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Trader Anonymity, Price Formation and Liquidity

by

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Trader Anonymity, Price Formation and Liquidity*

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Abstract: Using data from the Frankfurt Stock Exchange we analyze price formation and liquidity in a non-anonymous environment with similarities to the floor of the NYSE. Our main hypothesis is that the non-anonymity allows the specialist to assess the probability that a trader trades on the basis of private information. He uses this knowledge to price discriminate. This can be achieved by quoting a large spread and granting price improvement to traders deemed uninformed. Consistent with our hypothesis we find that price improvement reflects lower adverse selection costs but does not lead to a reduction in the specialist's profit. Further, the quote adjustment following transactions at the quoted bid or ask price is more pronounced than the quote adjustment after transactions at prices inside the spread. Our results indicate that anonymity comes at the cost of higher adverse selection risk.

JEL classification: G10

Keywords: anonymity, bid-ask spreads, floor trading, price improvement, specialists

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1 Introduction

Security markets differ along a variety of dimensions. These comprise, but are not limited to, different degrees of market transparency, of the automation of the trading process and of the intermediation through market makers or specialists. The present paper focuses on the degree of trader anonymity and its impact on price formation and liquidity. We define the degree of anonymity to be the degree of information about the identity of a potential counterparty that is revealed before a transaction takes place.

The issue addressed in this paper is important for a number of reasons. First, the degree of anonymity is potentially related to the extent to which informed traders can exploit their informational advantages and may, therefore, be related to the adverse selection costs. Second, many electronic trading systems are anonymous. Gaining insights into the impact of anonymity on price formation and liquidity may enhance our understanding of the relative merits of these trading systems. Third, a situation where an anonymous and a non-anonymous market coexist is often encountered in reality. The upstairs market for block trades, the development of anonymous proprietary trading systems and NASDAQ's anonymous SOES system are cases in point. The key to understanding the reasons for this coexistence may well be in an in-depth analysis of the effect of anonymity on market outcomes.

It is widely believed that institutional investors prefer anonymous trading systems because they do not want to publicly disclose their trading needs (see the survey results in Economides / Schwartz 1995 and Schwartz / Steil 1996). On the other hand, however, anonymity allows informed traders to remain unidentified and may thus aggravate the adverse selection problem. Further, in an anonymous market it is difficult for uninformed traders to signal their uninformed trading motives, e.g. in the sense of sunshine trading (Admati / Pfleiderer 1991).

Given the importance of the issue, surprisingly little is known about the effects of anonymity on price formation and liquidity. In the dual trading models of Röell (1990) and Fishman / Longstaff (1992), a broker has information about the trading motives of his customers. The market itself, however, is assumed to be anonymous. In Forster / George (1992) and Madhavan (1996) strategic traders have information about either the direction or the magnitude of liquidity trading. This knowledge about the composition of the aggregate order flow is qualitatively different, however, from knowledge about identities and trading motives of individual traders. Seppi (1990) models the coexistence of an anonymous trading floor and a non-anonymous upstairs market for block transactions. He finds that the upstairs market attracts uninformed traders.

Benveniste / Marcus / Wilhelm (1992) model the interaction between a specialist and brokers who have information about the trading motives of their customers. In their „active specialist“ case the brokers share this information with the specialist in order to maintain a reputation as a fair trader. Rhodes-Kropf (2001) presents a model in which a fraction of the uninformed traders are (through a mechanism which is exogenous to the model) identified by the market makers and receive better prices, reflecting the absence of adverse selection costs. Desgranges / Foucault (2000) develop a dynamic model of a non-anonymous market in which a trader possesses private information in some periods and has a hedging demand in other periods. They show that the trader, in case she is informed, may voluntarily choose not to trade with her regular market maker in order not to erode her reputation. The benefit of maintaining a good reputation comes in the form of lower transaction costs.

These models share the feature that the specialist (or market maker) has information about the trading motive of his counterparties, either because of identification ability or because of self-selection on the side of the trader. The specialist uses his information by discretionary granting price improvement. Orders of traders deemed uninformed are executed at prices inside the quoted spread whereas traders deemed informed have to pay the quoted spread.

However, price improvement may be granted for reasons other than those outlined above. Rhodes-Kropf (2001) develops a second model in which price improvement is related to customer market power, rather than to private information. Ready (1999) argues that price improvement is related to strategic behavior on the side of the NYSE specialist. The specialist may execute an incoming market order against the book, or he can trade for his own account. In the latter case NYSE order handling rules require that the transaction price improve upon the price limit of the best limit order, i.e., the rules require that price improvement be granted. The specialist has a third possibility. He can stop an incoming market order and delay the decision whether to execute it against the book or trade for his own account. If the specialist uses his discretion to maximize profits, he will impose adverse selection costs on limit order traders. In an empirical analysis using the NYSE's TORQ database Ready (1999) finds support for his hypothesis. Note that even in the case of strategic specialist behavior price improvement is the result of the specialist using information inferred from the order flow to price discriminate. What is different is the effect of price discrimination. It results in a re-distribution of trading profits between the specialist and limit order traders, rather than in a reduction in overall trading costs.

Direct empirical evidence on the effects of trader anonymity is rather scarce. Harris / Schultz (1997) find that market makers lose on trades with the „SOES bandits“ which are executed in the anonymous SOES system. Both Madhavan / Cheng (1997) and Booth et al. (2001) document that, consistent with the model of Seppi (1990), the upstairs market is primarily used by uninformed traders. Similarly, Smith et al. (2001) find that trades which are executed in the Toronto Stock Exchange's upstairs market are predominantly liquidity-motivated. Garfinkel /

Nimalendran (2001) find that NYSE stocks exhibit larger increases in the bid-ask spread on insider trading days[1] than NASDAQ stocks. The authors consider this to be evidence that the trading system of the NYSE is less anonymous. Consistent with this result, Heidle / Huang (1999) show that the probability of trading with an informed trader is higher on NASDAQ than on either the NYSE or the AMEX. De Jong / Nijman / Röell (1996) show that trades that are negotiated bilaterally (and thus non-anonymously) and are then executed through the Paris Bourse's CAC system have a much lower price impact than regular CAC trades.

Angel (1997) uses the TORQ database to investigate into price improvement on the NYSE. He documents that, among other variables, the size of the spread, the type and size of the order, and the market capitalization of the stock are related to the probability of price improvement. To the extent that these variables convey information about the trading motive, these results are consistent with price improvement being used as a means of price discriminating based on the information content of the order.

The present paper adds to this literature. It builds on a theoretical framework similar to that developed in Benveniste / Marcus / Wilhelm (1992) in order to derive and test hypotheses on the price formation in a non-anonymous market. We assume that the non-anonymity of the environment allows the specialist to assess the probability that a trader trades on the basis of private information. The specialist uses this knowledge to price discriminate. This can be achieved by quoting a large spread and granting price improvement to traders deemed unin-

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[1] An insider trading day is defined as a day on which officers or directors have traded in shares of their firm. Such trades have to be reported and are subsequently published by the SEC. Fishe / Robe (2001) analyze cases of illegal insider trading. They find that the size of the spread is unaffected by the insider trading activity, but that depth declines. The depth reduction is more pronounced on the NYSE than on Nasdaq. The authors interpret this as evidence that the NYSE specialists may more readily detect informed trading.

formed. Two testable implications can be derived from this. First, price improvement reflects lower adverse selection costs but does not lead to a reduction in the specialist's profit. Second, transactions that occur at the quoted prices are more likely to be initiated by informed traders. Therefore, the quote adjustment following these transactions should be more pronounced than the quote adjustment after transactions at prices inside the spread. We test these hypotheses empirically using data from the Frankfurt Stock Exchange, a non-anonymous market that is organized in a way similar to the New York Stock Exchange. The results are consistent with both hypotheses and, therefore, support the notion that a non-anonymous environment allows the identification of informed traders and may thus alleviate the adverse selection problem. Put another way, our results imply that anonymity is not achieved without a cost. The cost comes in the form of higher adverse selection risk.

Our paper extends the related analysis of Angel (1997) in several respects. First, and most importantly, we do not only analyze the determinants of price improvement but also analyze the profitability of executing the order and the quote adjustment in response to the execution. Second, we use a more recent data set from a non-US market.

The remainder of the paper is organized as follows. In section 2 we derive our hypotheses. In section 3 we describe the data set. The results of the empirical analysis are presented in section 4. Section 5 offers a concluding discussion of the implications for the design of trading systems.

2 Hypotheses

Our hypotheses build on the assumption that the non-anonymous environment allows the specialist to draw inferences about the motives behind individual trades. This may be achieved in either of two ways. First, the specialist may be able to draw inferences from the observed behavior of a counterparty. Second, the specialist may base his judgement on past trading experience with the trader in question. In both cases the specialist must be able to price discriminate, i.e., to offer different prices to different traders. A simple way to achieve price differentiation is to quote a large spread that incorporates a sufficient adverse selection component and to execute transactions with traders deemed uninformed at a price inside the quoted spread.

It is important to note that for this mechanism to work it is not necessary that the specialist can infer the trading motive with certainty. It is sufficient if he is able to correctly assign a higher probability for information-motivated trading to some traders.

The argument outlined above is similar in spirit to the basic idea of the model of Benveniste / Marcus / Wilhelm (1992). In this model the specialist interacts with brokers who represent customer orders. A broker has some information about the trading motives of his customers that is not known to the specialist. Whenever she represents an order that is likely to be information-motivated she faces a trade-off. She may try to obtain best execution for this order. This may secure her future business with the customer in question but, at the same time, erodes her reputation vis-a-vis the specialist.[2] Consequently, the specialist will offer her less favorable conditions in future transactions. This adversely affects the execution quality the broker can obtain for her uninformed customers. In order not to lose these customers the broker has an incentive not to search for best execution for her informed customers in the first place. Note that this does not necessarily entail violating her fiduciary duties vis-a-vis these customers. Not to search for best execution may simply mean accepting the quoted prices

[2] This assumes that the specialist is, in a probabilistic sense, able to identify information-motivated transactions after the fact. This is a realistic assumption, however, because the specialist observes the trade direction and the subsequent price movement.

rather than trying to negotiate a price improvement. This results in self-selection on the side of the brokers. Orders that are likely to be motivated by private information are executed at the quoted prices, orders that are likely to be liquidity-motivated tend to be executed at prices inside the quoted spread.

From the point of view of the empiricist who only has access to price and quotation data, the two cases - specialist identification ability and broker self selection - are observationally equivalent because they yield the same testable implications.

The first hypothesis is based on the observation that, given the conjectured behavior of brokers and / or specialists, price improvement reflects lower adverse selection costs and should, therefore, not be associated with lower market making profits. We thus have:

H1 *The specialist's profit on transactions with price improvement is not smaller than his profit on non price-improved transactions.*

In the "market power model" of Rhodes-Kropf (2001), price improvement is granted because investors have differing degrees of market power vis-a-vis the market maker. In this case, granting price improvement should reduce the market maker's profits. A test of hypothesis H1 may thus enable us to discriminate between information-related and non information-related explanations of price improvement. It should be noted, however, that the two hypotheses are not mutually exclusive.

The second hypothesis makes use of the fact that, under the conjectured behavior, a transaction that is executed at the quoted price (rather than at a price inside the quotes) has a higher probability of being initiated by an informed trader. The specialist should make use of this knowledge when adjusting his quotes. We thus have:

H2 The increase [decrease] in the quote midpoint after a buyer-initiated transaction [seller-initiated transaction] is stronger if the transaction took place at a price equal to the prevailing quote as compared to a transaction at a price inside the quotes.

One remark is in place before we proceed. Rhodes-Kropf (2001) develops a market power-based and an information-based model of price improvement. Both models yield the prediction that quoted and effective spreads rise as the percentage of informed traders increases. However, the *negotiated spread* (defined as the effective spread conditional upon price improvement being granted) will remain constant in the information-based model but increases in the market-power-based model. Relating the negotiated spread to a proxy for the fraction of informed traders thus appears to be a valid test to discriminate between the two models.

Unfortunately, this is not necessarily the case. In his information-based model, Rhodes-Kropf (2001) assumes that only uninformed traders receive price improvement. This assumption (which is necessary to obtain the desired result) requires that the market maker is able to identify a fraction of the uninformed traders *with certainty*. This is unlikely to be the case. Therefore, the test outlined above will not yield a clean discrimination between market power-based and information-based explanations for price improvement.

3 Data

We use data from the continuous trading sessions (called *variabler Handel*) on the floor of the Frankfurt Stock Exchange to test the hypotheses derived in the preceding section.[3] Trading at

[3] Besides the continuous trading session there are several call auctions each day; an opening auction, a closing auction and, in our sample period, a third auction at noon. An electronic trading system (until November 1997 IBIS, since then XETRA) operates parallel to the floor.

the Frankfurt Stock Exchange is organized in a way that is similar to the structure of the trading process on the NYSE. Trading is conducted through the *Amtlicher Kursmakler* (henceforth Makler). His position resembles that of the NYSE specialist. He has exclusive access to the information in the limit order book. The Makler may trade on his own account, but is not obliged to do so.

The Makler continuously quotes bid and ask prices. These are called *Pretrades*. The quotes posted by the Makler either represent limit orders in his book or his willingness to trade on his own account. The quotes are entered into an electronic system (BOSS-CUBE). Two characteristics of the Pretrades are noteworthy. First, there is no explicit quoted depth. It appears, however, that the depth at the quotes is reasonably high. The median transaction size for the sample stocks ranges from DM 89,000 ($ 50,857[4]) to DM 584,200 ($ 333,828) with the cross-sectional average being DM 277,238 ($ 158,421). Further, the percentage of transactions occurring at prices outside the quoted spread is low, averaging 0.9% in our sample. These facts lend support to our statement that quoted depth is reasonably high.

Second, the quotes are deleted automatically after each transaction. An undesirable consequence of this is that a quoted spread does not always exist and that, therefore, some transactions take place absent a valid quoted spread. On the other hand, the Makler is forced to enter new quotes shortly (usually a few seconds) after a transaction. These quotes should incorporate the price impact of the preceding transaction, a feature that will prove to be useful in the empirical analysis. Further, quotes are less likely to become stale and the incentive for the Makler to quote a wide spread (but effectively trade inside that spread) in order to avoid frequent re-posting of quotes is reduced – re-posting is mandatory after each transaction.

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4 Based on an exchange rate of 1.75 DM/$, which is representative for the middle of the sample period.

Besides any profits he may earn on his market making activities, the Makler receives a commission called *Courtage*. Both the buyer and the seller have to pay 0.04% (for stocks included in the DAX index) or 0.08% (for other stocks).[5]

When deriving our hypotheses we implicitly assumed that the Makler is the sole, or at least the dominant, supplier of liquidity. Empirical results reported in Freihube et al. (1999) document that this is indeed the case. The quoted spread is narrower than the spread obtained from the orders in the limit order book in more than 55% of the cases.[6] In these cases the spread represents the willingness of the Makler to trade on his own account rather than on behalf of a customer. Further, more than 46% of the transactions occur at prices inside the quoted spread. In many of these cases the Makler is trading on his own account. In fact, Freihube et al. (1999) find that the Makler participates in more than 80% of the transactions and accounts for more than 40% of the trading volume. These figures are higher than the comparable figures for the NYSE reported by Madhavan / Sofianos (1998). Applying a model that assumes that the Makler is the dominant supplier of liquidity thus appears to be justified. Freihube et al. (1999) also analyze the trading profits of the Maklers and conclude that they, on average, earn zero profits. Their income thus appears to be restricted to the commissions they receive.

The sample for the present study comprises the 30 stocks which constitute the DAX index and an additional 14 stocks which are part of the mid-cap index MDAX. The latter were selected by ordering all 70 MDAX stocks by trading volume and choosing every 5th. The four least liquid stocks had to be discarded from the data set because the number of observations was

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5 This is the regular rate that is paid by retail investors. Floor brokers (*Freimakler*) pay a lower commission.

6 Chung / Van Ness / Van Ness (1999) report a comparable figure for the NYSE. There, the quoted spread is narrower than the spread calculated from the best bid and offer in the limit order book in only 29.3% of the cases.

insufficient to reliably estimate the components of the spread. This leaves us with 40 stocks in the final data set.

The data set comprises time-stamped transaction prices, volume data and the quotes entered by the Makler. Trades were classified as being buyer-initiated or seller-initiated using the procedure proposed by Lee / Ready (1991). The data do not identify the transactions the Makler makes for his own account, nor does it contain information on the Makler's inventory position. The sample period spans the 44 trading days in June and July 1997. Two days (July 21st and July 23rd) were removed from the sample. On both days heavy trading caused a breakdown of the exchange's computer facilities. Trading had to be suspended several times.

The data set was screened carefully to eliminate outliers. Most outliers detected by the filtering rules we employed were obviously due to typing errors (e.g., an ask price of 730 instead of 370). Such errors were usually corrected by the Makler after some seconds.

4 Empirical results

4.1 Price Improvement: Importance and Determinants

In this section we present descriptive statistics on the frequency and magnitude of price improvement (see Petersen / Fialkowski 1994 and Ross / Shapiro / Smith 1996 for comparable results for the NYSE). We further estimate a Tobit model to analyze the determinants of the price improvement.

Table I shows the percentage of transactions with price improvement separately for the 30 DAX stocks, sorted into three groups by trading volume, and the 10 MDAX stocks.[7] Separate

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[7] This grouping is almost equivalent to a grouping by trading volume. Only one of the 10 MDAX stocks (SGL Carbon) has a trading volume that is larger than that of the least liquid DAX stock.

figures for small and large transactions are given. A small [large] transaction is defined as a transaction that is smaller than [larger than] the median transaction size for the stock in question. Price improvement is measured with respect to the quotes on the floor of the Frankfurt Stock Exchange. Quotes in the competing electronic trading system IBIS may be (and, in fact, frequently are) better. We address the issue of quote competition later.

Small transactions receive price improvement in 56.8% of the cases. There does not appear to exist a relation between this percentage and the total trading volume of the stocks. In fact, the correlation between the improvement frequency and the trading volume is 0.03. Large transactions receive price improvement less than half as often as small transactions. The aggregated figures in the table suggest a tendency for large transactions in less liquid stocks to receive price improvement less frequently than large transactions in more liquid stocks. The correlation coefficient is, however, only 0.17 and is not significantly different from zero.

Table I also reports the fraction of trades that occur at the quote midpoint. On average, the probability that a transaction takes place at the midpoint is about half the probability that it will receive any price improvement at all. Further, the probability that a small transaction is executed at a price equal to the quote midpoint is about twice as large as the corresponding probability for a large transaction. Transactions at the quote midpoint are less likely for less liquid stocks. The correlation coefficients between the frequency of transactions at the quote midpoint and the total trading volume are 0.34 for small transactions and 0.38 for large transactions. Both coefficients are significantly different from zero at the 5% level.

The last two columns of Table I report the price improvement as a percentage of the quoted spread. A figure, e.g. 44.04% for the small transactions, has to be interpreted as follows. On average, the effective spread on a small transaction is 44.04% smaller than the spread quoted immediately prior to the transaction. The figures thus represent the unconditional expectation of the reduction in transaction costs due to price improvement. The average percentage price improvement for small transactions amounts to more than 40% of the quoted spread and is more than twice as large as the corresponding value for large transactions. The figures suggest a tendency for the average degree of price improvement to be smaller for less liquid stocks. However, the correlation coefficients are only 0.16 and 0.27 for small and large transactions, respectively, and are not significantly different from zero at the 5% level (the latter coefficient is marginally significant at the 10% level).

The results presented in this section document that a significant fraction of the transactions on the floor of the Frankfurt Stock Exchange receive price improvement. The fact that small transactions are more likely to benefit from price improvement is consistent with the notion that informed traders are more likely to trade larger quantities.

One point should be addressed before we turn to the analysis of the determinants of the price improvement. The Makler on the floor of the Frankfurt Stock Exchange is exposed to competition not only by the limit order book, but also by competing markets. The most important competitor is the anonymous electronic trading system IBIS with a market share of approximately 40% in the sample period.[8] Although no Consolidated Quotation System exists, market participants on the floor are aware of the bid and ask prices in IBIS. This provides another rationale for price improvement on the floor. The Makler may grant price improvement in cases were his own quotes are inferior to those in IBIS.

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8 Besides IBIS and the Frankfurt Stock Exchange there are seven regional exchanges. They are of minor importance as evidenced by an aggregated market share of slightly above 10% for the DAX stocks. Therefore, and because quote data for the regional exchanges is unavailable, we do not explicitly include the regional exchanges in our analysis.

To investigate into this issue we obtained data on bid and ask quotes from IBIS. That data was, however, only available for the 30 DAX stocks. We matched transactions on the floor to the IBIS quotes in the moment the transaction occurred. We then sorted the transactions into two groups:

- transactions where the relevant quote in IBIS (i.e., the ask for buyer-initiated transactions and the bid for seller-initiated transactions) was better than the corresponding quote on the floor and
- transactions where the quote on the floor was at least as good as the IBIS quote.

Table II reveals that the occurrence of price improvement is indeed related to the competitiveness of the quotes. The probability of receiving price improvement is about twice as high when the IBIS quote is better than the floor quote. Similarly, the average magnitude of the price improvement is about twice as large when the IBIS quotes are better. Thus, quote competition appears to be one, but not the sole, determinant of price improvement.

In order to investigate into the determinants of price improvement in more detail, we use a regression analysis. The dependent variable is the degree of price improvement in each transaction, expressed as a percentage of the quoted spread immediately prior to the transaction.[9] We include independent variables that are related to the risks faced by the Makler.

Standard models of the bid-ask spread assume a fixed transaction size (among the exceptions are Easley / O'Hara 1987 and Glosten 1989). In these models, price improvement does not occur because the quoted prices incorporate a compensation for the inventory and adverse selection risk tailored to the fixed transaction size. In reality, however, transaction sizes are

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9 The problem, encountered in NYSE data, that quotes may be recorded ahead of the transaction that triggered them does not arise in our data set.

not fixed and the equilibrium spread is likely to depend on the transaction size. Price improvement may, therefore, be granted on those transactions where the equilibrium spread is smaller than the quoted spread. The descriptive results presented in Table I are consistent with this conjecture. The relation between transaction size and equilibrium spread may well be nonlinear, e.g. because of fixed order processing costs. To allow for such non-linearities we include both the transaction size, measured as the number of shares traded, and the squared transaction size on the right-hand side.[10]

Increased return volatility increases the risk the Makler faces and may, therefore, affect his willingness to grant price improvement. To capture this effect we include the absolute change in the midquote between the transaction in question and the preceding transaction as an independent variable. The size of the bid-ask spread itself may also depend on the inventory and adverse selection risk perceived by the Makler. Further, the size of the spread may be related to the Makler's (possibly time-varying, e.g., Brock / Kleidon 1992) market power. We therefore include the spread in the regression. Finally, a series of transactions on the same side of the market may reveal insider trading activity. We therefore include a dummy variable taking on the value 1 whenever the transaction is on the same side of the market as the

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[10] The Makler may also be more likely to grant price improvement on transactions that reduce his inventory. Unfortunately, we do not observe his inventory directly. We estimate a version of the regression model where we include a proxy variable for the inventory. We use the total number of shares bought or sold by all suppliers of liquidity on the specific trading day, up to (but excluding) the transaction in question. We sign the variable such that it carries a positive sign when the transaction in question reduces the inventory and a negative sign otherwise. We follow Manaster / Mann (1996) in setting the inventory at the beginning of each trading day to zero. Because the Maklers are able to lay off inventory in the electronic trading system (which offers considerably longer trading hours than the floor), cumulating inventory over the trading days would be inappropriate. The results of this version of the model are almost identical to those reported in the text.

preceding transaction and taking on a value of zero otherwise. This leads to the following model

$$\frac{\left(s_t^q - s_t^e\right)}{s_t^q} = \gamma_0 + \gamma_1 q_t + \gamma_2 q_t^2 + \gamma_3 \left|mq_t - mq_{t-1}\right| + \gamma_4 s_t^q + \gamma_5 D_t + \varepsilon_t \tag{1}$$

where t is a (transaction) time index, s_t^q and s_t^e are the quoted and the effective spread, respectively, q_t is the transaction size, measured as the number of shares traded, mq_t is the quote midpoint in effect immediately prior to transaction t and D_t is a dummy variable taking on the value one whenever transaction t is a continuation, i.e., occurs on the same side of the market as the preceding transaction.

The dependent variable in (1) can only take on values between zero and 1.[11] A value of zero, corresponding to a transaction at the quoted bid or ask price, is by far the most frequent observation in the sample. OLS estimation, therefore, seems inappropriate.[12] Instead, we treat the dependent variable as being censored at zero. The censoring assumption is appropriate

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[11] For transactions at a price outside the quoted spread, the dependent variable would be negative because the effective spread is larger than the quoted spread. In fact, some transactions (approximately 0.9%) occur at prices outside the spread. Most of these transactions, however, were the second (or a subsequent) transaction in a sequence of transactions *without* an intermediate quote publication. Since, as outlined in section 3, the quotes are deleted automatically after the first of the series of transactions, the subsequent transactions take, strictly speaking, place when there is no valid quoted spread. Therefore, the degree of price improvement is not defined. In the light of this we decided to exclude transactions at prices outside the last quoted spread from the analysis.

[12] Petersen / Fialkowski (1994), facing a similar problem, consider estimating a (multinomial) logit model because, in their data set, 97% of the observations for the dependent variable are 0, one eighth or two eighths. The variation in our data set is much greater because the minimum tick size is much lower. It amounts to DM 0.01 [0.05] for stocks trading at prices up to [above] DM 100.

because there are cases in which the unobservable equilibrium spread is larger than the quoted spread (and, consequently, the price improvement should be negative) but the Makler has to trade at his quoted prices. This may occur because he did not update his quotes. Similarly, the quoted bid or ask may be determined by a stale limit order. In addition, the Makler may occasionally trade at unfavorable prices in order to preserve price continuity.[13] To account for the censoring we estimate equation (1) as a Tobit model.

The results are shown in Panel A of Table III. The first five lines show the means of the estimated marginal effects for all stocks and for four groups of stocks (large, medium and small DAX stocks, and the 10 MDAX stocks). The marginal effects are obtained by multiplying the estimated coefficients by the fraction of uncensored observations. The lower part of the Table shows the number of positive and negative coefficients. The independent variables have explanatory power for the degree of price improvement. A Likelihood Ratio Test rejects the null hypothesis of no explanatory power for all 40 stocks. The average McFadden-R^2 is 0.158.

Consistent with the results shown in Table I and those reported by Petersen / Fialkowski (1994) and Ross / Shapiro / Smith (1996) for the NYSE, the degree of price improvement decreases with transaction volume. The volume coeffcient is negative for all 40 stocks and is significantly different from zero for 39. The relation between volume and price improvement

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[13] Note, however, that rules concerning price continuity are less strict than those for NYSE specialists. However, Freihube et al. (1999) document that stabilization ratios are only slightly lower than those reported for NYSE specialists.

appears to be nonlinear. In all but one case the coefficient on squared volume is positive, implying a concave relation between trade size and price improvement.[14]

Similar to Petersen / Fialkowski (1994) and Ross / Shapiro / Smith (1996) we find that the degree of price improvement is positively related to the size of the spread for all 40 stocks. This is consistent with an adverse selection interpretation of the spread. When facing higher adverse selection risk, the Makler widens his spread. If he subsequently trades with a counterparty known to be uninformed, there is a higher potential for price improvement than in periods with smaller spreads. An alternative interpretation (related to the strategic specialist in Ready 1999) that takes the role of public limit orders into account can also be given. The Makler's quote may represent limit orders in the book rather than his own willingness to trade. In this case, the adverse selection risk is passed on to the limit order traders. This is likely to happen when adverse selection risk, and consequently the spread, is high. Although the quotes represent limit orders in the book, the Makler may nevertheless participate in a trade. In this case, however, he has to improve on the price of the limit order in the book. Therefore, a strategy of partially withdrawing from the market and picking potentially profitable trades is also consistent with a positive relation between spreads and price improvement.

The coefficient on the volatility proxy – the absolute midquote change since the last transaction – is negative in 30 cases and significant in 13. This implies that the degree of price

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[14] The positive coefficient on squared volume does not, in general, cause the total effect of volume on the degree of price improvement to become positive. The „break-even volume“ (the transaction size at which the negative linear and the positive quadratic effect cancel out) is, in all but one case, at least six times the average transaction size for the stock in question. Note, however, that the marginal effects reported in Table III measure the effect of a change in an independent variable on the degree of price improvement at the mean of the independent variables.

improvement is negatively related to volatility once the size of the spread is taken into account.

Finally, the coefficient for the dummy variable indicating continuations is positive for the majority of the stocks. This is somewhat surprising because a sequence of transactions on the same side of the market is more likely when informed traders are present. It may, however, be the case that other variables, particularly the spread and the absolute quote change, already capture this effect.

As shown in Table II, quote competition also appears to be a determinant of price improvement. To address this issue, we re-estimate model (1) including an additional variable measuring the competitiveness of the floor quote. It is defined as

$$\frac{\left(a^f - a^i\right)}{0.5\left(a^f + a^i\right)} \text{ and } \frac{\left(b^i - b^f\right)}{0.5\left(b^i + b^f\right)}$$

for buyer-initiated and seller-initiated transactions, respectively. *a* denotes the ask price, *b* denotes the bid price, and the index (*f* for the floor, *i* for IBIS) indicates the market where the quote originates. The variable carries a positive sign whenever the quote on the floor is inferior to the quote in IBIS.

We have to restrict the analysis to the 30 DAX stocks because quote data from IBIS was unavailable for the MDAX stocks. The results are presented in Panel B of Table III. The competitiveness of the floor quotes proves to be an important determinant of price improvement. It carries the expected positive sign and is significant for 29 stocks. More importantly, however, coefficients of the other variables remain largely unchanged; the only exception being the spread. However, since the quotes on the floor are more likely to be less competitive when the spread on the floor is large, the spread and the competitiveness variable are positively correlated and the reduced magnitude of the coefficient for the spread should come as no surprise.

Taken together, the results of the Tobit analysis provide support for our hypothesis that price improvement is related to the „management“ of adverse selection risk in a non-anonymous environment.

4.2 Price improvement and market maker profits

Hypothesis 1 states that price improvement reflects lower adverse selection costs. Therefore, the Makler’s profits should be unaffected by the degree of price improvement. We test this hypothesis by estimating the Makler’s profit for each transaction and relating the profit to the degree of price improvement granted. We use the realized spread as our measure of the Makler’s profits. It was obtained by matching each transaction with a subsequent transaction at the opposite side of the market, i.e., each buyer-initiated transaction was matched with a subsequent seller-initiated transaction and vice versa. The realized spread is then calculated as

$$s^R = \frac{p_t^a - p_{t+1}^b}{p_t^a} \quad \text{or} \quad s^R = \frac{p_{t+1}^a - p_t^b}{p_t^b}$$

if the initial transaction was at the ask or at the bid, respectively. The „subsequent“ transaction was taken to be the next transaction at the opposite side of the market (version 1) and the next transaction at the opposite side of the market after at least five minutes (version 2).[15] Since the results are virtually identical we restrict the presentation to version 1.

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[15] The results of Huang / Stoll (1996), Harris / Schultz (1998) and Lightfood / Martin / Peterson / Sirri (1999) suggest that no systematic price movements are to be expected after 5 minutes.

We next categorize transactions according to the degree of price improvement. We differentiate between transactions at the quoted price, transactions at a price inside the quoted spread (excluding transactions at the midquote) and transactions at the midquote. Table IV shows the current spread (defined as the quoted spread in the moment the transaction is initiated), the effective spread, the realized spread and the modified adverse selection component (to be defined below) for each of the three price improvement categories.

The current spread is higher for transactions at prices within the spread or at the spread midpoint than for transactions at a price equal to the bid or ask quotes.[16] The differences are significantly different from zero. This is consistent with the results of the Tobit model discussed in the previous section. The effective spread is necessarily equal to the current spread if only transactions at the quoted prices are considered. Price improvement reduces the effective spread, the amount of the reduction being, on average, 57% of the quoted spread.[17] If only transactions at prices equal to the midquote are considered, the effective spread is zero by definition.

The realized spread averages 0.018%. It amounts to 0.007% for transactions at the quotes, 0.056% for transactions at prices within the quotes and 0.012% for transactions at the quote midpoint. The weighted average of the latter two categories is 0.035%. The realized spread on transactions where price improvement is granted is thus *larger*, rather than smaller, than the realized spread on transactions without price improvement. This supports the hypothesis that

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[16] It appears that the higher spread at least partially translates into Makler profits. As documented in the Table and discussed below, realized spreads on transactions where price improvement was granted are higher than the average realized spread.

[17] This figure is different from the corresponding figure in Table I because here the percentage price improvement is measured *conditional on price improvement being granted*.

granting price improvement does not reduce the Makler's profits. This result is inconsistent with the predictions of market-power based explanations for price improvement. According to these, the degree of price improvement reflects the bargaining power of the counterparty and should, therefore, be negatively related to the Makler's profits.[18]

Generally, a measure of the adverse selection component of the spread can be obtained by subtracting the realized spread from the effective spread (e.g. Huang / Stoll 1996).[19] This implicitly assumes that the Makler expects the same effective half-spread in the transaction in which he closes out his position as in the initial transaction. Put differently, he expects the same degree of price improvement in both transactions. This assumption is justified if one is only interested in an estimate of the average adverse selection component. When estimating the adverse selection component for different degrees of price improvement in the initial transaction, however, the procedure clearly results in biased estimates. To eliminate the bias we estimate the adverse selection component for the price improvement category *i* as

$$s_{a,i} = \left(0.5 s_{e,i} + 0.5 \bar{s}_e\right) - s_{r,i}$$

where $s_{e,i}$ denotes the average effective spread for price improvement category *i*. $\bar{s}_e$ is the average (over all price improvement categories) effective spread and $s_{r,i}$ is the average realized spread for category *i*. This definition of the adverse selection component assumes that the

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18 In fact, some of our results are consistent with market power on the side of the Makler. We documented that he earns a higher realized spread on transactions at prices within the spread. The adverse selection cost associated with these trades is smaller than it is for transactions at the quoted prices. It appears that only a fraction of this reduction is passed on to the traders, resulting in higher realized spreads for the Makler.

19 If inventory management reduces the realized spread, these inventory holding costs would also be reflected in the estimate of the adverse selection component. However empirical evidence for inventory management is hardly found in transaction-level data (see, e.g., Hasbrouck / Sofianos 1993, Manaster / Mann 1996).

Makler expects an effective half spread in the offsetting transaction that is equal to the average effective half-spread or, put differently, he expects to close his position in a transaction where he grants the average degree of price improvement.

As hypothesized, the price improvement is reflected in the adverse selection component rather than in the realized spread. The modified adverse selection component is 0.155% on average. However, for transactions at a price equal to the bid or ask quotes, the adverse selection component is larger, amounting to 0.20%. It drops to 0.103% for transactions at prices within the quotes and to 0.075% for transactions at the quote midpoint. This is consistent with our hypothesis that price improvement reflects lower adverse selection costs rather than lower market maker profits.

The results presented thus far are descriptive in nature and do not rule out the possibility that a relation between price improvement and realized spreads is masked by the influence of other variables. We therefore regress the realized spread s_t^r on the degree of price improvement $Impr_t$ (measured as a percentage of the quoted spread). We include the transaction volume, the absolute midquote change since the last transaction (as a measure of short-term volatility), the magnitude of the quoted spread and a dummy variable which takes on the value 1 when the transaction is a continuation as control variables. We allow for non-linearity of the relation between the realized spread and trade size by including a quadratic term on the right-hand side. The resulting model is

$$s_t^r = \gamma_0 + \gamma_i Impr_t + \gamma_2 q_t + \gamma_3 q_t^2 + \gamma_4 \left| mq_t - mq_{t-1} \right| + \gamma_5 s_t^q + \gamma_6 D_t + \varepsilon_t \qquad (2)$$

We estimated this model separately for each stock. Results are presented in Table V. An F-test rejects the null hypothesis of no explanatory power for 36 of the 40 stocks at the 5% level. The independent variables thus do have explanatory power, although the average R^2 is only

0.05. Consistent with our previous results, the degree of price improvement does not appear to be systematically related to the realized spread. 20 coefficients are positive, 20 are negative. A cross-sectional t-test does not reject the null hypothesis of a zero mean (t-value 1.24). For the majority of the sample stocks the realized spread is negatively related to the transaction volume. The coefficients on the square of volume indicate that this relation is non-linear.

Consistent with our earlier results, the realized spread is positively related to the magnitude of the quoted spread. Increases in quoted spreads are, therefore, not entirely driven by adverse selection costs but may also contain a component related to the Makler's market power. The remaining control variables – the volatility measure and the dummy variable for continuations – are unrelated to the realized spread. Taken together, both the descriptive results and the regression results lend support to the hypothesis that price improvement is related to adverse selection rather than to the profits earned by the Makler. The non-anonymity of the environment allows the Makler to assess the probability of a trade initiated by a specific counterparty to be motivated by private information and to adjust the terms of trade accordingly.

4.3 Price improvement and quote adjustment

Our second hypothesis states that the Makler's quote adjustment will be larger after a transaction at the quoted price than after a transaction at a price inside the spread because transactions at a price equal to the bid or ask quote are more likely to be initiated by informed traders.

We test this hypothesis by comparing the last midquote published prior to the transaction to a subsequent midquote for the three price improvement categories introduced in the preceding section. The changes in midquotes are signed such that upward revisions after buyer-initiated transactions and downward revisions after seller-initiated transactions have a positive sign.

This signing convention is consistent with the quote adjustment being related to adverse selection.

We calculate two versions of the quote adjustment measure. The first version relates the midquote immediately prior to the transaction to the next midquote after the transaction. Since quotes are deleted automatically from the system after each transaction and have to be re-entered manually, these new quotes should capture the conjectured price impact of the preceding transaction. To check the robustness of the results we also calculated a second version of the measure. It relates the initial midquote to the next midquote published at least five minutes after the transaction.

The results are shown in Table VI. The table reports the cross-sectional averages (weighted by the number of transactions) of the mean and median quote adjustment for each stock. Separate figures are given for small and large transactions and for four groups of stocks. Panel A [B] reports the results obtained when using the first [second] version of the quote adjustment measure. In each single case the quote adjustment after a transaction at the quoted price is larger than the adjustment after a transaction at a price within the quoted spread or at the midquote. Transactions at the quoted prices have a significant price impact, amounting to DM 0.48 on average. In most cases, the quote adjustment is more pronounced after larger transactions. This is what one would expect given that informed traders prefer larger trade sizes and that the quote adjustment may also be related to inventory considerations.

The quote adjustment after transactions where price improvement was granted is much lower. The average quote adjustment is DM 0.09 for transactions at prices within the quotes and -0.02 for transactions at prices equal to the current midquote. t-tests for individual stocks (results not shown) reveal that the differences between the quote adjustment after transactions at the quotes on the one hand and after transactions within the quotes and at the midquote on the other hand are highly significant. Panel B shows the results obtained when using the second version of the quote adjustment measure, i.e., when measuring the quote adjustment between the time of the transaction and the next quote published after at least five minutes. This version of the measure yields very similar conclusions.

The negative quote adjustment after transactions at the midquote is contrary to what one would expect. We therefore checked the results for the individual stocks. We found that the quote adjustment is negative for almost all stocks and significantly so for approximately half of the stocks. One possible explanation is inaccurate trade classification. The Lee / Ready (1991) method has been found to be rather unreliable for transactions at the midquote (see Ellis / Michaely / O'Hara 1999, Odders-White 1999).[20] To check the robustness of our results we employ the following procedure. We calculate the average *absolute* quote adjustment after transactions at the midquote. This method clearly results in an upward bias of the estimated quote change. We find, however, that even this upward-biased measure, though (by definition) positive, is smaller than the quote adjustment after transactions at the quotes shown in Table VI. This is true for the average over all stocks and for each of the four groups of stocks. We perform the same robustness check for the quote change after transactions at prices within the spread. Again, the conclusions remain unchanged. It thus appears that our results are not due to misclassification of trades.

To further check the robustness of the descriptive results we also regressed the quote adjustment on the degree of price improvement and a set of control variables. The dependent vari-

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[20] There is anecdotal evidence that there is more bunching of trades for reporting purposes on the floor of the Frankfurt Stock Exchange than on the NYSE. This is likely to make trade classification algorithms less reliable. Consistent with this, Theissen (2001) has documented that misclassification rates are higher in Frankfurt than on the NYSE or in Nasdaq.

able, $Ind_t\left(mq_{t+1}-mq_t\right)$ is the difference between the next midquote after the transaction and the midquote immediately prior to the transaction, multiplied by the trade indicator variable to conform to the signing convention outlined above. The control variables are the same as in equation (2). The model thus is

$$Ind_t\left(mq_{t+1}-mq_t\right)=\gamma_0+\gamma_i Impr_t+\gamma_2 q_t+\gamma_3 q_t^2+\gamma_4\left|mq_t-mq_{t-1}\right|+\gamma_5 s_t^q+\gamma_6 D_t+\varepsilon_t \qquad (3)$$

We estimated equation (3) for each stock separately. The results are presented in Table VII. The independent variables explain a significant part of the quote adjustment as evidenced by an average R^2 of 0.30. The coefficient on the degree of price improvement has the predicted negative sign and is significantly different from zero at the 5% level for all 40 stocks. Consistent with the results in Table VI, the quote adjustment is larger after larger transactions. The relation between transaction volume and quote adjustment is, again, non-linear.[21] There is some evidence that the quote adjustment is positively related to the previous absolute quote change that serves as a proxy for volatility. Further, the quote change is strongly positively related to the size of the spread. This is consistent with the notion that transactions that occur when the spread is high convey more information.

The regression results are thus consistent with the hypothesis that the non-anonymous environment allows the Makler to identify trades with a low information content. These trades tend to be executed at prices inside the prevailing spread and, due to their lower information content, do only trigger a small quote revision.

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21 This is consistent with the results reported by Kempf / Korn (1999). In a slightly different context, they show, using data on the DAX futures contract, that the midquote change subsequent to a transaction is a nonlinear function of the transaction size.

5 Discussion

The present paper analyses price formation and liquidity in a non-anonymous environment as it can be found on the floor of the NYSE or the Frankfurt Stock Exchange. Our main hypothesis is that the non-anonymity allows the Makler to assess the probability that a given counterparty trades on the basis of private information. The Makler uses this knowledge to price discriminate. This is achieved by quoting a large spread and granting price improvement to traders deemed uninformed.

The conjectured behavior yields predictions about the relation between price improvement and market maker profits and the relation between price improvement and quote adjustment. We use data from the Frankfurt Stock Exchange to test these hypotheses empirically. Our results lend strong support to both hypotheses. Granting price improvement does not reduce the Makler's profits as measured by the realized spread. Rather, the degree of price improvement is negatively related to the adverse selection component of the spread. This is consistent with the hypothesis that price improvement is granted to those traders that are less likely to trade on the basis of private information. We further document that the quote adjustment is significantly larger after transactions at the quoted bid or ask price than after transactions at a price inside the spread or after transactions at the quote midpoint. Taken together, our results support the hypothesis that the Makler makes use of the information conveyed by trader identities. The empirical findings suggest that this is associated with lower adverse selection costs. As one would expect in an environment with competing markets, price improvement is also used to improve upon the quotes in case they are inferior to those in the competing electronic trading system IBIS.

The results presented in this paper have important implications for the design of trading systems. Anonymity, albeit preferred by many institutional investors, is not obtained without cost. The advantages of a non-anonymous trading system are likely to be more pronounced the more severe the adverse selection problem for the stock in question is. This suggests that less liquid stocks, because of their higher adverse selection costs, should be traded in a non-anonymous environment. This view is supported by the experience in Germany. Here, non-anonymous floor trading and anonymous electronic trading for the same stocks co-exist. The floor has retained a large market share in less liquid stocks whereas the electronic trading system is the dominant market for blue chips. Consistent with the results of this paper, it has been found that the adverse selection component of the spread is larger in the electronic trading system (Theissen 2002).

The results of this paper suggest directions for future research. First, it will be interesting to see whether the results obtained for the Frankfurt Stock Exchange extend to other markets, e.g. the NYSE. Second, the results of the present paper predict that adverse selection costs for orders executed in NASDAQ‘s anonymous SOES system are higher than those for orders executed in the regular NASDAQ dealer market. This is also an issue that can be addressed empirically.

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Table I: Frequency and magnitude of price improvement

	Frequency of price improvement (%)		Transactions at the midquote (%)		Price improvement as a percentage of the quoted spread	
	small transactions	large transactions	small transactions	large transactions	small transactions	large transactions
all stocks	56.80	25.95	26.98	13.16	44.04	20.50
DAX large	53.95	25.79	28.31	13.81	43.07	20.73
DAX medium	64.27	28.00	27.62	13.76	47.87	21.73
DAX small	54.21	23.50	23.97	11.20	41.95	18.37
MDAX	52.12	22.86	20.63	9.54	39.43	17.59

The table shows the frequency of transactions occurring at prices inside the quoted spread (columns 2 and 3), the frequency of transactions occurring at a price equal to the quote midpoint (columns 4 and 5) and the price improvement as a percentage of the quoted spread in effect immediately prior to the transaction (columns 6 and 7). The figures in columns 6 and 7 are *not* conditioned on price improvement being granted. Results are reported for small and large transactions separately. A small [large] transaction is defined as a transaction of a size up to [equal to or larger than] the median transaction size of the stock in question. The last four lines report results for large, medium and small DAX stocks (sorted by trading volume) and the 10 MDAX stocks.

Table II: Price improvement and quote competition

	fraction of transactions with improvement			average improvement (%)		
	all	IBIS better	IBIS not better	all	IBIS better	IBIS not better
all DAX stocks	40.8%	54.0%	29.2%	31.6%	42.6%	21.5%
DAX large	39.2%	52.3%	21.5%	32.1%	43.4%	21.5%
DAX medium	44.7%	57.4%	32.9%	32.9%	42.7%	23.5%
DAX small	38.3%	52.6%	26.2%	29.8%	41.8%	19.6%

The figures in the table report the frequency and amount of price improvement conditional upon the quotes in the electronic trading system IBIS being better than those on the floor. "IBIS better" indicates that the quoted price in IBIS was better than the quoted price on the floor in the moment a transaction was recorded on the floor. In order to match quotes, transactions on the floor were classified using the Lee / Ready (1991) method. The first three columns report the fraction of transactions in which price improvement was granted. The last three columns report the average price improvement (unweighted average over the (sub)sample stocks) as a percentage of the quoted spread. As in Table I these figures are *not* conditioned on price improvement being granted. The last three lines report results for large, medium and small DAX stocks (sorted by trading volume). Quotation data from IBIS for the MDAX stocks was unavailable.

Table III: Determinants of price improvement

Panel A

	constant	q_t	q_t^2	$\lvert mq_t - mq_{t-1}\rvert$	s_t^q	D_t
DAX large	-0.0699	-8.25E-5	9.28E-9	-0.2299	0.6021	0.0920
DAX medium	0.03843	-3.86E-4	1.95E-7	-0.1312	0.3964	0.0540
DAX small	-0.0213	-2.89E-4	6.17E-8	-0.0900	0.4130	0.0173
MDAX	0.0100	-2.05E-4	7.62E-8	-0.0688	0.1333	0.0214
all	-0.0107	-2.41E-4	8.55E-8	-0.1300	0.3862	0.0462
# pos.	18	0	39	10	40	33
sign. 5%	10	0	36	0	39	18
# neg.	22	40	1	30	0	7
sign. 5%	13	39	0	13	0	1

Panel B

	constant	q_t	q_t^2	$\lvert mq_t - mq_{t-1}\rvert$	s_t^q	D_t	Δp_t
DAX large	-0.0227	-7.76E-5	8.43E-9	-0.2581	0.3787	0.0565	0.8091
DAX medium	0.0817	-3.66E-4	1.78E-7	-0.1445	0.2623	0.0214	0.4530
DAX small	0.0321	-2.87E-4	6.07E-8	-0.1007	0.2993	-0.0090	0.3466
all	0.0303	-2.44E-4	8.25E-8	-0.1678	0.3134	0.0230	0.5362
# pos.	18	0	30	10	30	19	30
sign. 5%	11	0	28	0	22	10	29
# neg.	12	30	0	20	0	11	0
sign. 5%	7	30	0	11	0	2	0

The table presents the results of the Tobit model

$$\frac{\left(s_t^q - s_t^e\right)}{s_t^q} = \gamma_0 + \gamma_1 q_t + \gamma_2 q_t^2 + \gamma_3 \left|mq_t - mq_{t-1}\right| + \gamma_4 s_t^q + \gamma_5 D_t \left(+\gamma_6 \Delta p_t\right) + \varepsilon_t \,.$$

where t is a (transaction) time index, s_t^q and s_t^e are the quoted and the effective spread, respectively, q_t is the transaction size, measured as the number of shares traded, mq_t is the midquote in effect immediately prior to transaction t and D_t is a dummy variable taking on the value one whenever transaction t is a continuation, i.e., occurs on the same side of the market as the preceding transaction. Δp_t is the percentage difference between the quoted price on the floor and the quoted prize in IBIS.

The model was estimated for each stock separately as a Tobit model with left-censoring at zero. The upper part reports mean values of the estimated marginal effects (defined as the estimated coefficient multiplied by the fraction of uncensored observations) for all stocks and for four groups of stocks (large, medium and small DAX stocks, and MDAX stocks). The lower part reports the number of positive and negative coefficients. Panel A reports results for the basic model. Panel B includes the variable Δp_t. Since quote data from IBIS was only available for the 30 DAX stocks, results in Panel B are restricted to the subsample of the DAX stocks.

Table IV: Price improvement and the components of the spread

	all transactions n = 67485	at quotes n = 40174	within quotes n = 14093	at midquote n = 13272
quoted spread (%) („current“)	0.263	0.240	0.337	0.256
effective spread (%)	0.173	0.240	0.145	0
realized spread (%)	0.018	0.007	0.056	0.012
modified adverse selection component	0.155	0.200	0.103	0.075

The table reports various spread measures for all transactions and for subsets of transactions that differ with respect to the degree of price improvement granted. The spread measures are the quoted spread in effect immediately prior to the transaction, the effective spread, the realized spread and the modified adverse selection component. The realized spread was obtained by relating each transaction price to the price of the next transaction at the opposite side of the market. The modified adverse selection component is defined in the text.

Table V: Price improvement and realized spread: regression results

	const.	*impr.*	q_t	q_t^2	$\lvert mq_t - mq_{t-1}\rvert$	s_t^q	D_t
DAX large	0.0122	-0.0107	-1.49E-05	2.68E-09	-0.0365	0.2057	-0.0068
DAX medium	0.0022	-0.0007	-3.21E-05	2.30E-08	-0.0235	0.1968	-0.0106
DAX small	-0.0442	0.0364	-4.50E-05	1.74E-09	0.028	0.1992	-0.0187
MDAX	-0.0060	0.0604	-1.22E-04	1.02E-07	-0.0142	0.1440	-0.0078
all	-0.0089	0.0214	-5.34E-05	3.25E-08	-0.0116	0.1864	-0.011
# pos.	18	20	8	30	22	35	12
sign. 5%	6	5	0	14	3	27	1
# neg.	22	20	32	10	18	5	28
sign. 5%	6	7	19	0	3	0	3

The table presents the results of the regression model

$$s_t^r = \gamma_0 + \gamma_i Impr_t + \gamma_2 q_t + \gamma_3 q_t^2 + \gamma_4 \lvert mq_t - mq_{t-1}\rvert + \gamma_5 s_t^q + \gamma_6 D_t + \varepsilon_t \ .$$

where t is a (transaction) time index, $Impr_t$ is the price improvement, measured as a percentage of the quoted spread, s_t^r is the realized spread, q_t is the transaction size, measured as the number of shares traded, mq_t is the quote midpoint in effect immediately prior to transaction t, s_t^q is the quoted spread and D_t is a dummy variable taking on the value one whenever transaction t is a continuation, i.e., occurs on the same side of the market as the preceding transaction. The model was estimated for each stock separately. The upper part of the Table reports mean values of the estimated coefficients for all stocks and for four groups of stocks (large, medium and small DAX stocks, and MDAX stocks). The lower part reports the number of positive and negative coefficients. Standard errors are based on the Newey-West covariance estimator.

Table VI: Price improvement and quote adjustment

Panel A: Next quotes published

		all	at quotes			within quotes			at midquote		
			small	large	all	small	large	all	small	large	all
all	mean	0.302	0.398	0.519	0.478	0.063	0.133	0.085	-0.011	-0.031	-0.018
	median	0.241	0.331	0.379	0.364	0.003	0.053	0.003	0	-0.010	0
DAX large	mean	0.109	0.113	0.199	0.168	0.028	0.065	0.040	-0.004	-0.005	-0.004
	median	0.081	0.096	0.185	0.171	0	0	0	0	0	0
DAX medium	mean	0.523	0.739	0.951	0.889	0.084	0.21	0.123	-0.010	-0.038	-0.021
	median	0.409	0.636	0.613	0.604	0	0.151	0	0	0	0
DAX small	mean	0.425	0.630	0.659	0.649	0.102	0.164	0.121	-0.064	-0.041	-0.056
	median	0.345	0.531	0.507	0.503	0.018	0.024	0.020	0	0	0
MDAX	mean	0.550	0.943	0.751	0.821	0.098	0.165	0.119	0.034	-0.300	-0.078
	median	0.523	0.685	0.541	0.576	0	0.001	0	0	-0.256	0

Panel B: Next quotes published after at least 5 minutes

	trades	all	at quotes			within quotes			at midquote		
stocks			small	large	all	small	large	all	small	large	all
all	mean	0.392	0.472	0.674	0.604	0.108	0.262	0.157	-0.035	0.003	-0.022
	median	0.272	0.380	0.488	0.455	0.048	0.149	0.063	-0.021	-0.004	0.000
DAX large	mean	0.141	0.133	0.263	0.215	0.012	0.100	0.042	0.003	0.022	0.009
	median	0.092	0.099	0.188	0.174	0.000	0.010	0	0	0	0
DAX medium	mean	0.683	0.918	1.232	1.137	0.187	0.453	0.269	-0.117	-0.053	-0.094
	median	0.442	0.748	0.844	0.794	0.128	0.330	0.148	-0.072	0.007	0
DAX small	mean	0.562	0.709	0.877	0.817	0.115	0.443	0.214	-0.028	0.075	0.007
	median	0.462	0.597	0.708	0.652	-0.008	0.227	0.050	-0.002	-0.005	-0.002
MDAX	mean	0.711	1.103	0.952	1.007	0.293	0.130	0.242	0.017	-0.020	0.005
	median	0.538	0.874	0.748	0.837	0.062	0.095	0.072	0.013	-0.138	0.011

The table reports the mean and median quote adjustment after a transaction. In Panel A [B] the adjustment is measured as the difference between the midquote immediately prior to the transaction and the next midquote published after [at least five minutes after] the transaction. It is signed such that an upward [downward] revision after a buyer- [seller-] initiated trade carries a positive sign.

Table VII: Price improvement and quote adjustment: regression results

	const.	*impr.*	q_t	q_t^2	$\lvert mq_t - mq_{t-1}\rvert$	s_t^q	D_t
DAX large	0.0133	-0.1995	8.50E-05	-1.82E-08	0.0408	0.6146	0.0079
DAX medium	0.234	-1.4906	2.41E-03	-2.85E-06	0.0481	2.0884	0.0752
DAX small	0.3064	-0.9479	1.82E-04	-1.23E-07	0.0385	0.9097	-0.0121
MDAX	0.4393	-1.0132	1.01E-04	-8.91E-09	0.0529	0.4539	-0.081
all	0.2483	-0.9128	6.93E-04	7.49E-07	0.0451	1.0166	-0.0025
# pos.	37	0	35	12	34	40	18
sign. 5%	25	0	20	1	7	40	3
# neg.	3	40	5	28	6	0	22
sign. 5%	0	40	0	16	1	0	7

The table presents the results of the regression model

$$Ind_t\left(mq_{t+1} - mq_t\right) = \gamma_0 + \gamma_i Impr_t + \gamma_2 q_t + \gamma_3 q_t^2 + \gamma_4 \left|mq_t - mq_{t-1}\right| + \gamma_5 s_t^q + \gamma_6 D_t + \varepsilon_t\,.$$

where *t* is a (transaction) time index, Ind_t is the trade indicator variable (1 for a buyer-initiated transaction, -1 for a seller-initiated transaction), $Impr_t$ is the price improvement, measured as a percentage of the quoted spread, q_t is the transaction size, measured as the number of shares traded, mq_t is the midquote in effect immediately prior to transaction *t*, s_t^q is the quoted spread and D_t is a dummy variable taking on the value one whenever transaction *t* is a continuation, i.e., occurs on the same side of the market as the preceding transaction. The model was estimated for each stock separately. The upper part of the Table reports mean values of the estimated coefficients for all stocks and for quartiles of stocks sorted by total trading volume. The lower part reports the number of positive and negative coefficients. Standard errors are based on the Newey-West covariance estimator.