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Price Discovery in Floor and Screen Trading Systems

by

Erik Theissen

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Bonn Graduate School of Economics
Department of Economics
University of Bonn
Adenauerallee 24 - 42
D-53113 Bonn

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Erik Theissen[**], University of Bonn

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JEL classification: G 10

Keywords: Floor versus screen trading, Error correction, Information shares, Common long memory components

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[**] Erik Theissen, University of Bonn, BWL 1, Adenauerallee 24-42, 53113 Bonn, Germany; Email: theissen@uni-bonn.de.

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1 Introduction

In recent years electronic trading systems proliferated in the world's financial markets. Screen trading systems are said to have a variety of specific advantages. They offer lower operating costs, remote access to the system and higher transparency (see, e.g., Domowitz / Steil 1998). It has even been argued that the survival of floor trading systems may be attributable to vested interests rather than to specific advantages offered by these trading systems (Domowitz 1993).

Although these arguments may seem convincing, empirical evidence on the relative advantages of floor and electronic trading systems is certainly needed before far-reaching policy implications are to be given. The objective of the present paper is to contribute to this evidence. We focus on the aspect of price discovery which is central to the operation of a financial market. Our research design makes use of a distinguishing feature of the German stock market, namely, the co-existence of two liquid markets for the same stocks.[1] Since 1991, a fully electronic trading system (IBIS, in November 1997 replaced by XETRA) operates parallel to the Frankfurt Stock Exchange. This allows us to directly compare the price discovery process in floor and screen trading systems.

The present paper is related to previous work on price discovery in floor and electronic trading systems. Both Grünbichler / Longstaff / Schwartz (1994) and Stucki / Wasserfallen (1994) compare a floor-based stock market to an electronic derivatives exchange. Grünbichler / Longstaff / Schwartz (1994) find that the screen-traded future leads the stock market whereas Stucki / Wasserfallen (1994) report that screen-traded equity options lag the stock market. The Bund futures contract, traded on the floor of the LIFFE and in the electronic DTB (now

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[1] In fact, there are nine rather than two markets because seven regional exchanges exist besides the Frankfurt Stock Exchange and the electronic trading system. Given their low market shares, we do not consider the regional exchanges in this paper. See Kehr (1997), Kirchner (1999) and Schmidt / Iversen / Treske (1993) for a treatment of this issue.

EUREX), has been analyzed in several papers (Breedon / Holland 1998, Fraser-Jenkins 1998, Kofman / Moser 1997, Martens 1998, Shyy / Lee 1995). Although the conclusions reached in these papers differ (partly due to different sample periods), the balance of the results indicates that the electronic market leads the floor. It should be noted, however, that the electronic market is the home market. Therefore, it may be the price-leader for reasons other than the trading mechanism.

The German stock market with its unique feature of parallel floor and screen trading has also been subject to empirical investigation. Kirchner / Schlag (1998) document that the prices in the electronic trading system adjust to the price established in the opening auction on the floor. Both Freihube / Theissen (2001) and Kempf / Korn (1998) compare the two markets using stock index data. Kempf / Korn (1998) find that the integration between the electronic trading system and the (equally electronic) futures market is higher than the degree of integration between the floor and the futures market. Freihube / Theissen (2001) document that the screen-based XETRA system contributes more to the price discovery process than the floor for the blue-chip index DAX. The reverse is true, however, for the mid-cap index MDAX.

Stock-level analyses are provided by Bühler / Grünbichler / Schmidt (1995), Kehr (1997) and Kirchner (1999). The results do not support the hypothesis that one of the markets is the leader in the price discovery process. These papers are closely related to ours. There is, however, an important difference. All three papers use transactions data.[2] This entails the problem of restructuring the data in a way that is consistent with the implicit assumption of synchronicity. A second problem lies in the fact that the number of observations is rather low

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[2] Data on bid and ask quotes is not available on a regular basis for the German stock market.

for less liquid stocks. Consequently, both Bühler / Grünbichler / Schmidt (1995) and Kirchner (1999) restrict their analysis to a small number of liquid stocks (four and eight, respectively).

In the present paper we use data on both transaction prices and bid and ask quotes. This allows us to construct an equally-spaced and (almost[3]) synchronous data set. Further, since quote changes are more frequent than transactions, we are able to include a larger number of stocks than some of the previous studies. This allows us to analyze the cross-sectional determinants of the relative contributions of the two markets to the process of price discovery.

We quantify the contributions of the two markets to the process of price discovery using two different approaches. The first consists in estimating the information shares of the two markets as proposed by Hasbrouck (1995). Our second approach builds on work by Schwarz / Szakmary (1994) and Gonzalo / Granger (1995). Schwarz / Szakmary (1994) propose a simple measure of the contributions to price discovery that can be obtained directly from the estimated coefficients of the error correction model. We give a formal justification for this measure. Gonzalo / Granger (1995) document how the common long memory components can be identified from a system of cointegrated variables. We show that the weights with which the time series enter the common long memory component are equal to the contributions to price discovery as defined by Schwarz / Szakmary (1994).

The main findings can be summarized as follows. Both markets contribute to price discovery. There is bidirectional Granger causality, and prices from both markets adjust to deviations from the long-run equilibrium. We apply both measures of the contributions to price discovery and find that they are very similar and highly correlated. Our results thus support the application of the simpler measure.

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[3] As will be pointed out in detail below, there are instances when no valid quotes exist on the floor. In these cases we use the last available quote midpoint.

The contributions of the two competing trading systems to the process of price discovery are almost equal when transaction prices are used for the estimation. Models based on quote midpoints, on the other hand, indicate that the electronic trading system has a larger share in the price discovery process. An additional cross-sectional analysis reveals that the contributions of the two trading systems to price discovery are positively related to their market shares.

The remainder of the paper is organized as follows. Section 2 reviews theoretical arguments in favor of better price discovery in floor or screen-based trading systems. Section 3 offers a brief description of the microstructure of the German stock market and describes our data set. In section 4 we describe our methodology. Section 5 documents the results of the error correction models. Section 6 concludes.

2 Theory

Floor and electronic trading systems differ with respect to a number of characteristics which are related to the speed of price discovery. Screen trading systems are less costly to operate and may, therefore, offer lower bid-ask spreads. The possibility of remote access may increase the number of traders and thereby also lead to an increase in liquidity. The magnitude of the transaction costs determines whether a trader can profitably trade on a given piece of information. Therefore, price discovery should be faster in screen-based trading systems.

Three further arguments corroborate this prediction. Orders can be entered faster into an electronic system and the execution of an order is immediate. Further, it is easier to disseminate market information, thereby increasing the transparency of the market and the information available to the traders. Greater pre-trade transparency allows to more accurately estimate the price impact of a trade. Finally, the anonymity of most existing electronic trading systems makes it easier for informed traders to exploit their informational advantage. Therefore, the screen trading system is likely to attract informed traders.

These arguments yield the prediction that the electronic trading system impounds new information faster into prices. When interpreting this, one important point should be noted. The arguments implying faster price discovery in screen-based trading systems are partly based on the presumption that it is easier for informed traders to exploit their informational advantage. This clearly imposes adverse selection costs on other traders. It is a priori unclear whether these costs overcompensate the advantages offered by electronic trading systems. Theissen (2001), also using data from the German stock market, finds that the adverse selection component of the spread is higher in the electronic trading system than on the floor. In spite of this, effective spreads are lower for liquid stocks but are higher for less liquid stocks than effective spreads on the floor. This suggests that the higher adverse selection costs overcompensate the advantages of screen-based trading systems for less liquid stocks whereas the advantages outweigh the costs for the more liquid stocks.

It should thus be kept in mind that faster price discovery does not necessarily imply higher overall market quality. Resolving the issue addressed here – the trade-off between informational efficiency and liquidity – is, however, beyond the scope of the present paper.

3 Market structure and data

The floor of the Frankfurt Stock Exchange (FSE) operates in a way similar to the floor of the New York Stock Exchange (NYSE). The equivalent of the specialist is the *amtlicher Kursmakler* (Makler in the sequel). He conducts the three daily call auctions – an opening auction, a second auction at noon[4] and the closing auction – and has exclusive access to the

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[4] The description documents the organization of trading during the sample period.

orders in the limit order book. He is allowed but, unlike the NYSE specialist, not obliged to trade for his own account. Orders are either routed electronically into the book or are communicated verbally on the floor. Based on the orders in the book and his willingness to trade as principal, the Makler announces bid and ask prices. These are entered into an electronic system and are called *Pretrades*. Although no quoted depth is publicly announced, the depth at the quotes appears to be reasonably high. This is evidenced by two observations. First, transactions at prices outside the quoted spread rarely occur. They account for only 0.9% of the transactions in our data set. Second, the average transaction size on the floor is larger than the average transaction size in the electronic trading system for all but one of the sample stocks.

The Pretrades are deleted automatically from the system after each transaction. This has two important implications for our empirical analysis. First, valid quotes do not always exist because it takes some time to re-enter quotes after a transaction. Second, since quotes have to be re-entered after each transaction, they are unlikely to become stale. Further, the incentive to quote a wide spread in order to avoid frequent re-posting is reduced – quotes have to be re-entered anyway.

As is the case on the NYSE, transactions may, and often do, occur at prices inside the spread. Approximately 40% of the transactions in our data set benefit from price improvement, 20% occur at a price that equals the quote midpoint.

IBIS, in operation from April 1991 to November 1997, was an anonymous, fully electronic open limit order book. The best bids and offers, together with the quantity bid or offered, were displayed on the trading screens. In order to trigger a transaction a trader had to explicitly accept a limit order displayed on the screen. This feature characterizes IBIS as a "hit-and-take" system. There were no designated market makers in IBIS. There has, however, been a considerable amount of voluntary market making. The Maklers were allowed to participate in IBIS trading.

Trading hours in IBIS extended from 8:30 am to 5 pm and were thus considerably longer than the trading hours on the floor (10:30 am to 1:30 pm). Throughout the paper we only use data from the three hours of parallel trading.

The minimum tick size is very low (DM 0.01 [0.05] for stocks trading at prices below [above] DM 100) and is equal in both trading systems. We therefore do not consider price discreteness to be an important issue.

Our data set contains time-stamped transaction prices, trading volumes and best bid and best ask quotes from both trading systems. This data was provided by Deutsche Börse AG for the 30 stocks which comprise the index DAX. The sample covers 42 trading days in the months June and July 1997.[5]

Insert Table 1 about here

Table 1 presents descriptive statistics for the sample stocks. The average trading volume in the three hours of parallel trading ranges from DM 132.8 million to DM 9.1 million. Similarly, the average daily number of transactions ranges from 335 to 36. The average effective spread ranges from 0.084% to 0.407% on the floor and from 0.095% to 0.544% in IBIS.

The market shares of the two trading systems in terms of trading volume are almost equal (unweighted average of the IBIS market share 51.6%). There is, however, a tendency for the market share of IBIS to be higher for more liquid stocks. If market share is measured in terms of the number of transactions, the market share of the electronic trading system is higher (unweighted average 62.9%). This indicates that the average transaction size is slightly larger on the floor. Finally, there is a tendency for effective spreads to be lower in IBIS for the most liquid stocks but to be lower on the floor for the less liquid stocks.[6]

4 Methodology

Error correction model

If price discovery is faster in one market, returns on this market should lead the returns on the other market. A convenient method to test for such a lead-lag relationship is to estimate the VAR model

$$\begin{aligned} r_t^f &= \alpha^f + \sum_{\tau=1}^{k} \beta_\tau^f r_{t-\tau}^f + \sum_{\tau=1}^{k} \gamma_\tau^f r_{t-\tau}^s + \varepsilon_t^f \\ r_t^s &= \alpha^s + \sum_{\tau=1}^{k} \beta_\tau^s r_{t-\tau}^s + \sum_{\tau=1}^{k} \gamma_\tau^s r_{t-\tau}^f + \varepsilon_t^s \end{aligned} \tag{1}$$

where r denotes log returns, t indexes time and f and s characterize returns from the floor and the screen trading system, respectively. When the coefficients γ_τ^f are (as a group) significantly different from zero, returns in the electronic trading system Granger-cause returns on the floor. Similarly, floor returns Granger-cause the returns in the electronic trading system when the coefficients γ_τ^s are different from zero. If both sets of parameters are different from zero, the process of price discovery is interdependent, i.e. there is bidirectional Granger causality.

Hasbrouck (1995) points out that the VAR specification is inappropriate when the prices in the two markets are cointegrated. In this case, the representation theorem (Engle / Granger

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5 Two of the 44 trading days in the sample months (July 21st and July 23rd) had to be discarded. On both days, the exchange's computer facilities broke down and trading had to be suspended several times.

6 For transactions on the floor an additional commission (the "Courtage") has to be paid. The regular rate for the stocks in our sample is 0.04% of the transaction value. Reduced rates apply for floor brokers (Freimakler) and some banks. This should be taken into account when comparing spreads from the two trading systems. See Theissen (2001) for details.

1987) posits that the model has to be augmented with an error correction term. This results in the error correction model

$$\begin{aligned} r_t^f &= \alpha^f + \sum_{\tau=1}^{k} \beta_\tau^f r_{t-\tau}^f + \sum_{\tau=1}^{k} \gamma_\tau^f r_{t-\tau}^s + \delta^f \left(p_{t-1}^f - p_{t-1}^s \right) + \varepsilon_t^f \\ r_t^s &= \alpha^s + \sum_{\tau=1}^{k} \beta_\tau^s r_{t-\tau}^s + \sum_{\tau=1}^{k} \gamma_\tau^s r_{t-\tau}^f + \delta^s \left(p_{t-1}^f - p_{t-1}^s \right) + \varepsilon_t^s \end{aligned} \quad (2)$$

where p denotes the log price. Generally, the cointegrating relation describes the long-run equilibrium of the system. In the present case, the two time series under scrutiny are two prices for the same stock established in two parallel markets. In equilibrium, the prices should be equal. The resulting long-run equilibrium is given by $p_T^f - p_T^s = 0$. The cointegrating vector is thus [1; -1]. The coefficients δ^f and δ^s indicate how the system responds to deviations from the long-run equilibrium. If the price on the floor is higher than the price in IBIS we would expect a negative price change on the floor and / or a positive price change in IBIS and vice versa. We thus expect $\delta^f < 0$ and $\delta^s > 0$.

An important aspect of the analysis is to quantify the contribution of the two markets to the process of price discovery. Two methods, one due to Hasbrouck (1995) and one due to Schwarz / Szakmary (1994), have been proposed. We will discuss both measures briefly.

Information Shares (Hasbrouck 1995)

The information share relates the contribution of an individual market's innovation to the total innovation of the common efficient price. The latter is identified as the common trend in the common trend representation of the model (Stock / Watson 1988). If the markets' innovations were uncorrelated (i.e., if the variance-covariance matrix Ω were diagonal), the information share of market j would be given by

$$S_j = \frac{c_j^2 \Omega_{jj}}{\mathbf{c\Omega c'}} \quad (3)$$

where **c** is the common row vector of the impact matrix in the common trend representation.[7] In practice, the innovations will be correlated.[8] Hasbrouck (1995) proposed to triangularize the variance-covariance matrix. A Cholesky factorization is used to obtain the lower triangular matrix **F** such that $\mathbf{FF'} = \mathbf{\Omega}$. The definition of market *j*'s information share then becomes

$$S_j = \frac{\left([\mathbf{cF}]_j\right)^2}{\mathbf{c\Omega c'}}. \tag{4}$$

Due to the nature of the Cholesky decomposition this procedure maximizes the information share of the first market and, consequently, minimizes the share of the second market. By permuting the order of the markets, upper and lower bounds for each market's information share are obtained. Following the literature, we use the mean of the upper and the lower bound as a unique measure of a market's information share.

Martens (1998) shows that, in the case of two markets with a cointegrating vector (1; -1), the information shares for markets 1 and 2 are given by

$$S_1 = \frac{\left(\tilde{\delta}_1 F_{11} + \tilde{\delta}_2 F_{21}\right)^2}{\tilde{\delta}_1 \Omega_{11} \tilde{\delta}_1 + \tilde{\delta}_2 \Omega_{21} \tilde{\delta}_1 + \tilde{\delta}_1 \Omega_{12} \tilde{\delta}_2 + \tilde{\delta}_2 \Omega_{22} \tilde{\delta}_2}; \; S_2 = \frac{\left(\tilde{\delta}_2 F_{22}\right)^2}{\tilde{\delta}_1 \Omega_{11} \tilde{\delta}_1 + \tilde{\delta}_2 \Omega_{21} \tilde{\delta}_1 + \tilde{\delta}_1 \Omega_{12} \tilde{\delta}_2 + \tilde{\delta}_2 \Omega_{22} \tilde{\delta}_2} \tag{5}$$

where $\tilde{\boldsymbol{\delta}} = \left(\tilde{\delta}_1; \tilde{\delta}_2\right)'$ is a vector orthogonal to the vector $\boldsymbol{\delta} = \left(\delta_1; \delta_2\right)'$ of the coefficients on the error correction term. This vector is defined (up to multiplication with a constant *x*) by

$$\begin{pmatrix} \tilde{\delta}_1 \\ \tilde{\delta}_2 \end{pmatrix} = x \begin{pmatrix} \left[-\dfrac{\delta_2}{\delta_1} \right] \\ 1 \end{pmatrix} \tag{6}$$

where *x* is an arbitrary constant. The information shares are then given by

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[7] See Hasbrouck (1995, p. 1181) and Martens (1998, p. 249).

[8] Hasbrouck (1995) points out that the correlation is negatively related to the sampling frequency. We address this issue by using both 1-minute and 5-minute sampling intervals.

$$S_1 = \frac{\left(\delta^* F_{11} + F_{21}\right)^2}{\delta^* \Omega_{11} \delta^* + \Omega_{21} \delta^* + \delta^* \Omega_{12} + \Omega_{22}};\ S_2 = \frac{\left(F_{22}\right)^2}{\delta^* \Omega_{11} \delta^* + \Omega_{21} \delta^* + \delta^* \Omega_{12} + \Omega_{22}} \qquad (7)$$

where $\delta^* = \left(-\delta_2\right) / \delta_1$.

Common factor weights

The coefficients δ^f and δ^s in the error correction model (2) determine the permanent effect that a shock to one of the variables has on the system. Schwarz / Szakmary (1994) therefore proposed to use the relative magnitude of the coefficients δ^f and δ^s to assess the contributions of the two trading systems to price discovery. Specifically, they proposed the measure[9]

$$\theta = \frac{\delta_s}{\delta^s - \delta^f};\ \left(1 - \theta\right) = \frac{-\delta^f}{\delta^s - \delta^f} \qquad (8)$$

If price discovery occurs in IBIS only, $\theta = 0$; if price discovery occurs exclusively on the floor, $\theta = 1$. If both trading systems contribute equally to the process of price discovery, $\theta = 0.5$.

The measure has, as it appears, been developed on intuitive grounds. However, a formal justification can be derived from the work of Gonzalo / Granger (1995). The common trend representation of the system can be written as

$$\mathbf{P}_t = \mathbf{A}_1 \mathbf{f}_t + \tilde{\mathbf{P}}_t \qquad (9)$$

where $\mathbf{P}_t$ is the vector of log prices, $\mathbf{A_1}$ satisfies $\boldsymbol{\beta}'\mathbf{A_1} = 0$ where β is the cointegrating vector, $\mathbf{f_t}$ is the common long-memory component and $\tilde{\mathbf{P}}_\mathbf{t}$ is an I(0) component. Gonzalo /

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[9] Schwarz / Szakmary (1994) defined $\theta = \frac{\left|\delta^f\right|}{\delta^s + \left|\delta^f\right|}$. This is equivalent to the definition given in the text as long as the coefficients δ^f, δ^s have the expected sign, i.e., $\delta^s > 0, \delta^f < 0$.

Granger (1995) impose two restrictions that allow to identify the common long-memory component $\mathbf{f_t}$:[10]

1. $\mathbf{f_t}$ is a linear combination of the series $\mathbf{P_t}$ and

2. $\mathbf{f_t}$ and $\tilde{\mathbf{P}}_\mathbf{t}$ form a permanent-transitory decomposition of $\mathbf{P_t}$ where the specific definition of the decomposition is given by Gonzalo / Granger (1995, p. 28).

The long-memory component is then defined up to multiplication with a constant by

$$\mathbf{f_t} = \tilde{\boldsymbol{\delta}}\mathbf{P_t} \tag{10}$$

where $\tilde{\boldsymbol{\delta}}$ is defined as before, i.e., is a vector orthogonal to δ. From this it follows that the weights with which the series enter the common long-memory component are defined by the elements of $\tilde{\boldsymbol{\delta}}$. The relative weight of market one is, from (6)

$$w_1 = \frac{\tilde{\delta}_1}{\tilde{\delta}_1 + \tilde{\delta}_2} = \frac{-\frac{\delta_2}{\delta_1}}{-\frac{\delta_2}{\delta_1} + 1} = \frac{-\delta_2}{\delta_1 - \delta_2} = \frac{\delta_2}{\delta_2 - \delta_1} \tag{11}$$

and the relative weight of market 2 is

$$w_2 = 1 - w_1 = \frac{-\delta_1}{\delta_2 - \delta_1} \tag{12}$$

From (2) we have $\delta_1 = \delta^f$; $\delta_2 = \delta^s$. It thus follows that $w_1 = \theta$; $w_2 = (1-\theta)$. The measure proposed by Schwarz / Szakmary (1994) thus measures the weight with which the series enter the common long memory component as identified by Gonzalo / Granger (1995).

[10] Ding et al. (1999) and Harris / McInish / Wood (1997) develop a method to estimate the long-memory factor and derive a measure of the contributions to price discovery from this estimate.

With the information share and the common factor weights we have two alternative measures of a market's contribution to price discovery. One important objective of our paper is to compare these measures.

Estimation procedure

Transactions do not occur at regular intervals, nor do transactions in the two parallel trading systems occur simultaneously. The data set thus has to be re-organized prior to estimation. We subdivided our sample into intervals of equal length and, for each interval, recorded the last available price and quote midpoint. Overnight returns were excluded from the estimation. We chose two interval lengths, one minute and five minutes.[11] Using quote midpoints in addition to transaction prices is potentially advantageous because bid and ask quotes are (almost[12]) permanently available. Quote data thus allows to construct an (almost) simultaneous data set.

In a first step we test the order of integration of the log price series. Augmented Dickey Fuller tests reject the null hypothesis of a unit root slightly more frequently than expected. We obtain 12% rejections at the 5% level of significance.[13] For the first-differenced series the null hypothesis of a unit root was rejected in each case at the 1% level of significance.

We next tested for cointegration. We used the likelihood ratio test procedure proposed by Johansen (1988, 1991). The results indicate that the time series from the floor and IBIS are cointegrated. The order of the error correction model was determined using the Schwarz information criterion. The appropriate lag lengths lie between 1 and 4 for the 5-minute series

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[11] There are alternative ways to organize the data set. Harris et al. (1995) propose to construct a matched sample of transactions. This procedure has the advantage that the matching algorithm can be chosen such that the delay between the observations from the two markets is minimized. The disadvantage is that the observations are not equally spaced, rather, the sample is formed in transaction time. Given that we use quote data, we can construct an almost synchronous sample and therefore prefer the procedure described in the text.

[12] As outlined above, bid and ask quotes on the floor are deleted after each transaction. Although new quotes are usually posted within a couple of seconds, there are instances where no valid quotes exist on the floor. In these cases we use the last available quote midpoint in the estimation.

[13] We have eight time series for each stock: 1-minute interval and 5-minute interval series of prices and quote midpoints from the floor and IBIS. The total number of tests is thus 240.

and between 1 and 20 for the 1-minute series. As outlined above we use the pre-specified cointegrating vector [1; -1] in the estimation.

5 Results

We present the results in three steps. The first subsection describes the results of the error correction model. In the second subsection we compare the information shares and the common factor weights. The last subsection analyzes the cross-sectional determinants of the contributions to price discovery.

ECM results

Table 2 shows the results for the one-minute intervals. They clearly indicate that both markets contribute to the process of price discovery. We find bi-directional Granger causality irrespective of whether the estimation is based on transaction prices or quote midpoints. The IBIS factor weight averages 0.534 with a minimum of 0.342 and a maximum of 0.726 when the estimation is based on transaction prices. The information share yields similar results. The average information share for IBIS is 0.570 with a minimum of 0.301 and a maximum of 0.791. The information shares are estimated precisely, i.e., the differences between the upper and the lower bounds are reasonably low, averaging 0.21.

In order to analyze whether IBIS contributes more to the process of price discovery we tested whether the average factor weight and the average information share is different from 0.5 using both a t-test and a non-parametric Wilcoxon test. The null hypothesis of a mean (t-test) and median (Wilcoxon test), respectively, of 0.5 is rejected at the 10% level for the common factor weights and at the 5% level for the information shares. The results are thus consistent with the hypothesis that IBIS has the leading role in the price discovery process. The differences between IBIS and the floor are, however, surprisingly small.

Insert Table 2 about here

The results obtained when estimating the model based on quote midpoints are more favorable for the electronic trading system. The average factor weight is 0.649 with a minimum of 0.400 and a maximum of 0.886. Similarly, the average information share is 0.655 (minimum 0.360, maximum 0.893). Both averages are significantly different from 0.5. A possible explanation for the difference between the results based on transaction prices and quote midpoints is the different quotation activity in the two trading systems. On the floor, only the Makler posts bid and ask prices.[14] In IBIS, on the other hand, limit order traders compete with each other. Consequently, the quotation activity is significantly higher and the quote midpoint changes more frequently. The market share of IBIS in terms of published quotes is 77.8% as compared to a 63.3% share in the number of transactions. Our estimation results indicate that these quote changes in IBIS convey information that is used by the Makler when he sets his own quotes.

<u>Insert Table 3 about here</u>

Table 3 shows the results based on the five-minute intervals. They are qualitatively similar. We again find bi-directional Granger causality and both the common factor weights and the information shares indicate that both markets contribute to price discovery. The average values for the transaction price model are 0.513 for the factor weights and 0.514 for the information shares. A t-test and a Wilcoxon test indicate that these average values are not significantly different from 0.5. It should be noted, however, that the information shares are estimated unprecisely as indicated by a very large range between the upper and the lower bound (average range 0.63).[15]

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[14] The Makler has to change the quoted prices when new limit orders are submitted that narrow the spread. However. as documented by Freihube et al. (1999), the role of limit orders in the process of liquidity provision on the floor is limited.

[15] As noted in section 4, only upper and lower bounds for the information shares can be given when the innovations in the two markets are correlated. Hasbrouck (1995) points out that the precision with which the information shares are estimated is related to the sampling frequency. The intuition is that the longer is the

The results are again more favorable for IBIS when the quote midpoint model is considered. The average values of the factor weights and the information shares are 0.650 and 0.565, respectively, and both averages are significantly larger than 0.5 at better than the 5% level. In four out of the 30 cases the coefficient on the error correction term is not significantly different from zero in the IBIS equation. This indicates that, in these four cases, quotes on the floor adjust to deviations between the trading systems whereas quotes in IBIS do not.

Information shares versus common factor weights

The results in the preceding subsection already indicated that the common factor weights and the information shares lead to qualitatively similar conclusions. We now turn to a more detailed comparison of these two measures of price discovery.

Insert Table 4 about here

Table 4 shows the means of both measures and their correlation. The mean IBIS factor weight and the mean IBIS information share are very similar and are not significantly different from each other in three out of four cases. The only exception is the 5-minute quote midpoint model. Note that this is the model for which the information shares are the least precise. This is evidenced by an average range between upper and lower bound of 0.687.

The correlation between the factor weights and the information shares is very high. It amounts to 0.972 for the 1-minute transaction price model, 0.967 for the 1-minute quote midpoint model and 0.947 for the 5-minute transaction price model. The model estimated from 5-

sampling interval, the higher is the probability that simultaneous price changes are observed in the two markets. This leads to higher correlation of the innovations which, in turn, translates into larger differences between the upper and the lower bound for the information share. Our results are consistent with this intuition. The differences between the upper and lower bounds are unanimously higher for the 5-minute models as compared to the 1-minute models. Further, the differences tend to be higher for more liquid stocks (note that the stocks in Table 2 and Table 3 are sorted by trading volume in descending order). More liquid stocks have higher transaction frequencies and, consequently, a given interval length is associated with higher contemporaneous correlation of the innovations.

minute quote midpoints yields the lowest correlation. The correlation coefficient of 0.831 is however, still strongly significant at usual levels.

Insert Figure 1 and Figure 2 about here

Figure 1 and Figure 2 visualize the results for the 1-minute models. It is apparent that the common factor weights and the information shares are very similar. Given that the factor weights are both theoretically well founded and easy to calculate, our results give strong support to the application of this simple measure.

Cross-sectional determinants of the common factor weights

Our data set allows us to address the question of what determines the contributions of the two trading systems to the process of price discovery. Since, as documented in the preceding subsection, both measures of these contributions are very similar, we restrict the analysis to the common factor weights.

The stocks in Table 2 and Table 3 are sorted by trading volume in descending order. It appears that the common factor weights of IBIS are positively related to the trading volume. This is corroborated by a correlation analysis. The correlation between $(1 - \theta)$ and the log of trading volume is 0.699 for the 1-minute transaction price model, 0.553 for the 1-minute quote midpoint model, 0.421 for the 5-minute transaction price model and 0.231 for the 5-minute quote midpoint model. All but the last coefficient are significantly different from zero at the 5% level.

Insert Figure 3 and Figure 4 about here

Figure 3 and Figure 4 illustrate the results. The figures show the IBIS common factor weights for all four models for stocks sorted by trading volume. The IBIS factor weights are larger when the estimation is based on quote midpoints (thus indicating greater contribution of IBIS to price discovery) and the weights show a tendency to be smaller for stocks with lower trading volume.

In order to obtain more detailed insight into the cross-sectional determinants of the contributions to price discovery we perform a regression analysis. The dependent variable is the IBIS common factor weight (1 - θ). There are several variables that may have explanatory power for the factor weights. First, it was found in previous studies that the market with the larger market share contributes more to price discovery.[16] Therefore, we use the market share of IBIS as an explanatory variable. Second, as outlined in section 2, smaller spreads enable investors to exploit smaller pieces of information. We therefore include the difference between the effective spread on the floor and the effective spread in IBIS on the right-hand side.

Finally, the amount of informed trading may be related to the contributions to price discovery. We use the adverse selection component of the bid-ask spread as a proxy for the amount of informed trading. We estimate the adverse selection component using a two-way decomposition similar to the one proposed by Huang / Stoll (1996). The difference between the adverse selection components is then included as an explanatory variable. To avoid multicollinearity we do not include effective spreads and adverse selection component at the same time but rather estimate two separate models. The two models are thus

$$\left(1-\theta_i\right) = a_0 + a_1 MS_{IBIS,i} + a_2\left(s^e_{floor,i} - s^e_{IBIS,i}\right) + \varepsilon_i$$

and

$$\left(1-\theta_i\right) = b_0 + b_1 MS_{IBIS,i} + b_2\left(s^a_{floor,i} - s^a_{IBIS,i}\right) + \eta_i$$

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[16] An exception is Martens (1998). He analyzes the Bund futures contracts traded on the LIFFE and the DTB. In low volatility periods the market share of the LIFFE is larger whereas the contribution to price discovery is smaller.

where MS_{IBIS} is the market share of IBIS, measured in terms of DM trading volume, s^e denotes the effective spread and s^a denotes the adverse selection component. i indexes the sample stocks. We expect that (1 - θ) is larger (i.e., the contribution of IBIS to price discovery is larger) the larger the market share of IBIS and the larger the spread on the floor relative to the spread in IBIS. We thus expect the coefficients a_1, a_2, b_1 and b_2 to be positive.

Insert Table 5 about here

We estimate both equations using the factor weights obtained from the 1-minute and 5-minute price and quote midpoint models. The results are presented in Table 5. The explanatory power is higher for the models based on prices as compared to the models based on quote midpoints and is higher for the 1-minute models as compared to the 5-minute models.

The intercept is larger in the models based on quote midpoints. This is consistent with our earlier finding that the IBIS factor weights are larger when the estimation is based on quote midpoints. The coefficient on the IBIS market share has the expected sign in all eight cases. It is significant at the 5% level or better in all models based on prices but in only one of the quote midpoint models. The coefficient on the spread differential also has the expected sign. It is significant, however, only in the 1-minute transaction price model. In the 1-minute midpoint model the coefficient is significantly different from zero only at the 10% level. The coefficient on the difference in the adverse selection components always has the expected positive sign but is never significantly different from zero.

The results thus indicate that the contribution to price discovery is positively related to the market share. The relation between the relative size of the bid-ask spread and the contribution to price discovery has the expected sign but is, at best, weak.

6 Summary

In the present paper we exploit a unique institutional feature of the German stock market, namely, the co-existence of floor and screen trading, to analyze the price discovery in traditional floor-based and electronic exchanges.

We estimate error correction models based on transaction prices and quote midpoints. The results confirm the finding that both systems contribute to price discovery. The contributions are almost equal when the estimation is based on transaction prices. The model based on quotes midpoints, on the other hand, leads to the conclusion that the electronic trading system contributes more to price discovery. This is consistent with the higher quotation activity in IBIS.

We analyze two different measures of the contributions to price discovery. The first is the information share proposed by Hasbrouck (1995), the second is a simple measure calculated from the coefficients of the ECM and first proposed by Schwarz / Szakmary (1994). We give a theoretical foundation for this measure by showing that it is equal to the weights with which the time series under scrutiny enter the common long memory component as defined by Gonzalo / Granger (1995). We therefore term this measure the common factor weight. Our analysis reveals that the information share and the common factor weights are very similar. Given that the common factor weights are easier to estimate, our results thus support the application of this measure.

An analysis of the cross-sectional determinants of the contributions to price discovery reveals that the contributions of the trading systems are positively related to their market shares. The relation between the relative size of the bid-ask spread and the contribution to price discovery is, at best, weak.

We document a positive relation between the total trading volume and the contribution of IBIS to price discovery. Taken together, the results thus imply that, first, floor trading systems are not necessarily inferior to electronic open limit order books in terms of contributions to price discovery and that, second, the advantages of electronic trading systems are more pronounced for more liquid stocks.

References

Breedon, F. and A. Holland, 1998, Electronic versus Open Outcry Markets: the Case of the Bund Futures Contract, Working Paper No. 76, Bank of England, January.

Bühler, A., A. Grünblichler and H. Schmidt, 1995, Parkett und Computer im Preisfindungsprozeß, *Zeitschrift für Bankrecht und Bankwirtschaft*, 7, 234-243.

Ding, D., F. deB. Harris, S. T. Lau and Th. McInish, 1999, An Investigation of Price Discovery in Informationally-Linked Markets: Equity Trading in Malaysia and Singapore, *Journal of Multinational Financial Management*, 9, 317-329.

Domowitz, I. and B. Steil, 1998, Automation, Trading Costs, and the Structure of the Trading Services Industry, *Brookings-Wharton Papers on Financial Services*, forthcoming.

Domowitz, I., 1993, Automating the Continuous Double Auction in Practice: Automated Trade Execution Systems in Financial Markets, in: Friedman, D. and J. Rust, (eds.), The Double Auction Market, Reading MA., S. 27-60.

Engle, F. and C. Granger, 1987, Co-Integration and Error Correction: Representation, Estimation, and Testing, *Econometrica*, 55, 251-276.

Fraser Jenkins, I., 1998, Open Outcry versus Electronic Screen Trading: A Comparison of Trading on LIFFE and the DTB between 1995 and 1998, Working Paper, Bank of England.

Freihube, Th. and E. Theissen, 2000, An Index Is an Index Is an Index? *Schmalenbach Business Review*, forthcoming.

Freihube, Th., C.-H. Kehr, J. Krahnen and E. Theissen, 1999, Was leisten die Kursmakler? Eine empirische Untersuchung am Beispiel der Frankfurter Wertpapierbörse, *Kredit und Kapital*, 32, 426-460.

Gonzalo, J. and C. Granger, 1995, Estimation of Common Long-Memory Components in Cointegrated Systems, *Journal of Business & Economic Statistics* 13, 27-35.

Grünbichler, A., F. Longstaff and E. Schwartz, 1994, Electronic Screen Trading and the Transmission of Information: An Empirical Examination, *Journal of Financial Intermediation*, 3, 166-187.

Harris, F., T. McInish and R. Wood, 1997, Common Long Memory Components of Intraday Stock Prices: A Measure of Price Discovery. Working Paper, Wake Forest University.

Harris, F., T. McInish, G. Shoesmith and R. Wood, 1995, Cointegration, Error Correctioin, and Price Discovery on Informationally Linked Security Markets, *Journal of Financial and Quantitative Analysis*, 30, 563-579.

Hasbrouck, J., 1995, One Security, Many Markets: Determining the Contributions to Price Discovery, *Journal of Finance*, 50, 1175-1199.

Huang, R. and H. Stoll, 1996, Dealer versus Auction Markets: A Paired Comparison of Execution Costs on NASDAQ and the NYSE, *Journal of Financial Economics*, 41, 313-357.

Johansen, S., 1988, The Mathematical Structure of Error Correction Models, *Contemporary Mathematics*, 80, 359-387.

Johansen, S., 1991, Estimation and Hypothesis Testing of Cointegrated Vectors in Gaussian Vector Autoregressive Models, *Econometrica*, 59, 1551-1580.

Kehr, C.-H., 1997, Preisfindung bei verteilter Börsenstruktur, Wiesbaden (Gabler-Verlag).

Kempf, A. and O. Korn, 1998, Trading System and Market Integration, *Journal of Financial Intermediation*, 7, 220-239.

Kirchner, T. and Ch. Schlag, 1998, An Explorative Investigation of Intraday Trading on the German Stock Market, *Finanzmarkt und Portfolio Management*, 12, 13-31.

Kirchner, T., Segmentierte Aktienmärkte, Wiesbaden (Gabler-Verlag)

Kofman, P. and J. Moser, 1997, Spreads, Information Flows and Transparency Across Trading Systems, *Applied Financial Economics,* 7, 281-294.

Martens, M., 1998, Price Discovery in High and Low Volatility Periods: Open Outcry versus Electronic Trading, *Journal of International Financial Markets, Institutions and Money*, 8, 243-260.

Schmidt, H., P. Iversen and K. Treske, 1993, Parkett oder Computer? *Zeitschrift für Bankrecht und Bankwirtschaft*, 5, S. 209-221.

Schwarz, Th. and A. Szakmary, 1994, Price Discovery in Petroleum Markets: Arbitrage, Cointegration, and the Time Interval of Analysis, *Journal of Futures Markets,* 14, 147-167.

Shyy, G. and J.-H. Lee, 1995, Price Transmission and Information Asymmetry in Bund Futures Markets: LIFFE vs. DTB, *Joiurnal of Futures Markets*, 15, 87-99.

Stock, J. and M. Watson, 1988, Testing for Common Trends, *Journal of the American Statistical Association* 83, 1097-1107.

Stucki, Th. and W. Wasserfallen, 1994, Stock and Option Markets: The Swiss Evidence, *Journal of Banking and Finance*, 18, 881-893.

Theissen, E., 2001, Floor versus Screen Trading: Evidence from the German Stock Market. *Journal of Institutional and Theoretical Economics*, forthcoming.

Table 1: Descriptive statistics

All figures are for the sample period (June and July 1997) and are for the three hours of parallel trading.

stock	av. daily volume, million DM	IBIS market share, %	av. daily number of transactions	IBIS market share, %	effective spread, % floor	effective spread, % IBIS
DBK	132.830	61.18	335.21	61.382	0.084	0.100
DAI	128.011	63.37	252.03	73.840	0.102	0.097
SIE	119.023	61.10	307.16	64.631	0.093	0.095
VOW	101.821	56.95	225.40	66.083	0.137	0.149
ALV	72.614	53.16	160.50	62.798	0.148	0.212
BAY	69.470	53.36	280.17	51.815	0.096	0.133
VEB	66.953	60.43	163.88	70.509	0.112	0.122
BAS	64.289	56.26	217.95	66.038	0.127	0.136
COB	61.701	48.89	209.45	66.660	0.159	0.151
HFA	59.105	59.02	206.86	59.910	0.089	0.157
DTE	47.916	57.19	195.38	70.376	0.159	0.144
DRB	46.845	45.62	128.81	63.862	0.170	0.170
MMW	44.021	47.29	97.19	47.700	0.170	0.236
SAP3	38.041	52.25	158.27	58.312	0.232	0.245
MUV2	32.147	44.08	59.79	54.006	0.260	0.401
BMW	31.479	56.92	75.43	73.578	0.267	0.267
BVM	30.200	48.74	83.83	65.859	0.269	0.305
BHW	29.191	52.16	113.14	55.135	0.152	0.241
THY	28.500	55.02	77.03	73.075	0.259	0.216
RWE	26.327	49.16	80.45	62.685	0.145	0.202
SCH	25.987	48.24	116.19	48.670	0.205	0.297
VIA	23.465	52.18	79.12	65.748	0.152	0.191
MEO	21.427	51.03	74.33	74.855	0.292	0.336
PRS	19.837	42.88	80.55	58.349	0.184	0.311
LHA	18.485	45.93	102.64	66.923	0.238	0.270
KAR	14.304	49.31	61.69	64.759	0.260	0.348
DEG	11.253	47.89	55.07	65.807	0.335	0.430
LIN	10.607	37.32	36.98	55.435	0.407	0.544
HEN3	9.566	50.21	50.24	63.416	0.242	0.351
MAN	9.107	41.77	46.76	55.304	0.236	0.350

Table 2: Summary results of the error correction model – one minute intervals

A "+" indicates that the respective coefficient (error correction, lag coefficients in equations with one lag) or group of coefficients (lag coefficients in equations with more than one lag) is significantly different from 0 at the 5% level. (1 - θ) is the weight of IBIS in the common long memory factor. The information share is for IBIS, the table reports the mean of the lower and upper bound and the range.

	prices							quote midpoints						
	lead-lag relationship		error correction		factor weights	information share		lead-lag relationship		error correction		factor weights	information share	
	floor leads	IBIS leads	floor adjusts	IBIS adjusts	1 - θ	mean	range	floor leads	IBIS leads	floor adjusts	IBIS adjusts	1 - θ	mean	range
DBK	+	+	+	+	0.726	0.791	0.256	+	+	+	+	0.667	0.655	0.365
DAI	+	+	+	+	0.694	0.763	0.261	+	+	+	+	0.886	0.893	0.179
SIE	+	+	+	+	0.665	0.725	0.269	+	+	+	+	0.764	0.779	0.287
VOW	+	+	+	+	0.494	0.497	0.364	+	+	+	+	0.636	0.624	0.42
ALV	+	+	+	+	0.476	0.525	0.268	+	+	+	+	0.641	0.662	0.337
BAY	+	+	+	+	0.53	0.545	0.33	+	+	+	+	0.642	0.644	0.359
VEB	+	+	+	+	0.55	0.631	0.246	+	+	+	+	0.682	0.725	0.265
BAS	+	+	+	+	0.58	0.609	0.237	+	+	+	+	0.705	0.698	0.266
COB	+	+	+	+	0.604	0.639	0.234	+	+	+	+	0.604	0.583	0.322
HFA	+	+	+	+	0.641	0.734	0.208	+	+	+	+	0.629	0.643	0.321
DTE	+	+	+	+	0.625	0.657	0.232	+	+	+	+	0.682	0.68	0.326
DRB	+	+	+	+	0.54	0.574	0.214	+	+	+	+	0.658	0.687	0.254
MMW	+	+	+	+	0.607	0.64	0.267	+	+	+	+	0.685	0.694	0.317
SAP	+	+	+	+	0.512	0.536	0.224	+	+	+	+	0.786	0.809	0.194
MUV	+	+	+	+	0.472	0.54	0.129	+	+	+	+	0.743	0.838	0.121
BMW	+	+	+	+	0.554	0.631	0.173	+	+	+	+	0.524	0.547	0.273
BVM	+	+	+	+	0.566	0.619	0.274	+	+	+	+	0.795	0.834	0.189
BHW	+	+	+	+	0.512	0.557	0.112	+	+	+	+	0.554	0.524	0.238
THY	+	+	+	+	0.602	0.655	0.186	+	+	+	+	0.793	0.877	0.096
RWE	+	+	+	+	0.539	0.58	0.207	+	+	+	+	0.608	0.636	0.217
SCH	+	+	+	+	0.391	0.323	0.151	+	+	+	+	0.616	0.554	0.24
VIA	+	+	+	+	0.592	0.672	0.192	+	+	+	+	0.578	0.579	0.235
MEO	+	+	+	+	0.478	0.565	0.128	+	+	+	+	0.688	0.752	0.242
PRS	+	+	+	+	0.369	0.334	0.178	+	+	+	+	0.555	0.515	0.257
LHA	+	+	+	+	0.503	0.543	0.259	+	+	+	+	0.64	0.684	0.206
KAR	+	+	+	+	0.468	0.488	0.176	+	+	+	+	0.589	0.556	0.187
DEG	+	+	+	+	0.442	0.442	0.13	+	+	+	+	0.573	0.52	0.153
LIN	+	+	+	+	0.342	0.301	0.175	+	+	+	+	0.4	0.36	0.172
HEN	+	+	+	+	0.487	0.536	0.064	+	+	+	+	0.543	0.492	0.094
MAN	+	+	+	+	0.458	0.458	0.141	+	+	+	+	0.598	0.592	0.116

Table 3: Summary results of the error correction model – five minute intervals

A “+” indicates that the respective coefficient (error correction, lag coefficients in equations with one lag) or group of coefficients (lag coefficients in equations with more than one lag) is significantly different from 0 at the 5% level. (1 - θ) is the weight of IBIS in the common long memory factor. The information share is for IBIS, the table reports the mean of the lower and upper bound and the range.

	prices							quote midpoints						
	lead-lag relationship		error correction		factor weights	information share		lead-lag relationship		error correction		factor weights	information share	
	floor leads	IBIS leads	floor adjusts	IBIS adjusts	1 - θ	mean	range	floor leads	IBIS leads	floor adjusts	IBIS adjusts	1 - θ	mean	range
DBK	+	+	+	+	0.591	0.542	0.825	+	+	+	+	0.406	0.48	0.889
DAI	+	+	+	+	0.592	0.542	0.818	+	+	+	-	0.845	0.568	0.856
SIE	+	+	+	+	0.675	0.582	0.755	+	+	+	-	0.952	0.621	0.756
VOW	+	+	+	+	0.424	0.474	0.802	+	+	+	+	0.613	0.513	0.891
ALV	+	+	+	+	0.507	0.521	0.759	+	+	+	+	0.758	0.58	0.802
BAY	+	+	+	+	0.455	0.489	0.792	+	+	+	+	0.449	0.476	0.837
VEB	+	+	+	+	0.589	0.573	0.693	+	+	+	+	0.784	0.626	0.713
BAS	+	+	+	+	0.552	0.518	0.732	+	+	+	+	0.744	0.578	0.77
COB	+	+	+	+	0.641	0.575	0.716	+	+	+	+	0.517	0.505	0.819
HFA	+	+	+	+	0.774	0.654	0.636	+	+	+	+	0.611	0.525	0.838
DTE	+	+	+	+	0.593	0.569	0.67	+	+	+	+	0.676	0.561	0.79
DRB	+	+	+	+	0.534	0.535	0.715	+	+	+	-	0.714	0.589	0.75
MMW	+	+	+	+	0.423	0.459	0.715	+	+	+	+	0.648	0.542	0.815
SAP	+	+	+	+	0.339	0.416	0.676	+	+	+	+	0.754	0.599	0.751
MUV	+	+	+	+	0.5	0.517	0.549	+	+	+	+	0.856	0.762	0.44
BMW	+	+	+	+	0.441	0.488	0.62	+	+	+	+	0.489	0.507	0.694
BVM	+	+	+	+	0.593	0.58	0.667	+	+	+	+	0.529	0.51	0.708
BHW	+	+	+	+	0.589	0.581	0.622	+	+	+	+	0.555	0.512	0.71
THY	+	+	+	+	0.568	0.575	0.573	+	+	+	+	0.818	0.784	0.369
RWE	+	+	+	+	0.533	0.543	0.558	+	+	+	+	0.661	0.583	0.682
SCH	+	+	+	+	0.31	0.329	0.483	+	+	+	+	0.574	0.509	0.717
VIA	+	+	+	+	0.523	0.553	0.506	+	+	+	+	0.533	0.505	0.623
MEO	+	+	+	+	0.587	0.601	0.591	+	+	+	-	0.942	0.723	0.549
PRS	+	+	+	+	0.266	0.329	0.522	+	+	+	+	0.53	0.495	0.661
LHA	+	+	+	+	0.556	0.55	0.659	+	+	+	+	0.7	0.614	0.66
KAR	+	+	+	+	0.526	0.538	0.55	+	+	+	+	0.599	0.548	0.63
DEG	+	+	+	+	0.416	0.433	0.471	+	+	+	+	0.584	0.54	0.491
LIN	+	+	+	+	0.349	0.354	0.446	+	+	+	+	0.481	0.46	0.535
HEN	+	+	+	+	0.484	0.539	0.363	+	+	+	+	0.559	0.537	0.429
MAN	+	+	+	+	0.464	0.468	0.407	+	+	+	+	0.61	0.598	0.446

Table 4: Information shares versus common factor weights

The table compares the information shares and the common factor weights. The common factor weights are for IBIS. The information share is the mean of the lower and the upper bound for the IBIS information share. The first two columns report the means for the four models. The third column gives the t statistic of a t-test of the null hypothesis of equal means. The last column shows the correlation between the two measures.

	mean of IBIS factor weights	mean of IBIS information shares	t-value; H_0: equality of means	correlation
1 minute, prices	0.534	0.570	1.32	0.972
1 minute, quote midpoints	0.649	0.655	0.20	0.967
5 minutes, prices	0.513	0.514	0.04	0.947
5 minutes, quote midpoints	0.650	0.565	2.84	0.831

Table 5: Determinants of the contributions to price discovery

The table presents the results of regressions of the common factor weights for IBIS on a set of explanatory variables. These are the IBIS market share in terms of DM trading volume, the difference between the effective spreads in the two trading systems and the difference between the adverse selection components of the spreads. t-values are given in parentheses.

	constant	IBIS market share	spread differential $s^e_{floor,i} - s^e_{IBIS,i}$	difference in adverse selection component $s^a_{floor,i} - s^a_{IBIS,i}$	adj. R^2
prices, 1 minute	0.184 (1.46)	0.007 (3.29)	0.670 (2.34)		0.62
	–0.028 (0.24)	0.011 (5.34)		0.020 (0.08)	0.55
quote midpoints, 1 minute	0.501 (2.67)	0.004 (1.07)	0.766 (1.80)		0.28
	0.287 (1.78)	0.007 (2.45)		0.135 (0.38)	0.19
prices, 5 minutes	0.128 (0.60)	0.008 (2.02)	0.342 (0.70)		0.26
	0.096 (0.55)	0.008 (2.66)		0.314 (0.81)	0.26
quote midpoints, 5 minutes	0.527 (1.65)	0.003 (0.50)	0.519 (0.714)		0.01
	0.517 (2.01)	0.003 (0.69)		0.632 (1.10)	0.04

Figure 1: Information shares versus common factor weights: prices, 1 minute intervals

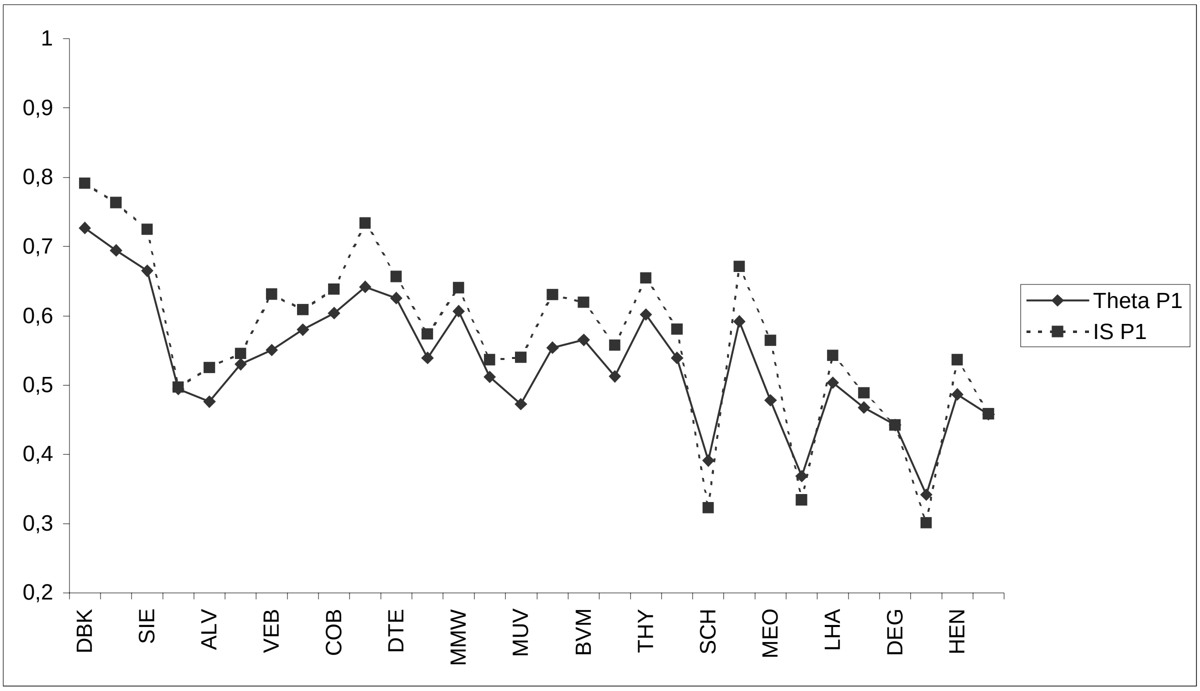

Figure 2: Information shares versus common factor weights: quote midpoints, 1 minute intervals

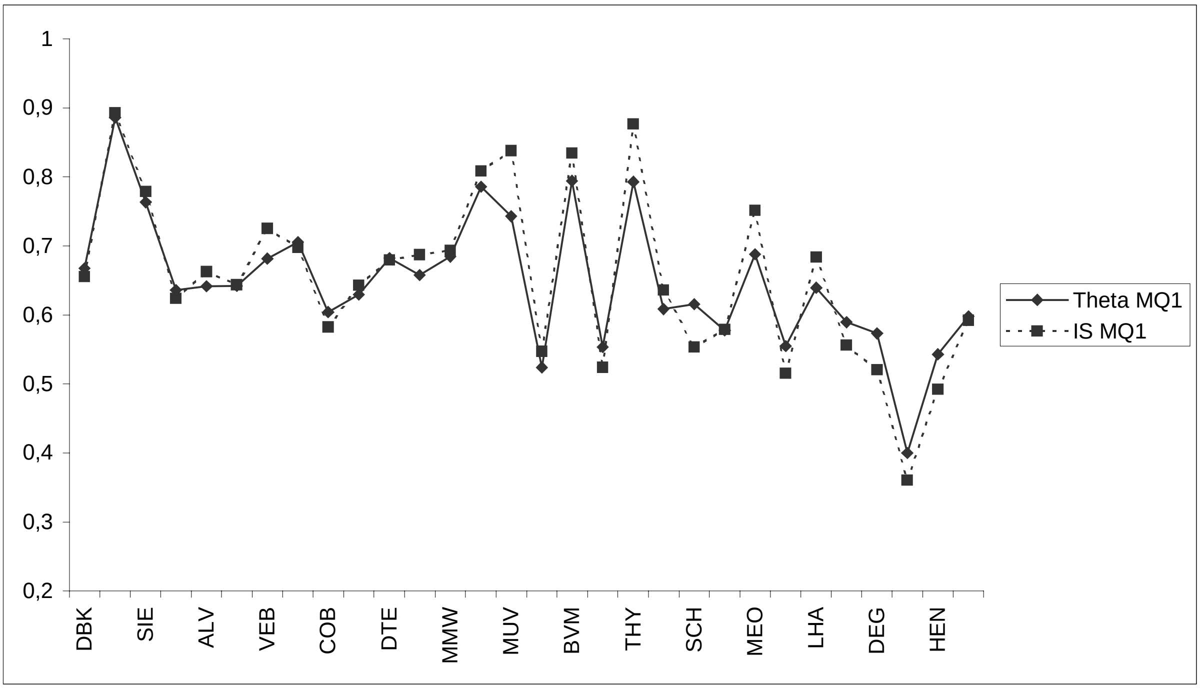

Figure 3: Common factor weights: one-minute intervals

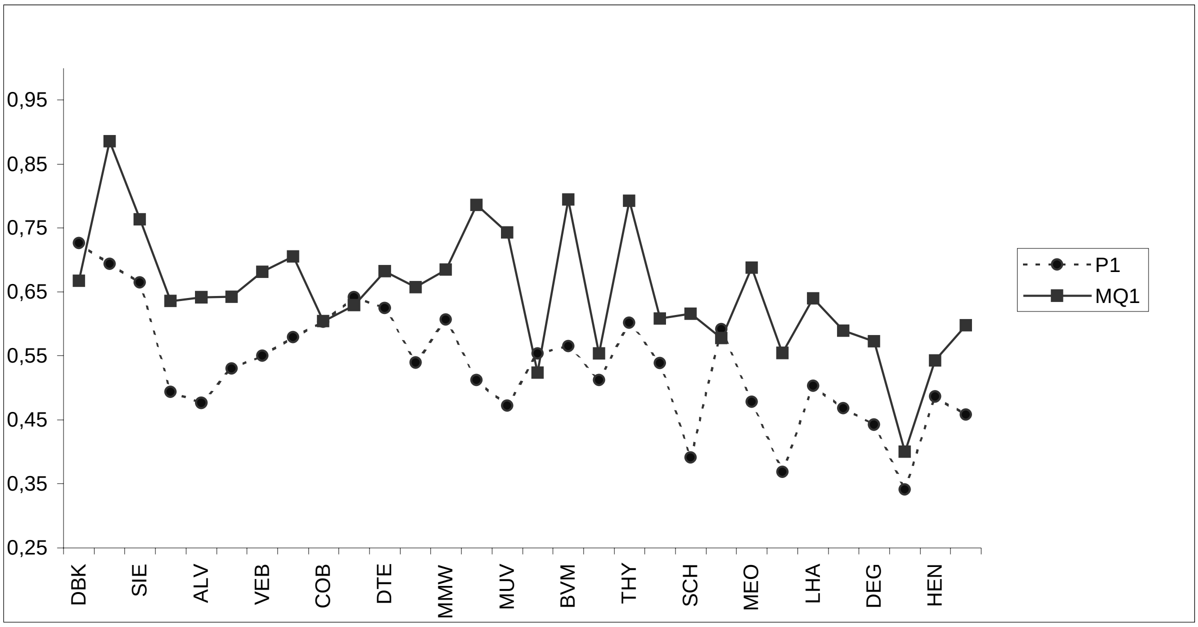

Figure 4: Common factor weights: five-minute intervals