effects. The balance, $1 - \alpha - \beta$, reflects order processing and monopoly rents.

In the absence of public information, the price of a security changes for three reasons. First, in the absence of quote changes, prices change as transactions take place either at the bid or the ask. This effect is measured by the term, $Q_{t+1} - Q_t$. Second, prices change because quotes are adjusted in response to the inventory effects of past trades. The term βQ_t represents the inventory motivated adjustment in quotes as a result of the trade at t. Third, prices change because quotes are adjusted in response to the information conveyed by the last trade. The term $\alpha(Q_t - Q_t^*)$ represents the change in the bid or ask price in response to the information conveyed by the unexpected portion of the trade at t.

In the absence of inventory or information effects, when $\alpha = \beta = 0$, quotes would remain constant, and the price change would depend solely on the pattern of order flow, $Q_{t+1} - Q_t$. For example, suppose the bid is \$20 and the ask is \$21, and a trade at t takes place at the bid of \$20. If the next trade takes place at the ask, the observed transaction price change, according to (2) is $(S/2)[Q_{t+1} - Q_t] = 0.5[1 - (-1)] = \$1$. However, if quotes were to fall after the trade at the bid, say to \$19.75 bid and \$20.75 ask, the price change would be \$20.75 − \$20 = \$0.75. (If one assumes that half the trades at $t + 1$ take place at the ask and half at the bid, the average price change would be \$0.5 in the first case and \$0.375 in the second case.)

Price changes associated with order processing, market power, and inventory are transitory. Prices "bounce back" from the bid to the ask (or from the ask to the bid) to yield a profit to the supplier of immediacy. Price changes associated with adverse information are permanent adjustments in the equilibrium price. This difference is helpful in distinguishing the sources of the spread empirically. In general, the bounce back in price after a trade is less than the quoted half-spread because the information conveyed by the trade produces a permanent adjustment in the price.[4]

The model (2) abstracts from market design, yet market design appears to have an effect on friction. Research by Madhavan (1992) and Biais (1993) provides theoretical analyses of dealer versus auction markets. Empirical evidence comparing dealer and auction markets is large, including Christie and Schultz (1994), Christie and Huang (1994), Huang and Stoll (1996b), and Barclay et al. (1999). In this paper, I will also examine the evidence for signs of market structure effects.

III. Data

Data are obtained primarily from the TAQ data set distributed by the NYSE, which contains trade prices, quotes, and shares traded for exchange listed and Nasdaq stocks. The period covered is December 1, 1997, to February 28, 1998, a period of 61 trading days. Certain data are also extracted from CRSP and Compustat. The procedure was to create daily values for each stock for each of the 61 trading days. These daily data are then analyzed. I summarize friction measures by day and consequently ignore important intraday variations first investigated by Wood, McInish, and Ord (1985) for NYSE stocks and Chan, Christie, and Schultz (1995) for Nasdaq issues.

[4] An empirical issue in applying the model (2) is price discreteness. During my sample period the minimum price variation is 1/16. If the model predicts price changes less than that we may not observe them, and sometimes we may observe larger price changes as prices are rounded up or down. Harris (1991), Hausman, Lo, and MacKinlay (1992), and Ball and Chordia (1999) deal with this issue. My approach is to rely on daily averaging and a large sample of stocks to capture basic tendencies.

The initial sample of stocks consisted of all ordinary common shares with ticker symbols on CRSP and on TAQ and traded for the three-month period. Securities such as ADRs and REITs are excluded. Stocks were excluded from this initial sample of 7,144 for the following reasons in the following order:

1.	Closing price below $2 on at least one day	924
2.	Not traded every day	2,176
3.	Undocumented	1
4.	Stock splits	153

The final sample consists of 3,890 stocks (1,760 NYSE/AMSE and 2,184 Nasdaq), or 237,290 daily observations.

Within each day, transactions price and volume data from all exchanges are included in calculating daily summary measures. Quotes from the exchanges other than the exchange of listing are excluded because of concerns about the correctness of time stamps. Price and quote data must occur between 9:30 a.m. and 4:00 p.m. For each transaction the quote preceding the transaction by at least five seconds is associated with the trade.[5] Thus there is one quote for each trade (except when there is no opening quote).

IV. Measures of Friction

Friction can be measured as a static concept, corresponding to S in (2), or as a dynamic concept, corresponding to ΔP in (2). In this section I define alternative friction measures, provide evidence of their magnitude, and discuss their basic characteristics.

A. *Quoted and Effective Spreads*

The quoted and effective spreads are static measures observable at the moment of the trade. They measure total friction; that is, they reflect both real and informational friction. Because the spread is the cost of a round trip—two trades—and I wish to standardize on the friction associated with one trade, I define half-spreads. The quoted half-spread is defined as

$$S = (A - B)/2, \tag{3}$$

where A is the ask price and B is the bid price. A quoted half-spread is associated with each transaction in the underlying transactions database. The daily average value of the quoted half-spread is calculated by weighting each spread by the number of trades at that spread.

Because many transactions take place inside the quoted spread, the quoted half-spread overstates the actual level of friction. An alternative measure of friction is the effective spread. The effective half-spread is defined as

$$ES = |P - M|, \tag{4}$$

[5] Following Lee and Ready (1991).

where P is the trade price and M is the quote midpoint just prior to the trade. The daily average value of the effective half-spread is calculated by weighting each spread by the number of trades at that spread. The effective spread is frequently less than the quoted spread, as shown by Petersen and Fialkowski (1994), Lee (1993), Huang and Stoll (1996a, 1996b), and Bessembinder and Kaufman (1997). Ready (1999) provides a model of price improvement that analyzes the NYSE specialist's decision to stop stock and trade inside the spread.[6]

B. Traded Spread

Chan and Lakonishok (1993, 1995) and Keim and Madhavan (1997) find that institutions do not know the prices of their individual trades because brokers typically report only the average trade price for the day. Consequently, institutions measure their trading costs by comparing their average trade price to some benchmark, such as the stock's closing price or the stock's volume weighted average price (VWAP) during the day. Similarly, market makers assess their daily performance by comparing the average price of purchases during the day to the average price of sales. If inventory does not change, this is a measure of market makers' profits.

In this spirit, I calculate a new measure of trading friction—the daily traded half-spread. The traded half-spread is half the difference between the average price of trades at the ask side less the average price of trades at the bid side. A trade is at the ask side if its price is closer to the ask than to the bid. It is at the bid side if its price is closer to the bid than the ask. Trades at the quote midpoint are allocated equally between the bid and ask side. If there is not at least one trade on the bid side and one on the ask side, the traded spread for that day is not defined and is treated as missing from the data set.

Two versions of the traded spread, differing in the weighting of trades, are calculated. The first weights each trade equally. The second weights by trade volume. The first traded half-spread measure is

$$TS1 = \frac{\bar{P}_1^A - \bar{P}_1^B}{2}, \tag{5}$$

where

$$\bar{P}_1^A = \frac{1}{m}\sum_1^m P_i^A,$$

$$\bar{P}_1^B = \frac{1}{n}\sum_1^n P_i^B,$$

m = number of trades on the ask side of the market, and
P_i^A = price of the ith trade on the ask side.

Similarly, n is the number of trades on the bid side and P_i^B is the price of the ith trade on the bid side.

[6] A specialist stops stock when he guarantees the current quote to an incoming market order and seeks to improve the price.

The second traded half-spread measure is

$$TS2 = \frac{\bar{P}_2^A - \bar{P}_2^B}{2}, \tag{6}$$

where

$$\bar{P}_2^A = \frac{1}{\sum w_i^A} \sum_1^m w_i^A P_i^A,$$

$$\bar{P}_2^B = \frac{1}{\sum w_i^B} \sum_1^n w_i^B P_i^B,$$

w_i^A = share volume of the ith purchase, and
w_i^B = share volume of the ith sale.

In markets where quoted spreads are not available, such as futures markets, the spread is often estimated by a traded spread measure where the trades are identified from trade reports by market participants. For example, Manaster and Mann (1996) measure trading costs by the difference at which floor brokers buy and sell during a five-minute time interval.

What is the relation of the traded spread to the quoted spread or to the effective spread? The quoted spread is a measure of total friction—the sum of real and informational frictions. The traded spread is a measure of real friction because it reflects real earnings for suppliers of immediacy. The traded spread is an estimate of what the supplier of immediacy earns on a round trip of two trades, whereas the traded half-spread is half this amount and reflects what a trader can expect to earn on one trade. If quotes do not change in response to trades, the traded half-spread equals the quoted half-spread. If quotes respond to trades, the traded half-spread will be less than the quoted half-spread.[7]

The model (2) describes the relation between what is earned on a trade—the price change on the left hand side—and the quoted half-spread, $S/2$. Consequently the model can be used to examine the relation of the traded spread to the quoted spread.[8] Taking the expectation of (2) conditional on Q_t gives

$$E(\Delta P_{t+1}|Q_t) = \frac{S}{2}\left[E(Q_{t+1}|Q_t) - Q_t + \beta Q_t + \alpha(Q_t - Q_t^*)\right]. \tag{7}$$

[7] An alternative to the traded spread is what I have termed the realized spread (Stoll (1985)). The realized half-spread is the expected price change conditional on a trade at the bid or at the ask. Huang and Stoll (1996b), for example, calculate the conditional average price change over five-minute and 30-minute periods after a trade.

[8] The traded spread measure is less restrictive than the model because the sequencing of trades is less critical to the result. For example, in the model the expected price change is with respect to the next trade, whereas the traded spread bases the expected price change on the change from the average bid (ask) to the average ask (bid). Consequently slow mean reversion during the day, which would lower the expected price change in the model, would have less effect in the traded spread measure.

The traded half-spread is an estimate of the left hand side of (7), and $S/2$ represents the quoted half-spread.

To illustrate (7), consider the expected price change after a trade at the bid where $Q_t = -1$. (The expected price change after a trade at the ask is symmetrical.) Assume for simplicity that the trade at t was expected to be a purchase or a sale with equal probability so that $Q_t^* = 0$. If order processing is the only source of the spread so that $\alpha = \beta = 0$ and if the next trade arrives randomly so that $E(Q_{t+1}|Q_t) = 0$, expected price change after a trade at the bid is

$$E(P_{t+1}|Q_t) = \frac{S}{2}(-Q_t) = \frac{S}{2}. \tag{8}$$

In this order-processing world, the model implies a traded half-spread equal to the quoted half-spread.

On the other hand, if adverse information is the only source so that $\alpha = 1$, $\beta = 0$ and if the next trade arrives randomly, the expected price change is

$$E(P_{t+1}|Q_t) = \frac{S}{2}[-Q_t + Q_t] = 0. \tag{9}$$

In this adverse-information world, the model implies a traded half-spread of zero corresponding to a quoted half-spread of $S/2$.

If a portion of the spread is due to inventory costs, (7) is affected in two ways. First, the presence of inventory effects means that $\beta > 0$. When $\beta > 0$, quotes are adjusted downward in response to the trade at the bid by $\beta Q_t = -\beta$, and this downward adjustment reduces the expected price change. For example, if the next trade is at the ask, the price will not bounce back as far as it would if the ask quote had not been lowered. The second effect is offsetting. The adjustment of quotes induces negative serial correlation in trade arrivals, which will bring inventory levels back to normal over the long run. The downward quote adjustment after a trade at the bid increases the probability that the next trade will be at the ask rather than the bid, so that $E(Q_{t+1}|Q_t = -1) > 0$.[9] This second effect increases the expected price change. Because inventory positions are long lived, the first effect is likely to exceed the second when examining a short period around a single trade. However, if inventory equilibrates over the day, the initial inventory adjustment of βQ_t will tend to be offset by the subsequent trade arrivals so that over the day $\beta Q_t = -E(Q_{t+1}|Q_t)$.

Normally, the quoted spread reflects all components—order processing, inventory, and information. Over a longer horizon, the information component can be approximated by the difference between the quoted and traded

[9] I assume here that there are no other sources of serial dependence in trade arrivals. The relation between the traded and quoted spread modeled by (7) does not account for demand-side serial dependence in order flow. For example, if purchases tend to be made when prices are low and sales when they are high, the traded spread could be less than the quoted spread. Such trends should, however, be anticipated by traders in placing their orders and should not be observed over a reasonable sample of days.

spreads if the two inventory effects are offsetting. To illustrate this point, consider a situation in which the information component is 40 percent ($\alpha = 0.4$), the inventory component is 20 percent ($\beta = 0.2$) and the order-processing component is the balance, 40 percent. Assume also that the expected trade indicator for a trade following a trade at the bid is $E(Q_{t+1}|Q_t = -1) = 0.2$, and assume that the expected trade indicator for the trade at time t was $Q_t^* = 0$. Substituting these values in equation (7) yields

$$E(\Delta P_{t+1}|Q_t = -1) = \frac{S}{2}[0.6]; \tag{10}$$

that is, the traded half-spread implied by the model is 0.6 of the quoted half-spread. Estimating the information component as the difference between the quoted and traded half-spreads produces an information component of $S/2 - 0.6(S/2) = 0.4(S/2)$, consistent with the assumption of $\alpha = 0.4$. The estimate is correct because the short run inventory adjustment of quotes ($\beta = 0.2$) is assumed to be equal to the long run adjustment of trading frequency ($E(Q_{t+1}|Q_t = -1) = 0.2$).

C. Empirical Evidence about Quoted, Effective, and Traded Spreads

Table II provides average values of the quoted, effective, and traded spreads. First, as expected, the effective spread is less than the quoted spread. On the NYSE/AMSE, the overall average quoted and effective half-spreads are 7.87 cents and 5.58 cents respectively in the three months ending February 1998. The corresponding values for Nasdaq are 12.57 cents and 10.70 cents.

Second, spreads are higher in Nasdaq than on the NYSE/AMSE even after casual adjustment for differences in stock prices. This inference is supported by a more complete analysis below. Barclay et al. (1999) have shown that spreads declined by 30 percent with the introduction of the SEC's order handling rules; yet Table II and the evidence presented later in this paper imply that important differences remain between the two markets.[10] I suspect the remaining difference reflects the greater role of limit orders on the NYSE in narrowing the spread and the fact that, on Nasdaq, there is not a separate commission charge for institutional customers.

Third, the data in Table II provide a guide to the importance of real and informational factors in the spread. Because the traded spread measures what suppliers of immediacy earn to bear the cost of real friction, the difference between the traded spread and the quoted or effective spread is a measure of expected losses to informed trades. On the NYSE/AMSE, the difference from the quoted half-spread is about 4 cents and the difference from the effective half-spread about 2.5 cents. The differences are of about the same magnitude on Nasdaq. This difference implies that both real frictions and information factors determine the spread.

[10] Bessembinder (1999), in a matched sample approach, also finds that differences remain.

Table II

Half-Spread Measures by Exchange and Market Value Decile

In cents per share. The quoted half-spread is half the difference between the ask and the bid, averaged over the day. The effective half-spread is the absolute value of the trade price less the quote midpoint averaged over the day. The traded half-spread is half the difference between the average price of trades on the ask side less the average price of trades at the bid side. In calculating the daily average prices, trade prices are equally weighted (version 1) or weighted by shares traded (version 2). The stock price is the closing price. The values in the table are averages over 61 days and over the stocks in each category. Measures of statistical significance are not shown. However, all spread measures are significantly different from zero with every t-ratio exceeding 10 and most exceeding 30.

	Market Value Decile										
	Smallest	2	3	4	5	6	7	8	9	Largest	Overall
Panel A: NYSE/AMSE											
Quoted half-spread	8.278	8.563	8.633	8.269	8.548	7.794	7.297	7.901	6.907	6.488	7.869
Effective half-spread	6.087	6.068	6.112	5.787	6.060	5.491	5.094	5.698	4.865	4.568	5.583
Traded half-spread 1	3.652	3.404	3.209	2.965	3.070	2.763	2.926	3.149	2.796	2.868	3.080
Traded half-spread 2	3.877	3.772	3.834	3.597	3.706	3.419	3.539	3.887	3.733	4.047	3.741
Stock price (dollars)	9.33	15.69	22.68	25.20	30.34	32.58	35.58	44.97	50.73	64.45	33.15
Panel B: Nasdaq											
Quoted half-spread	8.557	9.346	10.596	11.412	12.561	14.442	15.260	15.772	15.484	12.241	12.569
Effective half-spread	7.396	8.072	9.156	9.799	10.702	12.215	12.691	13.065	13.012	10.905	10.702
Traded half-spread 1	5.763	6.332	7.194	7.660	8.494	9.625	9.898	10.314	10.452	9.580	8.532
Traded half-spread 2	5.610	6.028	6.837	7.228	7.859	8.944	9.214	9.518	9.684	9.024	7.995
Stock price (dollars)	5.16	7.38	9.03	11.14	13.56	17.07	20.79	25.04	30.57	39.08	17.88

Fourth, the comparison of the NYSE/AMSE and Nasdaq suggests that the dollar value of information frictions is about the same and that the source of the difference in the spreads between the two markets is real frictions, including the market mechanism. On the NYSE/AMSE, the traded half-spread as measured by TS2 (3.7 cents) is 47 percent of the quoted half-spread (7.9 cents), and on Nasdaq the traded half-spread as measured by TS2 (8 cents) is 63 percent of the quoted half-spread (12.5 cents). These findings imply that Nasdaq dealers earn a larger fraction of the spread than do NYSE suppliers of immediacy, consistent with Huang and Stoll (1996b). Dollar losses to informed traders, as measured by the difference between the quoted spread and the traded spread, are about the same on the two markets.

Fifth, Table II provides evidence about the relation of spreads, market value, and stock price. One expects dollar spread measures to increase with stock price and market value, and, except for top two deciles, they do on Nasdaq. However, on the NYSE/AMSE, dollar spreads are higher for the smallest stocks with the lowest prices than for the largest stocks with the highest prices. For example, the effective spread for the smallest 10 percent of stocks with an average stock price of \$9.33 is 6.09 cents, whereas the effective spread for the largest 10 percent of stocks with an average stock price of \$64.45 is 4.57 cents. It will be the case that percentage spreads (not shown in Table II) decline with stock price and market value in both markets.

D. Covariance of Price Changes

Roll (1984) shows that the serial covariance of price changes in an informationally efficient market with real frictions is given by $\text{cov} = -\frac{1}{4}S^2$. This result can be derived by calculating the serial covariance of equation (2) under Roll's assumptions that $\alpha = \beta = 0$, namely, that the spread is not the result of informational factors or inventory considerations. The spread can be inferred as $S = 2\sqrt{-\text{cov}}$. If the source of the spread is totally informational, the bid-ask bounce, as Glosten and Milgrom (1985) first showed, will not be observed, for in that case the transaction price is a martingale. The Glosten and Milgrom case can be derived from equation (2) by calculating the serial covariance under the assumption that $\alpha = 1, \beta = 0$ and that transactions arrive randomly.[11] In that case the covariance is zero and the implied spread is zero. Thus the friction measured by the Roll measure reflects primarily noninformational factors.[12]

[11] In the random transaction process the serial covariance in Q_{t+1} is zero, and the probability of a purchase equals the probability of a sale, which is 0.5, so that the expected trade sign is $Q_t^* = 0$.

[12] Use of the serial covariance as a measure of friction assumes that there are no other sources of the serial covariance. It is possible, for example, that trades tend to be serially correlated or bunched, even if only for mechanical reasons. The positive serial covariance due to the bunching of trades could overwhelm the serial covariance reflecting friction. Price discreteness (Ball and Chordia (1999)) could also affect the serial correlation. As a simple approach to this problem, the serial covariance of price changes is also measured based on 20 percent of the trade prices. For example if the number of trades is 50, the covariance is calculated from 10 prices, taking every fifth price. The behavior of this covariance measure was similar to the measure using all data, and results are not presented for it.

Stoll (1989) showed that, like price changes, quote changes exhibit negative serial covariance when the spread reflects inventory costs. This is because suppliers of immediacy adjust quotes to induce inventory equilibrating trades. When a sale takes place, the bid and ask tend to fall to discourage additional sales and to encourage additional purchases. As equilibrating trades occur, the quotes return to their former level. In the absence of inventory effects, quote changes would not exhibit negative serial covariance, although price changes would. Consequently, a finding that quote changes exhibit negative serial correlation would be evidence of inventory effects.

The following covariances are estimated for each day:

$\mathrm{cov}\,P$ = daily serial covariance in trade-to-trade price changes,
$\mathrm{cov}\,A$ = daily serial covariance in trade-to-trade ask changes, and
$\mathrm{cov}\,B$ = daily serial covariance in trade-to-trade bid changes.

An average of each covariance measure is calculated for each stock from the 61 daily covariance estimates. Averages of these stock averages are then calculated for stocks classified by exchange and market value. The resulting averages are, in turn, transformed according to the Roll model and reported in Table III as Roll price, Roll ask, and Roll bid. For example, the half-spread implied by the serial covariance of price changes is Roll price = $\sqrt{-\overline{\mathrm{cov}\,P}}$, where $\overline{\mathrm{cov}\,P}$ is the average serial covariance of price changes for the stocks in each size category. When multiplied by 100, the dimensions of this variable are cents per share.

The average covariance in any size category is always negative. Hence, there is never any difficulty in applying the transformation. The proportion of the stocks with negative serial covariances, given in the third line of each panel in Table III, is large. In Nasdaq, 100 percent of the serial covariances are negative in each size category except one. On the NYSE/AMSE, no size category has fewer than 96 percent of the firms with negative serial covariances.[13] The t-values, reported in the second line of each panel, indicate that the null hypothesis of zero covariance is soundly rejected. This t-value is based on the distribution of average covariances in each size category.

The empirical results for the Roll price variable match those for the traded spread in Table III. Both measure the earnings of suppliers of immediacy, and both are of the same order of magnitude, although the Roll price measure is somewhat larger than the traded spread measure, particularly in the largest stocks. The pattern across size categories is about the same for the covariance-based friction measures as for the spread measures in Table III. Dollar losses to informed traders, as measured by the difference between the quoted spread and Roll price, are about the same in NYSE/AMSE and Nasdaq.

[13] This contrasts with the early results of Roll, who found more frequent cases of positive serial covariances. The difference is that I calculate an average of 61 daily covariances, each based on all trades in the day, whereas Roll calculates a single covariance either from one observation per day or one observation per week.

Table III

Covariance Measures of Friction by Market Value Decile and Exchange

Covariance estimates are transformed according to Roll (1984). Roll $y = \sqrt{-\overline{\text{cov}\,y}}$, where $\overline{\text{cov}\,y}$ is the average of a stock's daily serial covariance of price changes, ask changes, or bid changes. The table reports 100(Roll y), that is, in cents. The t-value is based on the sample of covariances in each market value category. The prop. cov < 0 is the proportion of companies in the size decile with average covariances less than zero.

	Market Value Decile										
	Smallest	2	3	4	5	6	7	8	9	Largest	Overall
Panel A: NYSE/AMEX											
Roll price (cents)	4.49	3.68	3.32	3.33	3.28	3.11	3.08	4.17	3.85	5.18	3.81
t-value	−4.78	−20.39	−18.49	−9.93	−7.33	−11.56	−26.34	−2.04	−3.49	−3.40	−10.90
Prop. cov < 0	1.00	1.00	0.98	0.98	0.97	0.96	0.99	0.99	0.99	1.00	0.99
Roll ask (cents)	3.28	3.09	8.62	3.07	3.75	2.93	1.97	5.10	1.36	1.13	4.00
t-value	−3.96	−7.79	−1.30	−8.56	−2.58	−4.02	−12.19	−1.20	−9.14	−7.73	−2.59
Prop. cov < 0	1.00	1.00	0.99	0.99	0.99	0.98	1.00	0.99	0.96	0.99	0.99
Roll bid (cents)	2.57	2.82	3.06	2.92	5.72	2.33	1.83	10.28	1.35	1.10	4.28
t-value	−14.85	−11.80	−10.53	−8.12	−1.51	−4.74	−8.74	−1.02	−16.43	−8.54	−1.72
Prop. cov < 0	1.00	0.99	1.00	1.00	0.99	0.97	0.99	0.98	0.97	0.99	0.99
Panel B: Nasdaq											
Roll price (cents)	6.45	7.36	8.48	9.27	10.61	12.49	13.05	13.08	14.36	13.17	11.15
t-value	−11.89	−13.77	−12.68	−10.48	−12.18	−8.86	−10.02	−11.63	−3.47	−3.99	−15.33
Prop. cov < 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Roll ask (cents)	2.44	2.53	2.81	3.18	3.50	4.52	4.74	4.93	7.31	4.50	4.28
t-value	−7.98	−11.06	−1.01	−8.23	−9.00	−6.51	−8.11	−6.67	−1.40	−2.66	−4.65
Prop. cov < 0	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00
Roll bid (cents)	2.13	2.30	2.82	3.06	3.24	4.19	4.58	4.90	5.97	3.98	3.90
t-value	−9.52	−12.53	−8.96	−7.45	−10.23	−7.04	−6.82	−6.21	−1.60	−2.60	−6.33
Prop. cov < 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Perhaps the most interesting finding in Table III is the very strong negative serial covariance in quote changes.[14] In the case of Nasdaq, 100 percent of the companies in each decile except one have negative serial covariances in quotes. On the NYSE/AMSE, the fraction negative is only slightly less. This result provides strong evidence of inventory effects. Information-based theories do not admit of transient quote changes (except under quite special assumptions). Further, the magnitude is the same for both exchanges despite the large differences in spreads and in the price covariance.[15]

E. Price Impact

A natural measure of trading friction is the sensitivity of a stock's price to trades. Kyle (1985) provides a theoretical model for such a measure based on the adverse information conveyed by a trade. Scholes (1972) and Kraus and Stoll (1972) provide empirical evidence of the price reaction to large secondaries and block trades. Empirical models of the intraday price impact are in Glosten and Harris (1988), Huang and Stoll (1994, 1997), Madhavan et al. (1997), Lin et al. (1995) and others. Brennan and Subrahmanyam (1996) investigate if adverse information as measured by the price impact of trading affects asset pricing.

In contrast to most of the recent literature, which measures price impact from intraday transactions data, my approach is to measure price impact over the day in response to the trading imbalance for the day.[16] The imbalance for day t, I_t, is the sum of the signed trade quantities during the day expressed as a percentage of daily volume. A trade is classified as a sale if the trade price is closer to the bid than to the ask. It is classified as a purchase if the trade price is closer to the ask. Trades at the midpoint are allocated half to sales and half to purchases.[17]

The price change for the day, ΔP, is measured as the change in the quote midpoint from close to close, adjusted for the return in the S&P 500 index:

$$\Delta P_t = C_t - C_{t-1}(1 + R_{It}), \tag{11}$$

where C_t is the closing midpoint on day t and R_{It} is the daily return on the S&P 500 index.[18] The midpoints are used to abstract from the bid-ask bounce.

[14] Recall that the serial covariance in quotes is based on all quotes in the sample (one for every trade), not just on quote changes.

[15] Direct evidence of inventory effects is found, for example, in Hansch, Naik, and Viswanathan (1998).

[16] Breen, Hodrick, and Korajczyk (1999) also calculate a price impact coefficient, albeit over shorter time intervals, and examine its properties.

[17] My imbalance measure is similar to that of Easley, Kiefer, and O'Hara (1997). They use imbalance in trades as a measure of the direction of informed trading to estimate the parameters of their information process. I use the imbalance in volume, which accounts for the size of trades.

[18] It would make sense to use the open-to-close return, but the index return from open to close is identical to the close-to-close index return because last trade prices are used in calculating the index. In addition, stocks typically open at their prior day's close. As a result and in the interest of simplicity, the close-to-close return was used.

The price impact coefficient is λ in the following regression:

$$\Delta P_t = \lambda_0 + \lambda I_t + \lambda_2 I_{t-1} + e_t \tag{12}$$

where I_t is the percentage imbalance on day t, defined as

$$I = \frac{\sum_1^m w_i^A - \sum_1^n w_i^B}{\sum_1^m w_i^A + \sum_1^n w_i^B}(100) \tag{13}$$

and w_i^A, w_i^B are the share volume of the ith purchase and sale respectively. The prior day's imbalance is included to determine if prices bounce back the day after an imbalance. The regression is estimated for each stock using 61 daily observations.

The price impact coefficient, λ, in equation (12) measures the sensitivity of the quote change over a day to the daily imbalance. Insofar as the quote change is permanent, λ measures the information content of the day's imbalance. If prices bounce back the next day, one would conclude that the price impact also reflects real factors. Friction also depends on the frequency and magnitude of imbalances. It may be that the price impact coefficient is large, but if imbalances are small, the level of friction is small.

The regression results, summarized in Table IV, indicate that there is a significant price impact. The coefficient of interest, λ, is positive in 98 percent of the stocks on both the NYSE/AMSE and Nasdaq. The t-statistic based on the distribution of parameter estimates is 30. The average value of the t-statistic from the individual regressions exceeds 2 in both markets. If the price impact were reversed on the following day, one would observe a negative value for λ_2. This coefficient is, however, statistically significant in fewer than five percent of the individual regressions and has opposite signs on the NYSE/AMSE and Nasdaq. The lack of a reversal implies that the price impact coefficient reflects the information content of the net imbalance for the day.[19]

As shown in Table V, average values of λ, classified by exchange and market value, increase from about 0.002 in the smallest size category (and lowest price category) to about 0.024 in the largest size category (and highest price category) in both the NYSE/AMSE and Nasdaq. For example, on the NYSE/AMSE, a 20 percent imbalance has an effect of \$0.002(20) = 4 cents per day for the smallest size category and \$0.0238(20) = 47.5 cents per day for the largest size category. The estimates are similar for Nasdaq. Although the price sensitivity to a given percentage imbalance is larger for large stocks,

[19] However there is evidence in Hasbrouck and Sofianos (1993) and Madhavan and Smidt (1993) that inventory adjustment is long lived, albeit difficult to measure, which implies that some of the price impact is reversed in subsequent days.

Table IV

Price Impact Regressions

$$\Delta P_t = \lambda_0 + \lambda I_t + \lambda_2 I_{t-1} + e_t$$

ΔP_t is the change in the closing quote midpoint adjusted for the return on the S&P 500 index; I_t is the difference between the daily share volume on the ask side and on the bid side expressed as a percentage of daily volume. Regressions are run using 61 daily observations for each stock. The table summarizes the average values of the coefficients.

	NYSE/AMSE	Nasdaq
Mean λ_0	−0.0314	0.0311
$t(\lambda_0)$*	−10.494	16.957
mean t of individual regressions	−0.242	0.529
% positive	40.4	71.2
% positive and significant (5%)	1.3	6.7
% negative and significant (5%)	4.1	0.46
Mean λ	0.007671	0.007298
$t(\lambda)$*	30.121	29.708
mean t	2.435	2.711
% positive	97.9	97.9
% positive and significant (5%)	63.1	71.2
% negative and significant (5%)	0.0	0.0
Mean λ_2	−0.000701	0.000168
$t(\lambda_2)$*	−6.504	1.982
mean t	−0.064	0.240
% positive	48.7	59.7
% positive and significant (5%)	2.5	4.7
% negative and significant (5%)	4.3	2.6
Mean adj R^2	0.0929	0.1192
Number of days	61	61
Number of stocks	1,706	2,184

*t-ratio is based on the distribution of the parameter estimates

the average price impact is not necessarily larger, because large (and more actively traded stocks) experience smaller percentage imbalances. For example, on the NYSE/AMSE, the average imbalance is 37 percent per day for the smallest size category and 15.2 percent per day for the largest size category, as shown in Table V.

I take as an unconditional measure of price impact for stock i the predicted price impact for the average imbalance defined as $\lambda_i \operatorname{Avg}|I_{it}|$, where $\operatorname{Avg}|I_{it}|$ is the average absolute imbalance in stock i over the days in the sample. This variable has dollar dimensions like the friction measures in Tables II and III. Table V shows that the predicted price impact increases with company size (and stock price), like the earlier dollar friction measures. For example, on the NYSE/AMSE, the predicted daily price impact is 6.99 cents in the smallest size category and 33.70 cents in the largest size category. On Nasdaq, the corresponding impacts are 5.27 cents and 32.16 cents.

Table V

Price Impact and Opening Volatility, by Market Value Decile and Exchange

λ is the price impact coefficient. Avg $|I|$ is the average value of a firm's daily absolute imbalance between share purchases and share sales. Trades per day is the average number of trades in a stock. $OV = |O_t - O_{t-1}| - |C_t - C_{t-1}|$, where O_t is the opening price on day t and C_t is the closing price on day t. The t-values are based on the sample of stocks in each market value category.

	Market Value Decile										
	Smallest	2	3	4	5	6	7	8	9	Largest	Overall
Panel A: NYSE/AMSE											
λ	0.0020	0.0028	0.0038	0.0043	0.0056	0.0057	0.0062	0.0094	0.0133	0.0238	0.0077
t-value	16.2855	15.3479	18.5018	14.5015	10.9981	14.3991	15.8437	12.6316	13.8796	16.6539	30.1215
% negative	0.59	1.75	3.51	1.76	1.17	4.68	4.12	1.75	0.58	0.59	2.05
Avg $\|I\|$ (percent)	37.5054	34.8256	32.9240	30.7341	28.6406	26.6314	24.8490	22.7853	19.3111	15.2737	27.3486
t-value	70.0980	62.9680	63.4140	63.7280	59.9690	65.7720	63.9710	50.7740	63.4800	60.6750	127.9340
λ Avg $\|I\|$ (dollars)	0.0699	0.0882	0.1175	0.1239	0.1460	0.1447	0.1434	0.1878	0.2412	0.3370	0.1599
Trades per day	25.50	40.89	53.38	63.13	79.93	101.13	142.13	229.31	336.70	828.55	189.89
OV*100 (cents)	1.0257	0.7145	0.5921	0.2113	1.3015	1.621	1.4171	1.607	2.465	1.7305	1.2690
t-value	6.51	4.11	2.19	0.82	4.15	5.78	4.82	3.89	4.80	2.86	11.24
% negative	29.0	35.0	43.0	50.0	39.0	34.0	36.0	33.0	32.0	39.0	37.0
Panel B: Nasdaq											
λ	0.0015	0.0025	0.0028	0.0037	0.0044	0.0058	0.0064	0.0089	0.0123	0.0246	0.0073
t-value	18.6099	17.4329	18.1236	17.3763	17.6787	15.7399	16.0515	15.5058	18.3715	14.5512	29.7075
% negative	3.21	1.38	3.20	0.46	2.74	1.38	1.83	2.75	1.83	1.83	2.06
Avg $\|I\|$ (percent)	36.4491	33.8216	32.4701	31.6640	30.2985	30.3733	29.0376	27.2566	23.5435	17.8518	29.2758
t-value	99.0290	83.8340	84.2240	69.5580	62.2600	53.7840	50.7410	47.2500	44.9330	30.6350	153.1630
λ Avg $\|I\|$ (dollars)	0.0527	0.0770	0.0853	0.1078	0.1203	0.1562	0.1595	0.1997	0.2454	0.3216	0.1526
Trades per day	28.07	41.94	47.81	59.70	68.31	90.39	104.22	130.81	202.29	897.05	166.95
OV*100 (cents)	1.4756	2.0472	2.5192	3.2944	3.5715	4.4719	4.9122	5.6224	5.0466	4.5932	3.756
t-value	8.33	9.74	9.27	11.95	11.18	10.02	9.91	11.17	9.16	9.22	29.22
% negative	29.0	20.0	21.0	19.0	19.0	21.0	18.0	20.0	20.0	26.0	21.0

The predicted impact stated as a percent of the stock price in each size category declines with size, as is the case for the other friction measures. For example, the percent impact on the NYSE/AMSE (Nasdaq) is 0.75 percent (1.02 percent) for the smallest size category and 0.52 percent (0.82 percent) for the largest (based on the stock prices in Table II). These daily percentage price impacts are somewhat larger than those found by Chan and Lakonishok (1993) in a study of institutional trades. They find that institutional buy programs have a daily impact of 0.34 percent, whereas sell programs have a daily impact of -0.04 percent. The Chan and Lakonishok impacts are based on trade prices, not quotes, and consequently include the effect of the bid-ask bounce.[20]

One difference remains between the price impact measure of friction and the earlier measures; namely, that the price impact is measured over the day, whereas the other measures are calculated per trade. Table V reports the average number of daily trades for the stocks in each size category. For example, the average number of trades for the smallest category of NYSE/AMSE (Nasdaq) stocks is 25.50 (28.07), whereas the average number of trades for the largest category of NYSE/AMSE (Nasdaq) stocks is 828.55 (897.05). If one were to calculate the price impact over the number of trades in an imbalance, the price impact would be quite small. Consider, for example, the 6.99 cent daily price impact associated with the average imbalance of 37.51 percent in the smallest NYSE/AMSE stocks. If one assumes that the percentage imbalance in trades is the same as the percentage imbalance in shares, the imbalance in trades is $(0.37505)(25.50) = 9.56$ trades. The price impact per trade in the imbalance amounts to about $6.99/(0.37505)(22.50) = 0.731$ cents per trade. The imbalance in large NYSE/AMSE stocks would amount to about $33.7/(0.152737)(828.55) = 0.266$ cents per trade. These amounts are considerably smaller than the information effect of about 2.5 cents per trade computed earlier as the difference between the effective spread and the traded spread. The result is puzzling because the information effect for the day should simply be the sum of the information effects for the individual trades, and this does not seem to be the case.

F. Volatility at the Open

Trading frictions can be particularly severe at the opening of a market. Amihud and Mendelson (1987) and Stoll and Whaley (1990) have shown that open-to-open volatility exceeds close-to-close volatility. Volatility at the opening may reflect real friction, such as imperfections in the opening mechanism, or informational friction, such as overreactions to overnight news as traders try to determine the equilibrium price. I measure opening volatility (relative to volatility at the close) as

$$OV = |O_t - O_{t-1}| - |C_t - C_{t-1}|, \tag{14}$$

[20] In a later paper, Chan and Lakonishok (1995) examine the multiday effects of institutional buy and sell programs. The effect is larger over several days. Barclay and Warner (1993) examine the role of trade size in price impacts and conclude that medium size trades are most responsible for moving prices.

where O_t = the opening price on day t and C_t = the closing price on day t. This measure has dollar dimensions, in keeping with other friction measures used above, whereas Amihud and Mendelson (1987) and Stoll and Whaley (1990) use returns. The variable, *OV*, differs from the other friction measures in that it is a volatility measure intended to measure friction at a particular time of the day—the open—and the other measures represent trading frictions regardless of time of day.

An average value of *OV* is calculated for each stock over the 61 days in the sample. Consistent with the findings of Amihud and Mendelson (1987) and Stoll and Whaley (1990), Table V shows that open-to-open volatility is significantly higher than close-to-close volatility in both markets and in all size categories. The pattern of *OV* across size deciles and markets is similar to the pattern for spread measures. First, *OV* increases with size (and price) except for the largest decile, where there is a slight decline. Second, *OV* is larger on Nasdaq than on the NYSE/AMSE. For example the average value of *OV* for decile nine is 2.465 cents on the NYSE/AMSE and 5.0456 cents on Nasdaq. These values are 1.7305 and 4.5932 cents respectively in decile 10.

These results imply that friction is greater at the open than at other times in both markets and in all size categories. Per-share dollar volatility at the open tends to increase with size, but this increase is not as uniform as it is for the other friction measures. On the NYSE/AMSE, per-share dollar volatility declines over the first four size deciles and then increases until the next to largest category. On Nasdaq the increase in dollar volatility is more uniform; however, volatility declines at the largest two deciles. Volatility as a percentage of stock price declines with size, as is the case for the other friction measures.

V. The Relation among Alternative Friction Measures

I have provided evidence about seven measures of friction–quoted spread, effective spread, traded spread, covariance of price changes, covariance of quote changes, daily price impact, and opening volatility—and examined the implications of the evidence for the sources and magnitude of friction. My concern now is to determine the extent to which there are common sources of these different friction measures. Are these measures correlated? Are they each related in the same way to firms' characteristics? If they are, friction is a relatively simple one-dimensional concept. If not, friction is a more complex multifaceted concept. My interest in cross-sectional commonality of different friction measures contrasts with recent work, such as Chordia, Roll, and Subrahmanyam (1998), on the extent of time series commonality in a given friction measure, such as the spread.[21]

Different friction measures need not be correlated. Real friction measures, such as the traded spread or the covariance measure, could be uncorrelated with quoted spreads if differences across stocks in quoted spreads were a

[21] In a quite different approach, Hasbrouck and Seppi (1998), employing principal components, look for commonalities in returns and order flow for the 30 Dow Jones stocks.

reflection only of adverse information. One would expect friction at the open to be correlated with friction during the rest of the day, but if volatility at opening were a reflection of market structure or informational frictions specific to the opening, that might not be the case. Similarly, the daily price impact might reflect frictions different from those reflected in the other measures.

I examine the association of the different friction measures first by the degree of cross-sectional correlation and second by the degree to which different measures are related to the same underlying trading characteristics that explain cross-section differences in quoted spreads (as in Table I).

A. Correlation of Friction Measures

The upper right side triangle of Table VI provides correlations for NYSE/AMSE and the lower left-hand triangle provides correlations for Nasdaq. All variables, except λ, are expressed as a fraction of the average stock price. Several of the measures are highly correlated, but others are not. There are important similarities in the two markets but also important differences. Although much has been made of the distinction between the quoted and effective spread, the two measures are highly correlated in both the NYSE/AMSE (0.9921) and Nasdaq (0.9946).[22] Clearly, in measuring cross-sectional variations in total friction, quoted and effective spreads are equivalent.

The traded spread measures are highly correlated with the quoted and effective spreads, particularly in Nasdaq. This substantial correlation is interesting because the traded spread is a dynamic measure influenced by price changes, whereas the quoted and effective spreads are static measures. The correlation would not exist if differences in quoted spreads were the result only of adverse information, for then traded spreads would be the same across stocks and would be uncorrelated with quoted spreads.

The average serial covariances of price and quote changes, transformed by the Roll equation, are correlated with the quoted spread. The implication of this association is the same as in the case of the traded spread. It reflects the fact that noninformation sources of the spread are important in explaining differences in friction across stocks.

The price impact coefficient, λ, is negatively correlated with other measures. This reflects the fact that λ increases with stock price whereas the proportional spread decreases with stock price. On the other hand, the price change for the average imbalance stated as a fraction of the price ($\lambda \, \text{Avg}\,|I|/P$), a better measure of adverse information effect of the normal imbalance in a stock, is positively correlated with other spread measures, although the correlation is quite weak. The weak correlation suggests that the cross-sectional behavior of informational friction is quite different from the cross-sectional behavior of real frictions.

[22] Petersen and Fialkowski (1994, p. 281) report a correlation of only 0.10 for 1991 NYSE stocks.

Table VI

Correlation of Friction Measures by Exchange

Proportional friction measures are calculated by dividing the average dollar friction measure for each stock by the stock's average closing price. The first line is the cross-sectional correlation coefficient, and the second line is the probability that it is not different from 0.0.

	S/P	ES/P	$TS1/P$	$TS2/P$	RollP/P	Rollask/P	Rollbid/P	λ	λ Avg $\|I\|/P$	OV/P
					NYSE/AMSE					
Spread/P		0.9921	0.9553	0.9543	0.9281	0.6545	0.8022	−0.3251	0.3565	0.2317
		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Effective spread/P	0.9946		0.9694	0.9635	0.9278	0.6705	0.7960	−0.3171	0.3677	0.2368
	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Traded spread 1/P	0.9682	0.9814		0.9836	0.9232	0.6117	0.7284	−0.2799	0.4029	0.2661
	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Traded spread 2/P	0.9545	0.9695	0.9900		0.9110	0.6020	0.7342	−0.2744	0.4111	0.2700
	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Roll price/P	0.9611	0.9618	0.9544	0.9440		0.5865	0.7307	−0.2591	0.3734	0.2359
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001
Roll ask/P	0.8588	0.8369	0.7837	0.7687	0.8179		0.5795	−0.2454	0.1443	0.1425
	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001
Roll bid/P	0.8767	0.8577	0.8097	0.7912	0.8507	0.8351		−0.3097	0.1870	0.1315
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001
λ	−0.4519	−0.4349	−0.4086	−0.3968	−0.4366	−0.4215	−0.4202		0.3898	−0.0424
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001	0.0800
λ Avg $\|I\|/P$	0.0542	0.0932	0.1178	0.1348	0.0579	−0.0829	−0.0263	0.2882		0.1027
	0.0113	0.0001	0.0001	0.0001	0.0068	0.0001	0.2193	0.0001		0.0001
Open volatility/P	0.1713	0.1686	0.1632	0.1525	0.1756	0.1495	0.1623	−0.0471	0.1232	
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0279	0.0001	
					Nasdaq					

The correlation of open-to-open volatility with other measures is positive but weak, which suggests that friction around the opening has a different source from friction at other times of the day. The result is surprising because one would expect stocks that are difficult to trade during the day might also be difficult to open in the morning, something that does not appear to be the case. Opening volatility reflects opening difficulties or news events that are uncorrelated to other sources of friction.

B. Are Different Friction Measures Related in the Same Way to Firms' Trading Characteristics?

Table I showed that the quoted spread varies cross-sectionally in a highly predictable manner as a function of a few firm characteristics. Are the other friction measures related in the same way and to the same degree to the same company trading characteristics? Table VII provides evidence about this question. Nine different friction measures are regressed against company trading characteristics. Each observation for a company is an average over the 61 daily observations, except the price impact variable, which is the estimated λ over the 61 days multiplied by the average absolute daily imbalance for the 61 days. All friction measures are expressed as a percentage of the average price. The independent variables are the log of the average daily dollar volume, the stock's return variance in the prior year, the log of the stock's market value, the log of the average closing price, the log of the average number of trades per day, and the average absolute percentage imbalance.[23]

Consider first the total friction measures—the quoted and effective half-spreads.[24] The two total friction measures are strongly related to the same variables in the same way. On the NYSE/AMSE (Nasdaq), over 79 percent (71 percent) of the cross-sectional variation is explained. Both the quoted and effective spread measures decrease in dollar volume and in stock price and both increase in variance of return and average percentage imbalance. These associations are highly significant in both the NYSE/AMSE and Nasdaq. The role of market value and number of trades is not consistent in the two markets, as these variables are not statistically significant in Nasdaq, whereas they are significant on the NYSE/AMSE. The intercepts of each regression are higher on Nasdaq than on the NYSE/AMSE, which implies that spreads continue to be larger on Nasdaq than on the NYSE/AMSE even after controlling for company characteristics and even after dramatic changes in Nasdaq trading procedures.[25]

[23] To test if the contemporaneous quarterly observations produce spurious associations, regressions were also estimated in which monthly average friction measures were regressed against company trading characteristics from the prior month. The results are virtually unaffected. These monthly regressions are available from the author.

[24] The regression for the quoted half-spread is the same as in Table I, except that the average absolute percentage imbalance is included as an independent variable and a single regression is estimated using quarterly averages rather than three separate regressions using monthly averages.

[25] Consistent with Huang and Stoll (1996b) for an earlier period before the SEC order handling rules.

Table VII

Friction Measures Regressed against Company Characteristics

Coefficients are in the first line, and t-values are below. Friction measures are expressed as a fraction of the average stock price. The dependent mean and all coefficients except that on σ^2 are multiplied by 100. Variables are averages for each stock calculated over the 61 days in the sample period. The ratio of the friction variable to the stock price is computed after the average for the friction variable and stock price are computed. S is the daily average quoted half-spread. ES is the daily average effective half-spread. $TS1$ is half the daily difference between the average price of trades at the ask side of the market and the average price of the trades at the bid side, with each trade receiving equal weight. $TS2$ is half the daily difference between the average price of trades at the ask side of the market and the average price of the trades at the bid side, with each trade weighted by its share of volume. Rollprice, Rollask, and Rollbid are defined as $\sqrt{-\overline{\text{cov}\, y}}$, where $\overline{\text{cov}\, y}$ is the average of daily serial covariances of price changes, ask changes or bid changes, respectively. $\lambda\, Avg|I|$ is the stock's price impact coefficient estimated over the 61 days in the sample times the average absolute daily percentage imbalance between purchases and sales. $OV = |O_t - O_{t-1}| - |C_t - C_{t-1}|$, where O_t is the opening price on day t and C_t is the closing price on day t. P is the stock's closing price. Log V is the natural log of the average daily dollar volume. σ^2 is the daily return variance for the prior year. Log MV is the log of the stock's market value at the end of November 1997. Log P is the log of the average closing stock price. Log N is the log of the average number of trades per day. Avg $|I|$ is the average daily percentage imbalance between the volume at the ask and at the bid.

	Dep Mean	Intercept	Log V	σ^2	Log MV	Log P	Log N	Avg $\|I\|$	Adj R^2
				Panel A: NYSE/AMSE					
S/P	0.389	1.9401	−0.1360	1.5757	0.0400	−0.2126	0.0880	0.0049	0.7974
		21.77	−12.08	18.00	5.75	−18.64	5.45	4.88	
ES/P	0.278	1.4074	−0.1042	1.2309	0.0282	−0.1498	0.0763	0.0041	0.7959
		21.36	−12.52	19.02	5.48	−17.77	6.39	5.50	
$TS1/P$	0.164	0.9329	−0.0733	0.7154	0.0172	−0.1117	0.0765	0.0025	0.762
		20.02	−12.46	15.62	4.74	−18.74	9.07	4.78	
$TS2/P$	0.185	0.9457	−0.0756	0.7411	0.0200	−0.1083	0.0731	0.0027	0.7477
		19.37	−12.26	15.45	5.26	−17.33	8.27	4.95	
Rollprice/P	0.173	0.9168	−0.0625	0.7188	0.0185	−0.1316	0.0611	0.0018	0.7122
		16.84	−9.09	13.44	4.36	−18.88	6.20	2.84	
Rollask/P	0.114	0.4278	−0.0382	0.5234	0.0306	−0.0732	−0.0069	0.0026	0.3555
		5.30	−3.75	6.60	4.86	−7.08	−0.47	2.85	
Rollbid/P	0.105	0.4244	−0.0293	0.4479	0.0216	−0.0634	−0.0105	0.0017	0.5393
		8.76	−4.79	9.41	5.73	−10.22	−1.20	3.04	
λ Avg $\|I\|/P$	0.578	1.6065	−0.1615	2.1445	−0.1090	−0.0017	0.5276	0.0157	0.4497
		8.87	−7.05	12.05	−7.72	−0.07	16.08	7.66	
OV/P	0.057	0.4166	−0.0184	0.3569	−0.0095	−0.0224	0.0342	−0.0019	0.0671
		4.39	−1.54	3.82	−1.28	−1.85	1.99	−1.78	
				Panel B: Nasdaq					
S/P	0.945	2.8948	−0.1426	0.4938	0.0114	−0.1881	−0.0230	0.0135	0.7122
		16.65	−7.49	8.54	1.00	−9.68	−1.05	8.80	
ES/P	0.814	2.7134	−0.1502	0.4466	0.0048	−0.1529	0.0285	0.0115	0.7177
		18.38	−9.29	9.09	0.49	−9.26	1.53	8.81	
$TS1/P$	0.646	2.2365	−0.1334	0.3464	0.0040	−0.1179	0.0528	0.0085	0.6895
		18.43	−10.04	8.58	0.49	−8.70	3.45	7.92	
$TS2/P$	0.619	2.0424	−0.1078	0.3557	0.0074	−0.1557	0.0300	0.0070	0.6801
		16.80	−8.09	8.79	0.92	−11.46	1.96	6.54	
Rollprice/P	0.672	2.2426	−0.1060	0.2991	0.0073	−0.1176	−0.0232	0.0057	0.6666
		17.63	−7.61	7.06	0.87	−8.27	−1.44	5.08	
Rollask/P	0.213	0.4523	−0.0111	0.1198	0.0070	−0.0447	−0.0436	0.0036	0.5754
		8.13	−1.82	6.47	1.90	−7.19	−6.21	7.37	
Rollbid/P	0.205	0.5217	−0.0247	0.0994	0.0096	−0.0398	−0.0255	0.0035	0.5788
		9.84	−4.25	5.63	2.75	−6.72	−3.82	7.42	
λ Avg $\|I\|/P$	1.004	3.2086	−0.4057	0.6902	−0.1260	0.1495	0.9230	0.0225	0.5073
		11.88	−13.71	7.68	−7.07	4.95	27.08	9.44	
OV/P	0.249	1.1299	−0.0879	0.0351	−0.0430	0.0660	0.1449	0.0031	0.0346
		5.54	−3.93	0.52	−3.19	2.90	5.63	1.73	

Petersen and Fialkowski (1994) interpret the difference between the quoted and effective spreads as price improvement, and Ready (1999) provides a model of price improvement on the NYSE. Although I do not pursue this matter in detail here, one can infer the relation of price improvement to firms' characteristics by regressing the difference between the quoted and effective spread on firms' characteristics. The coefficients and t-values for this regression are in Table VIII (the first row in each market). Price improvement is positively related to the stock's volatility. This reflects the fact that there are more opportunities for price improvement in volatile stocks. Similarly, price improvement is positively related to the average imbalance in a stock. Stocks with larger average imbalances tend to have wider spreads and more opportunities for price improvement. Price improvement is negatively related to stock price, reflecting the role of tick size. Although the minimum tick is only 1/16 in the period of this study, the tick size is more likely to be binding for low-priced stocks, and hence the opportunity for price improvement is greater for low priced stocks than for high-priced stocks.[26] Price improvement is negatively related to an activity variable—dollar volume on the NYSE/AMSE and number of trades on Nasdaq—reflecting the fact that there is less opportunity and less need for price improvement in actively traded stocks.

Surprisingly, the dynamic real friction measures—the traded spread measures and the Roll spread implied by the serial covariance of price changes—are related in much the same way and to the same degree with firms' characteristics as the static total friction measures (see regressions 3, 4, and 5 in each market in Table VII). On the NYSE/AMSE, over 71 percent of the cross-sectional variation in these variables is explained by firms' characteristics. On Nasdaq, over 66 percent is explained in this way. The similarity of coefficients and statistical significance implies that quoted spreads, effective spreads, traded spreads, and price covariances measure the same things. Not only do higher spreads imply higher traded spreads and higher Roll implied spreads, as shown by the correlations in Table VI, but also these variables vary cross-sectionally in a consistent manner as a function of company trading characteristics. Insofar as the traded spread and covariance measures are indeed measures of real friction, these results imply that the cross-sectional variation of quoted spreads and effective spreads reflects primarily real frictions in trading stocks. The fact that the intercepts for the traded spread and the Roll implied spread regressions are uniformly larger for Nasdaq than for the NYSE/AMSE implies that real friction is greater on Nasdaq than on the NYSE/AMSE.

What can we infer about informational friction? I take the difference between the effective spread, ES, and the traded spread, $TS1$, as one measure of informational friction. In Table VIII, the second regression within each market provides evidence on the association of the difference, $ES - TS1$,

[26] The minimum tick size was reduced from \$1/8 to \$1/16 in June 1997 in both the NYSE and Nasdaq.

Table VIII

Differences in Friction Measures Regressed on Firms' Characteristics

Coefficients are in the first line and t-values below. Variables are averages for each stock calculated over the 61 days in the sample period. The ratio of the friction variable to the stock price is computed after the average for the friction variable and stock price are computed. S is the daily average quoted half-spread. ES is the daily average effective half-spread. $TS1$ is half the daily difference between the average price of trades at the ask side of the market and the average price of the trades at the bid side, with each trade receiving equal weight. Rollprice is defined as $\sqrt{-\overline{\text{cov}\,y}}$, where $\overline{\text{cov}\,y}$ is the average of daily serial covariances of price changes. P is the stock's closing price. Log V is the natural log of the average daily dollar volume. σ^2 is the daily return variance for the prior year. Log MV is the log of the stock's market value at the end of November 1997. Log P is the log of the average closing stock price. Log N is the log of the average number of trades per day. Avg $|I|$ is the average daily percentage imbalance between the volume at the ask and at the bid.

Dependent	Intercept	Log V	σ^2	Log MV	Log P	Log N	Avg $\|I\|$	Adj R^2
				Panel A: NYSE/AMSE				
$(S - ES)/P$	0.5327	−0.0319	0.3448	0.0118	−0.0628	0.0117	0.0008	0.6907
	16.99	−8.05	11.20	4.83	−15.66	2.07	2.32	
$(ES - TS1)/P$	0.4745	−0.0308	0.5155	0.0109	−0.0380	−0.0003	0.0016	0.7031
	14.97	−7.70	16.56	4.42	−9.38	−0.05	4.41	
$(ES$ − Rollprice$)/P$	0.4906	−0.0416	0.5121	0.0097	−0.0182	0.0152	0.0024	0.5502
	11.42	−7.68	12.14	2.89	−3.32	1.95	4.84	
				Panel B: Nasdaq				
$(S - ES)/P$	0.1814	0.0075	0.0473	0.0067	−0.0352	−0.0515	0.0020	0.5594
	4.90	1.86	3.83	2.72	−8.51	−11.02	6.19	
$(ES - TS1)/P$	0.4769	−0.0168	0.1002	0.0008	−0.0349	−0.0244	0.0030	0.5370
	9.16	−2.94	5.78	0.23	−6.00	−3.71	6.52	
$(ES$ − Rollprice$)/P$	0.4708	−0.0442	0.1475	−0.0025	−0.0353	0.0517	0.0058	0.4123
	6.87	−5.89	6.47	−0.55	−4.61	5.98	9.55	

expressed as a fraction of the stock price, with company characteristics. The informational component, measured in this way, depends on firms' characteristics in much the same way as the real friction measures. Informational friction is positively associated with the return volatility of a stock and with the stock's average imbalance. More volatile stocks and stocks with greater trading imbalances are likely to be stocks with more adverse information. The informational component tends to be negatively associated with activity measures such as volume or number of trades. This is reasonable if we recall that what is being measured is the adverse information friction in one trade. Of two stocks with the same potential for adverse information over the trading day, the one with greater trading volume will have a smaller adverse information effect per trade. The informational friction component also declines with the stock price, reflecting in part the mechanical fact that friction is measured as a fraction of the stock price and also the possibility that stock price proxies for stability, greater disclosure, and a lower probability of informed trading.

The third regression in each set in Table VIII measures informational friction by the difference between the effective spread and the transformed Roll price covariance. The conclusions for this measure are the same as for the measure, $ES - TS1$, with the exception that the number of trades has a positive effect in Nasdaq.

The intercept term for the informational regressions in Table VIII reflects informational friction not explained by firms' characteristics. Consider for example the regression with the dependent variable $(ES - TS1)/P$. The fact that the constant for the NYSE/AMSE (0.4745) is about the same as the constant for Nasdaq (0.4769) implies that informational frictions in the two markets are the same after adjusting for company trading characteristics. The difference in trading costs on the two markets therefore must reflect differences in real frictions, not in informational frictions. A comparison of the constant terms for the regression with the dependent variable, $(ES - \text{Rollprice})/P$, leads to the same conclusions.

Turn now to the quote covariances. The quote covariances do not reflect the bounce of transaction prices from bid to ask and back but only the serial covariance in the quotes induced by trades. The observed negative serial covariance in quotes implies the presence of inventory costs. Are these inventory costs associated with firms' trading characteristics? The cross-sectional regression results—regressions 6 and 7 in Table VII—indicate they are. Although the R^2 is smaller than for the other regressions, the same variables are highly significant. Both the transformed ask and bid covariances (Rollask/P, Rollbid/P) are negative in activity variables like volume or number of trades, negative in price and positive in variance and in imbalance, like the other real friction measures. The intercepts are only slightly higher on Nasdaq than on the NYSE/AMSE, which suggests that the difference in trading costs in the two markets is not due to inventory costs.

The price impact measure, which I have interpreted as a measure of informational friction, is strongly related to firms' characteristics, despite the low correlations with other friction measures observed in Table VI. It displays a somewhat different cross-sectional pattern than the other friction measures. The magnitudes of the intercept and the coefficients are larger, which reflects the fact that the price impact is for the day, whereas the other measures are per trade. As one would expect, price impacts are smaller for firms with larger volumes and larger market values. They are larger when the return variance is larger. Firms with a large average number of trades (holding constant price and market value) tend to have larger price impacts. Although this is also true for some of the other friction measures, particularly on the NYSE/AMSE, the effect is stronger for the price impact measure. The coefficients on volume and on the number of trades suggest that price impact declines in average trade size. Although this appears counterintuitive at first, it is not. It simply says that the reaction of the price to an imbalance is greater for stocks that have smaller average trade sizes.

The intercept is higher for the Nasdaq regression (3.21 percent per day) than for the NYSE/AMSE regression (1.61 percent per day), implying that daily price impacts are larger in Nasdaq, holding constant firms' characteristics. Insofar as the price impact reflects informational frictions, as I have argued, the result is at variance with the implications of the other regressions that suggest informational frictions are about the same in the two markets. This difference deserves further investigation, for it may reflect a difference in the process by which information is incorporated into price. Recall that the price impact measure is based on changes in the quote midpoint, whereas the other measures are the fraction of the effective spread not ascribed to real friction. If quotes adjust to imbalances more quickly in one market than another, the two measures would give different results. For example if quotes in Nasdaq adjust in anticipation of imbalances, the quoted spread need not be as large as it otherwise would have to be. One might observe a larger price impact on Nasdaq and at the same time conclude that the fraction of the spread due to informational factors is the same on the two markets.

The final measure of friction—opening volatility—is virtually unrelated to stock characteristics. This is somewhat surprising because the correlations with other friction measures are significant. The results suggest that the friction around the opening reflects something different from the friction at other times of the day and that this source of friction is not related to stock characteristics that are important for other friction measures. In particular, as suggested by Amihud and Mendelson (1987) and Stoll and Whaley (1990), opening volatility may reflect the difficulty of dealing with opening order imbalances or digesting overnight news, matters that are uncorrelated with company characteristics.

VI. Conclusions

I have distinguished total friction and its components, real and informational frictions. Real frictions use up real resources. Informational frictions redistribute wealth. I have provided evidence about some simple and robust measures of friction, distinguishing between static and dynamic measures. I have examined whether the different measures are correlated and related in the same way to stock characteristics. I find important and robust regularities in the nature of friction and its cross-sectional behavior. Real friction, arising from order-processing costs and inventory costs, is important, and evidence of informational friction is also in the data.

The evidence from transactions data for a sample of 1,706 NYSE/AMSE stocks and 2,184 Nasdaq stocks in the three months ending on February 28, 1998, leads to a number of specific conclusions:

- The quoted spread and the effective spread, which accounts for negotiation inside the quoted spread, reflect total friction. Over all NYSE/AMSE stocks, the quoted and effective half-spreads are 7.9 and 5.6 cents respectively. Over all Nasdaq stocks, the quoted and effective half-spreads are 12.6 and 10.7 cents, respectively. The correlation of the quoted and effective spreads exceeds 99 percent, which indicates that these measures are equivalent as indicators of cross-sectional differences in total friction.
- Spreads vary systematically with characteristics of stocks in a manner that is as robust and significant as any empirical relation in finance.
- I introduce a new measure of real trading friction, the traded spread, which resembles what institutional investors use to calculate their trading costs. The traded spread is a measure of real friction, for it measures what demanders of immediacy pay. It is calculated as the difference between the average price of trades at the ask side and the average price of trades at the bid side. The traded half-spread (using volume weights) averages 3.7 cents over all stocks on the NYSE/AMSE and 8.0 cents over all stocks on Nasdaq.
- The half-spread implied by the serial covariance of price changes—the Roll implied spread—also measures real friction, as it captures the bid-ask bounce. Its magnitude—3.81 cents on the NYSE/AMSE and 11.15 cents on Nasdaq—and its cross-sectional behavior are consistent with the magnitude and behavior of the traded spread.
- Stocks with high total friction (as measured either by the quoted or effective spread) also tend to have high real friction (as measured by the traded spread or Roll implied spread). This implies that cross-sectional variations in friction result from real frictions.
- I find evidence of an inventory component of the spread in the significant negative serial covariance of bid and ask quote changes. Only inventory effects would generate negative serial covariance in quotes.
- I find evidence of an informational component of the spread. The informational component of the spread is reflected in the difference between total friction (such as the quoted or effective spread) and real friction (such as the traded spread or the Roll implied spread). The informational friction averages 2 to 2.5 cents per share on both NYSE/AMSE and Nasdaq. The cross-sectional behavior of the informational component is similar to that for the real friction measures. The good news is

that these different friction measures reflect a common source of friction. The bad news is that real and informational components, which are dramatically different in theory, do not seem to be dramatically different in their cross-section relation to company characteristics.

- I calculate a daily price impact coefficient as the effect on quote midpoints of the daily percentage imbalance between purchases and sales. I interpret the coefficient as a measure of the information content of trades as in Kyle (1985). The price impact for the average daily imbalance is about 15 cents per day across all stocks. The implied price impact *per trade* in a daily imbalance is less than 0.5 cents per day, which contrasts with the informational friction of 2 to 2.5 cents per share per trade estimated from trade to trade price changes. The price impact measure is also not highly correlated with other friction measures, a puzzle that deserves additional analysis.
- Friction at the opening is not correlated with other friction measures and does not depend on company trading characteristics. Opening volatility appears to reflect characteristics of the opening and the overnight news arrival, not the trading characteristics of stocks.
- Market structure has an effect on friction measures. There continues to be a significant difference between the NYSE/AMSE auction market and the Nasdaq dealer market in the magnitude of frictions, and the difference is in real friction rather than informational friction. After controlling for company characteristics, real friction measures are larger in Nasdaq than in the NYSE.

What are the next steps? Work remains both in deepening our understanding of friction and broadening the scope of research. Can we relate measures of friction inferred from trade and quote data more precisely and more directly to sources of friction? Are differences in informational frictions across stocks related to differences in the market for information in those stocks? Are differences in the option value of a quote associated with differences in communication speed and the maturity of such options? Are differences in real measures of friction associated with differences in the cost of processing orders in different stocks? Are differences in inventory costs associated with differences in the difficulty of reaching a desired inventory?

My approach has been cross-sectional. Yet there are interesting questions, just beginning to be studied, about systematic variation in friction through time. If friction has systematic components in cross section, one might expect systematic friction components to exist in time series, but it would be helpful to understand the source of any common factor. For example, are changes in the spread over time a reflection of trading pressures or of informational factors?

Study of the asset pricing implications of friction will no doubt be an important area of research. In such studies we need to be clearer about the theoretical implications of real versus informational frictions. Which should be priced and why?

Finally the study of friction is important because it is the study of how markets operate. Academic analyses of markets—from Stigler's (1964) criticism of the SEC's Special Study of Securities Markets, to the Institutional Investor Study (1971), to studies of derivatives and program trading in the 1980s, to the Nasdaq controversy in the early 1990s, to debates about optimal tick size—have played an important role in shaping policy and practice. This will continue as we ponder how the Internet and electronic trading will alter markets.

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