TOBIAS KIRCHNER UND CHRISTIAN SCHLAG*

An Explorative Investigation of Intraday Trading on the German Stock Market

1. Introduction

Empirical investigations of stock markets have shown that there are typical patterns in returns, volatility and trading activity over the trading day. It was found that the volatility of intradaily returns is highest during the first trading hour, declines during the trading day, and rises again at the end of the day.[1] Examinations of stock volume also documented a U-shaped pattern (for example CHEN, ELLIS and WOOD (1994) and JAIN and JOH (1988)). For returns, JAIN and JOH (1988) showed that the average returns across hours are significantly different and that there exists a day of the week effect with significantly negative returns on Monday morning. This latter effect was also documented by HARRIS (1986). Furthermore, HARRIS (1989) finds an end-of-the-day effect on the NYSE with a large positive mean price change for the last transaction of the day.

Different explanations for these intraday patterns are offered in the literature. One is that the special behaviour of prices and volume at the beginning and at the end of the trading day is due to the discontinuity in trading possibilities (see BROCK and KLEIDON (1992)). Alternative explanations are offered in the context of models based on information economics (see KYLE (1985) and ADMATI and PFLEIDERER (1988)). Finally, also the mechanism of price determination, i.e. the mircostructure of a market, can have an impact on the intraday behavior of prices and returns (see STOLL and WHALEY (1990)).

The main problem of an empirical investigation of intraday patterns is to separate the influences of market structure, overnight trading halt and asymmetric information. For example, although STOLL and WHALEY (1990) find open-to-open returns (computed using batch auction prices) to be more volatile than close-to-close returns (computed using prices from the continuous market) this does not necessarily imply that batch trading is generally inferior to continuous trading. The opening call auction on the NYSE follows a long period without trading, so that there is also a much greater price uncertainty at the opening than over the rest of the day which may cause higher volatility so that this increase in volatility could also be due to the overnight trading halt.

This paper contains a detailed descriptive analysis of the intraday behavior of volume and volatility on the German market. The specific market structure and the use of transaction returns (in addition to interval returns commonly used in other studies) are furthermore useful in identifying

* Die Arbeit entstand am Institut für Entscheidungstheorie und Unternehmensforschung der Universität Karlsruhe (TH) bei Herrn Prof. Dr. Hermann Göppl. Die Autoren danken Prof. Dr. Walter Wasserfallen für die wertvollen Kommentare. Dipl.-Wi.-Ing. Tobias Kirchner, Institut für Entscheidungstheorie und Unternehmensforschung, Universität Karlsruhe (TH), D-76128 Karlsruhe, Tel.: ++49 721 - 608 - 4389. PD Dr. Christian Schlag, Professur für Finanzwirtschaft, Johann Wolfgang Goethe-Universität, D-60054 Frankfurt am Main, Tel.: ++49 - 69 - 798 -22674.

the explanatory power of each of the competing hypotheses for the observed patterns. In Germany there are several parallel markets for the group of the most liquid stocks. These markets differ with respect to some important characteristics like basic market structure (floor trading vs. computer trading), trading time and price determination mechanism. Furthermore, it is a unique feature of the floor markets in Germany that there are three batch auctions per day. The analysis of transaction returns offers important advantages for the analysis of e.g. the price behavior around batch auctions, since the results are not sensitive to differences in liquidity between stocks. Details on this issue are provided in section 4.
The remainder of the paper is organized as follows. Section 2 contains a description of the theoretical explanations as well as the previous empirical findings for intraday patterns of returns and volumes. Section 3 describes the structure of the German stock market, especially the two major markets FSE and IBIS. Section 4 contains a description of the data and the methodology used in this study. Section 5 presents the results of the empirical investigations, and section 6 provides a summary and an outlook.

2. Hypotheses Concerning Intraday Patterns

In this section the different theoretical explanations and the previous empirical results concerning intraday patterns of volatility and volume will be discussed in more detail. We will start out with the theory:

2.1 Overnight trading-halt hypothesis (OTH)

The OTH was developed by BROCK and KLEIDON (1992). These authors argue that the accumulation of overnight information in the absence of an oppurtunity to trade means that investors have to reestablish their optimal portfolios at the open of the next trading day. In the process of doing so they have a higher propensity to trade combined with a lower price elasticity of demand and/or supply resulting in higher transaction volumes. To be able to trade immediately investors are also willing to accept wider bid-ask spreads which in turn cause a higher volatility of transaction returns. A similar argument can be used to explain higher volumes and volatilities around the end of the day since investors may want to adjust their portfolios given that no trading takes place during the overnight period. Taken together the OTH predicts higher volatilities and higher volumes at the beginning and at the end of the trading day with no distinct pattern over the rest of the day.

2.2 Information flow hypothesis (IFH)

The IFH offers an alternative explanation for intraday-patterns which is based on information economics. In the context of KYLE (1985) the information accumulated during the overnight trading halt would be gradually incorporated into prices over time at the beginning of the next trading day due to the strategic behavior of traders with superior information. The profit maximizing strategy for these investors is not to submit one large order which would immediately uncover the trader as being one with superior information. Instead a series of orders is submitted to the market. On the other hand the other market participants will learn about the true value of the asset observing the order flow so that information is revealed. The IFH thus predicts a steady decline in return volatility and volume after the open. In the model of ADMATI and PFLEIDERER (1988) patterns of high volume and volatility arise endogenuously due to the existence of asymmetric information and the strategic behaviour of both informed and uninformed investors. However, this model cannot explain the timing of these patterns.

2.3 Market microstructure hypothesis (MMH)

Another possible reason for systematic intraday patterns is the influence of market microstructure

on security prices. For example, on the NYSE opening prices are determined in a batch auction, whereas all transactions during the rest of the day are executed sequentially. Stoll and WHALEY (1990) regard the higher volatility of open-to-open returns as a consequence of the monopolistic position of the specialist during the opening auction. If there is a systematic advantage for the specialist in a batch auction we would expect to see this higher volatility in every auction, no matter at what time it takes place during the trading day.

Besides the more descriptive papers cited in the introduction[2] there are some papers trying to separate the influence of non-trading periods and trading mechanisms empirically, using data from exchanges with different sequences of batch auctions and continuous trading. For example, on the German stock market there are batch auctions at the open, at noon and at the close with continuous trading for the rest of the day. In a recent study THEISSEN (1995) finds that open-to-open returns are consistently more volatile than both noon-to-noon and close-to-close returns. He concludes from these results that the trading mechanism cannot be responsible for differences in volatility. Similar results were obtained for other stock exchanges. For example, AMIHUD, MENDELSON, and MURGIA (1990) examine the Milan stock exchange, whereas AMIHUD and MENDELSON (1991) investigate the Tokio Stock Exchange. In a recent paper GERETY and MULHERIN (1994) compare the volatilities of daily returns computed with prices recorded at different hours of the trading day. Since the variances of these returns steadily decline after the opening rather than to drop sharply, the authors conclude that trading facilitates the incorporation of information into prices, and that the call auction at the open is not destabilizing.

The structure of the German market offers a unique opportunity to perform tests of the explanatory power of the three competing hypotheses. Its institutional characteristics are described in the next section.

3. Market Structure

3.1 Floor Trading

Floor trading on the German stock market takes place on seven regional stock exchanges plus the Frankfurt Stock Exchange (FSE) which is by far the most important exchange in terms of trading volume and number of firms listed.[3] About 75% of the total DM volume of all German stocks was traded on the FSE in 1994 (see DBAG (1995)). There is no consolidated order flow for the eight floor exchanges, since there is no system paralleling the National Market System in the U.S.

The FSE is open five days a week from 10:30 a.m. to 1:30 p.m. The stocks with the highest liquidity and the highest market capitalization are traded in the first segment called 'Amtlicher Handel' (AH). The stocks in this segment are in turn divided into two groups. Stocks belonging to the first group ('Variabler Handel', VH) are traded continuously, while the stocks in the second group are traded only once a day at a price called 'Einheits-kurs' which is determined in a batch auction at noon.

The second market segment is called 'Geregelter Markt' (GM). For the stocks in this segment there is only one price per day as for those in the second group of the AH. Requirements for the admission to the GM are less strict than for the AH, and one of the major purposes of the GM was to make it easier for companies to go public. There are only very few requirements for admission to the third segment, the so-called 'Freiverkehr'. For stocks listed in this market segment there is also only one price per day.

There are no exchange designated market makers or specialists on the FSE. Instead in the AH there is the 'Kursmakler' (appointed by the exchange) who is responsible for setting prices which properly reflect current market conditions.[4] The Kursmakler is furthermore the only person who can see the order book on the FSE. In general the functions of the Kursmakler are more like those of an auctioneer, since he or she usually does not trade on his own account.

Special characteristics of the trading process on the FSE in the continuous market of the AH are batch auctions at the open, at noon and at the close with a continuous market for the rest of the trading day.
The batch auction at the opening is similar to the opening procedure at the NYSE with one significant difference. At the NYSE the specialist can easily step in to absorb order imbalances at the prospective opening price (STOLL and WHALEY (1990)). Since the specialist knows the size of the order imbalance it is argued that he can earn a monopolist rent at the opening by providing the supply or demand that is needed to clear the market. The Kursmakler on the FSE does not usually absorb excess demand or supply so that he acts more like a classical auctioneer. If supply does not equal demand during the opening auction the Kursmakler announces the highest bid and the lowest ask price. Only in the case when this outcry does not generate further orders by market participants the Kursmakler can (like the NYSE specialist) trade on his own account to absorb the excess supply or demand. Three types of orders participate in the noon auction. These are odd lot orders (less than 50 shares), the residues of orders exceeding multiples of 50 shares[5] , and all round lot orders that have not been executed until the beginning of the noon auction at 12:00 p.m. For the stocks in the second segment of the AH the price set during the noon auction is the only price of the day. The auction at the close works like the auction at the opening.
All the orders that could not be executed at the opening price remain in the order book for the period of continuous trading. With new orders coming in the Kursmakler has to check whether further orders can be matched. If this is the case a trade takes place a new transaction price is recorded. This is also true for the period between the noon and the closing auction. However, there are no observable bid-ask spreads on the FSE.
Taken together the market structure of the FSE is similar but not exactly equal to a pure order-book system. It also contains elements of a specalist market like the NYSE.
The fact that there are three batch auctions per day forms the basis for a unique plausibility test of the MMH. An increase in volatility axound each of the three auctions would provide support in favor of the MMH, indicating that batch trading is more volatile than continuous trading. Although the situation in Tokyo is similar with two daily batch auctions our data still has the advantage that there is absolutely no trading halt between the auctions in Frankfurt as opposed to the two hour break between the two daily sessions at the Tokyo Stock Exchange.

3.2 Computerized Trading

Besides the eight floor markets there is the computer trading system IBIS.[6] During the sample period 37 stocks, a number of government bonds and some warrants were traded on IBIS.[7] In 1994 the IBIS trading volume for the 30 stocks in the Deutscher Aktienindex (DAX)[8] accounted for about 34% of the total DM trading volume for these stocks on all German exchanges.
Trading time on IBIS is five days a week from 8:30 a.m. to 5 p.m. All banks as well as all Kursmaklers and Free Maklers can participate in IBIS which is an open order book system. On their trading screens market participants can continuously observe both sides of the book with prices as well as quantities. The minimum size of a transaction on IBIS is either 100 or 500 shares which is why IBIS is considered a trading system designed mainly for institutional investors. Furthermore, traders will remain anonymous on IBIS whereas on the floor of the FSE the Kursmakler can see which trader is buying or selling. Some participants act as 'voluntary market makers' for the securities on IBIS, i.e. they stand ready to buy and sell securities at their quoted prices.[9]
With the options and futures exchange Deutsche Terminbörse (DTB) opening at 9:30 a.m. and closing at 4 p.m.[10] the trading day for stocks (on

the FSE and IBIS) and their derivatives in Germany can be divided into the following segments:

- before 8:30 a.m.: no trading
- 8:30 a.m. to 9:30 a.m.: trading on IBIS only
- 9:30 a.m. to 10:30 a.m.: trading on IBIS and DTB
- 10:30 a.m. to 1:30 p.m.: trading on IBIS, DTB and FSE
- 1:30 p.m. to 4 p.m.: trading on IBIS and DTB
- 4 p.m. to 5 p.m.: trading on IBIS only
- after 5 p.m.: no trading.

The fact that trading on IBIS starts two hours before the open of the FSE offers an opportunity to check if the price behavior on the FSE is consistent with the IFH. If IBIS prices contain useful information for market participants we expect return volatility and volume at the open of the FSE to be smaller than at the open of IBIS, since investors can readjust their portfolios on IBIS long before they have an opportunitiy to trade on the FSE. The same is true for the end of the trading day, so that we should not see an increase in volatility or volume on the FSE towards the close. Of course, these predictions are based on the assumption that investors do not have preferences for either IBIS or the FSE for any other reasons, i.e. only if the two markets are perfect substitutes for each other.

4. Data and Methodology

Two data sources are used in the course of this study. The first is the KISS tape which contains time stamped transaction prices for the 30 stocks in the DAX[11], but no volumes.[12] The second source is the IBIS tape which also contains time stamped transaction prices, but in addition it also shows the volumes of the individual trades.

The basic sample period for KISS data ranges from January 1990 to December 1994, the IBIS data cover the period from July 1991 to December 1994. To investigate intraday patterns on the German stock market the daily trading time was divided into fifteen minute intervals. This interval length was chosen on the basis of a preliminary analysis of the trading activity on the FSE. The mean time between two consecutive transaction for the 30 DAX stocks on the FSE was 4.68 minutes in 1994 with a median of about 3 minutes. Thus, to avoid a very large percentage of empty intervals fifteen minutes seemed an appropriate choice for the interval length.

With fifteen minute intervals the first IBIS interval is the period from 8:30 a.m. to 8:45 a.m., for KISS the first interval starts at 10:30 a.m. and ends at 10:45 a.m. Since the last price of the day on the FSE is set in the course of a batch auction starting at 1:30 p.m. some time may go by until this price is actually recorded. The last interval (interval 12) starts at 1:15 p.m. and has an open end, i.e. it also contains all the observations recorded after 1:30 p.m. The same procedure is applied to IBIS data with interval 34 containing all observations after 4:45 p.m.

The 30 stocks in the DAX are grouped into five classes (equally weighted portfolios) according to their total DM trading volume on the FSE and IBIS in the respective previous year, i.e. the classification for 1994 was done on the basis of 1993 volume data. Table A.2 in the appendix shows some descriptive statistics for the five groups as well as the stocks included in the respective groups in 1994. It is obvious that group 1 contains by far the most liquid stocks. The average annual DM trading volume for these stocks is 105 billion DM which is more than three times the average volume for stocks in group 2. Furthermore, the mean time between two consecutive trades on the FSE is considerably shorter for the stocks in groups 1 and 2 than for the other firms. This effect is even more pronounced for IBIS where the mean time between two trades is around 17 and 18 minutes for the least liquid stocks, respectively.[13] These descriptive statistics are a preliminary indication that the 30 DAX stocks cannot be seen as a homogeneous group but that there are some important differences between them.

For the following empirical analyses the return for stock i in interval j is computed as the difference of the logarithmic stock prices at the end of intervals j – 1 and j. With S_{ij} denoting the price of stock i in interval j the return r_{ij} is computed as

$$r_{ij} = \ln S_{ij} - \ln S_{i,j-1} \qquad (1)$$

If there are several price observations for stock *i* in interval *j* the return for this interval is computed using the first and the last of these two prices. This is the only case when a return possibly contains two prices from the same interval. A problem exists when there is no price observation for a stock in a certain interval. In this paper returns are computed only for those intervals for which a stock price is recorded, they are set to missing when no price obvservation is available for a given interval.

For each interval j the return for the group of stocks g is defined as the equally weighted average of the returns of the component stocks. With $r^g_{1,j},\ldots,r^g_{6,j}$ denoting the returns for the six stocks (possibly containing missing values) in group g in interval j and n^g_j as the number of non-missing return observations the return for this group r^g_j is given as

$$r^g_j = \frac{1}{n^g_j}\sum_{l=1}^{n^g_j} r^g_{l,j} \quad g = 1,\ldots,5 \qquad (2)$$

For the following analysis mean returns and volatilities of the five groups of stocks in the various intervals of the trading day are the main variables of interest. The mean return for a given group in a given interval is computed as the time series average of the interval returns for this group in 1994. All the returns and absolute returns in the following tables and graphs were multiplied by 100.

Volatility is computed as the time series average of non-missing absolute returns. For a given group the average of absolute returns is used. This eliminates diversification effects, but the aggreagation is only used to simplify the presentation of the empirical results and not to analyse any portfolio effects.

Trading activity is measured by the number of transactions in a given interval. For IBIS the share volume is also available. However, recent empirical research, especially the paper by JONES, KAUL and LIPSON (1994), demonstrated a closer relationship between the number of transactions and volatility than between share volume and volatility. Given this evidence the lack of an observable trading volume for KISS does not seem to be a severe limitation.

The trading activity for a given stock is measured as the annual average of the number of trades per day in a given interval. The variable of interest in section 5 is the group average of this trading activity measure. This variable will be denoted by NT. Thus, $NT^g_{l,j}$ is the annual average of the number of transactions per day for stock l of group *g* in interval j. The value for group g is then computed as the average over the component stocks, i.e.

$$NT^g_j = \frac{1}{6}\sum_{l=1}^{6} NT^g_{l,j}, \quad g = 1,\ldots,5 \qquad (3)$$

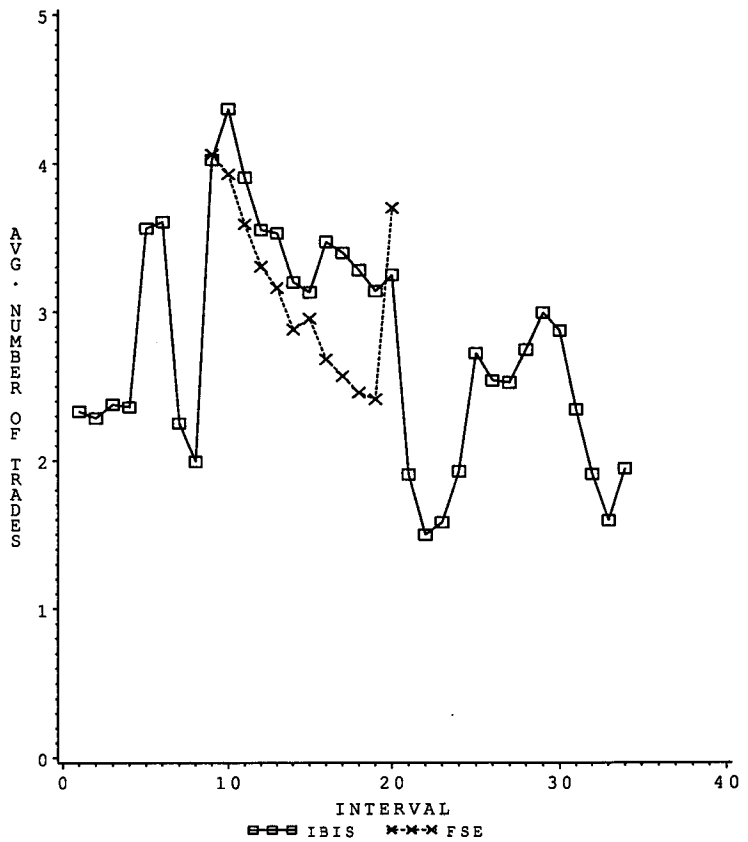
Besides interval returns, transaction returns are also investigated in this paper. A transaction return is simply the change in the logarithmic stock price irrespective of the point in time when the two prices were observed. The transaction returns for a given group of stocks is computed as the average transaction returns of the individual stocks. The main advantage of transaction returns as opposed to interval returns becomes obvious when we want to test if the behvaior of volatilities is consistent with the MMH or the IFH. It is crucial in this context to analyze price changes from consecutive trades, no matter how much time has elapsed between them. The analysis of interval returns will deliver biased results, especially when there are large differences in liquidity between the stocks in the sample. Furthermore, events (like an auction) located in the interior of an interval cannot be investigated at all using interval returns, here one has to use transaction returns.

Non-parametric tests, like the Friedman test and the Wicoxon sign test, are used in this paper to avoid potential problems caused by distributional assumptions for the underlying variables. Some of the hypotheses tested in this paper build upon explicit rankings of certain variables over different times of the day. For example, the null hypothesis of no information effect on volatility implies that mean absolute returns are constant from immediately after the opening until, e.g., the noon auction. To test this null hypothesis of equal volatility in all intervals against the alternative that volatility decreases monotonically over the day (information flow hypothesis) the nonparametric test developed by PAGE (1963) will be used. The main advantage of the Page test over the classical F-test is that the former allows for an explicitly formulated monotonicity alternative.[14]

5. Empirical Results

The emphasis of the empirical analysis will be on the year of 1994. The stability of the results was checked comparing them to the period from 1990 to 1993 (FSE) and 1992 to 1993 (IBIS). When significant differences between 1994 and other years were observed they will be described in more detail. We will present results for transaction frequencies and volatilitites (based on interval and transaction-by-transaction data) for the two markets separately, as well as our findings for the interaction between the floor and the computerized market at the times of the three batch auctions on the FSE.[15] The results of the analysis will then be used to perform a plausibility test of the theoretical explanations for intraday patterns.

Figure 1: Average number of transactions on IBIS and the FSE 1994



5.1 Transaction Frequency

Figure 1 shows the average number of transactions per stock over the fifteen minute intervals for all stocks together on the FSE an on IBIS. The grand means of the two markets are presented to facilitate comparisons. In general the shapes of the graphs for the five groups are qualitatively very similar on both markets so that they are not presented individually.

It is evident that during the trading time of the FSE (IBIS intervals 8 to 20) the number of transactions is most of the time higher on IBIS than on the FSE, except for the interval containing the closing auction. The main reason for this result is that the trading activity for the most liquid stocks is higher on IBIS than on the FSE. For the other groups we obtain the opposite result. This is also reflected in table A.2 in the appendix which shows that for group 1 the mean time between two consecutive transactions is shorter on IBIS than on the FSE whereas it is the other way round for the other stocks. IBIS is thus a system on which mainly large stocks are traded. For the less liquid stocks in the DAX trading on IBIS is not as relevant.[16]

As indicated by the graph in figure 1 the patterns for the number of transactions are different on the FSE and on IBIS. For the FSE we obtain the classical U-shape with high transaction frequencies early in the trading day and towards the close. However, this special shape is due only to a sharp increase in the last FSE interval, since there is an almost monotonic decline from the open to the period immediately before the close.

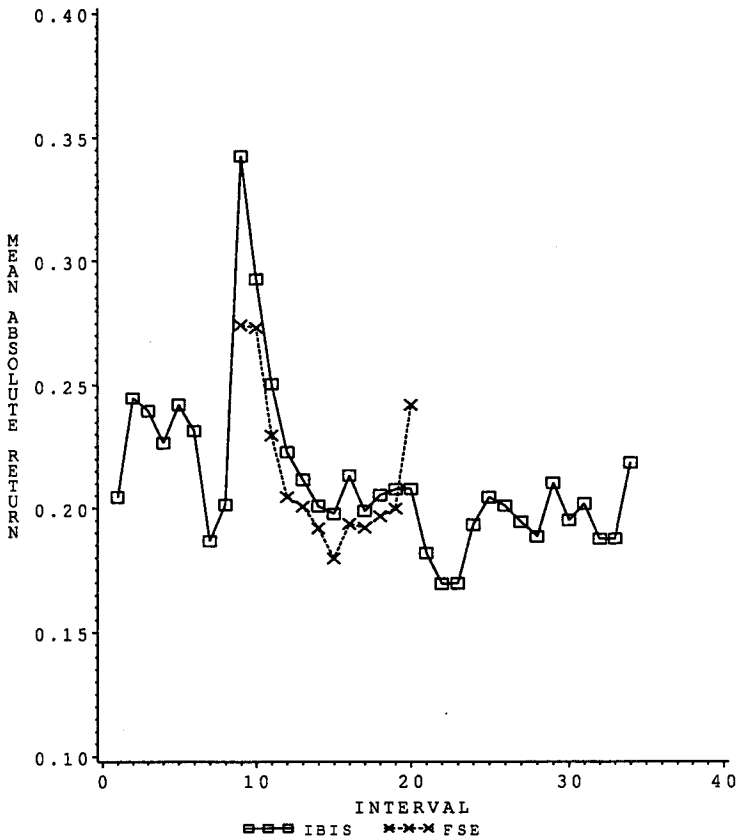
On IBIS the first upward jump after a slow start occurs in interval 5, i.e. from 9:30 a.m. to 9:45 a.m. when trading in stock options and stock index derivatives starts on the options and futures exchange DTB. After a rather active period of 30 minutes the number of transactions decreases rapidly until the FSE opens at 10:30 a.m. (interval 9). The patterns of trading activity on IBIS and the FSE are then very similar, the two curves are almost parallel. After the close of the FSE the average number of transactions decreases sharply on IBIS reaching the daily minimum in interval 22. This period of low trading activity on IBIS also corresponds to a time with considerably fewer than average trades on the DTB (see LÜDECKE (1995)). Afterwards trading activity again increases until the close of the DTB at 4:00 p.m. (interval 30). Then the number of transactions declines steadily before a slight increase occurs at the close of the market. Overall it is obvious that the two markets are pretty well integrated since the behavior of trading activity is very similar. Furthermore, it is clear that the level of trading activity on IBIS is also determined by the fact if the DTB is open or not.

Concerning the hypotheses presented in section 2 the results for the transaction frequency obviously contradict the OTH. We do not find the predicted U-shape in trading activity for IBIS. Although we observe the expected U-pattern for the FSE, this is nevertheless evidence against the OTH, since investors do not have to wait until the open of the FSE to readjust their portfolio holdings, and they can still trade after the FSE close. As mentioned above such an interpretation always rests on the assumption that the two markets are indeed substitutes for each other. If on the other hand investors are reluctant to trade on IBIS, e.g. because they doubt if prices reflect true fundamental values, they might wait for the FSE to open before they arrange their trades. So our results can be seen as a hint that investors do not consider IBIS and the FSE to be 'one market', instead trading activity on IBIS seems to driven by the DTB and the FSE.

5.2 Volatility

Mean absolute returns on IBIS and the FSE are shown in figure 2. The average absolute return is computed as the equally weighted average of the five group means. This method was chosen since the much larger number of observations for group 1 would have biased the results towards the group 1

Figure 2. Mean absolute returns on IBIS on the FSE 1994



averages. During the three hour period of floor trading in Frankfurt the two curves in figure 2 are almost perfectly parallel, again with the exception of the noon and the closing auctions on the FSE. The overall level of volatility is slightly higher on IBIS than on the FSE, but the difference decreases over the day. It is more pronounced for less liquid stocks, whereas for group 1 the volatilities on the two markets are almost undistinguishable.

There is a clear pattern in the graph for the FSE. Volatility is high at the open (intervals 9 and 10), afterwards it decreases over the morning until interval 15. In the afternoon mean absolute returns remain almost constant over the intervals 16 to 19. At the close (interval 20) volatility moves up again.[17]

Of course, the shape of the graph alone does not allow the conclusion of a decreasing pattern in volatility. To test the hypothesis of decreasing mean absolute returns the Page test was applied to the mean absolute returns for the five groups in intervals 9 through 14. The resulting test statistic was far beyond the critical value for the 1% level so that the null hypothesis of constant mean absolute returns has to be rejected. Furthermore, a Wilcoxon sign test was used to test the hypothesis of equal mean absolute returns in intervals 19 and 20 for the five individual groups. The test statistic was signifikant at the 1% level for all five groups.

One way to study if information or market structure effects are the driving factors for intraday volatility is to look at transaction returns around the three auctions.

Table 1: Mean absolute transaction returns after the open on the FSE

	Group				
Transaction return	1	2	3	4	5
1	0.1053	0.1273	0.1812	0.2262	0.3234
2	0.0966	0.1150	0.1699	0.1990	0.2882
3	0.0931	0.1064	0.1620	0.1870	0.2576
4	0.0934	0.1063	0.1532	0.1744	0.2485
5	0.0908	0.1084	0.1433	0.1687	0.2407

Transaction return 1 denotes the return computed from the opening price and the first price from the continuous market each day. Analogously, transaction return 2 is computed using the first and the second price from the continuous market, and so on. The numbers in the table are the 1994 grand mean of the absolute transaction returns of the stocks within a given group.

Absolute transaction returns after the open on the FSE mirror the behavior of interval returns as shown in figure 2 very closely. It is evident from table 1 that the return from the opening price to the first price of the continuous market is the largest in absolute value for all five groups. Absolute transaction returns then decrease monotonically over time. As in the case of interval returns the Page test was used to test the null hypothesis of equal mean absolute returns against the alternative of a monotonically decreasing pattern. The resulting test statistic was highly significant at the 1% level.

Taken together the evidence for the FSE suggests that there is uncertainty in the market at the open, but in the course of trading information is incorporated into prices so that volatility is reduced. The gradual decline in volatility thus supports the hypothesis of informationally induced volatility at the open in contrast to the notion of a microstructural impact.

To investigate this issue further we also analyzed transaction returns around the noon auction. In contrast to the open the volatility of transaction returns around the noon auction is more or less constant within the groups so that the results are not presented in detail.[18]

Table 2 shows the means of the five last absolute transaction returns of the day on the FSE. From the numbers in the table it becomes obvious that it is mainly the last transaction return which causes the volatility shift at the end of the day observed in figure 2. In contrast to the results for the first price changes of the day there is no clear pattern in transaction return volatility. Thus, although there is no systematic tendency in mean transaction returns there is still some kind of a 'day-end' anomaly for the German market, since the volatility of the last return of the day is significantly higher.[19]

The result of an increasing volatility at the close again does not imply a microstructural impact on volatility, i.e. the MMH is not necessarily supported. Market participants may have special motives inducing trades at the close which could drive up volatility. Examples for these higher incentives to trade around the close are contained in the OTH developed by BROCK and KLEIDON (1992). Further support against the microstructure explanation is provided by the observed increase in volatility around the close on the NYSE which does not have a closing auction (see MCINISH and WOOD (1990)).

Looking at the FSE separately the data seem to support the IFH, since there is a steady decline in transaction return volatility after the open and there is no volatility increase at noon.

Table 2: Mean absolute transaction returns before the close on the FSE

	Group				
Transaction return	1	2	3	4	5
–4	0.0831	0.0903	0.1253	0.1381	0.2113
–3	0.0820	0.0910	0.1287	0.1454	0.2178
–2	0.0835	0.0923	0.1296	0.1337	0.2048
–1	0.0793	0.0930	0.1274	0.1298	0.2049
0	0.0961	0.1135	0.1474	0.1483	0.2622

Transaction return 0 denotes the return computed from the last price from the continuous market and the closing price. Analogously, transaction return –1 is computed using the last but one and the last price from the continuous market, and so on. The numbers in the table are the 1994 grand mean of the absolute transaction returns of the stocks within a given group.

As in the case of trading activity the pattern for IBIS is quite different from the one found on the FSE. As can be seen from figure 2 IBIS interval volatility is relatively low at the beginning of the day with a jump from interval 1 to interval 2. The fact that there is no clear pattern at the beginning of the day is a consequence of the lower liquidity for some stocks on IBIS, since opening returns are sometimes not recorded until interval 6 or 7. On the other hand a look at mean absolute transaction returns in table 3 shows that they are monotonically decreasing over the first five trades for all five groups which again supports the IFH.[20] The increase in return volatility in interval 5 is most likely caused by the opening of the DTB at 9:30 a.m. This hypothesis is supported by the observation that the largest upward movement in volatility is found for group 1 containing the stocks with the most actively traded options on the DTB.

Table 3: Mean absolute transaction returns after the open on IBIS

	Group				
Transaction return	1	2	3	4	5
1	0.0980	0.1225	0.1737	0.2218	0.3257
2	0.0807	0.1107	0.1453	0.2001	0.2825
3	0.0719	0.0976	0.1374	0.1841	0.2743
4	0.0714	0.0909	0.1332	0.1723	0.2576
5	0.0719	0.0934	0.1244	0.1582	0.2479

Transaction return 1 denotes the return computed from the first price and the second price recorded on IBIS each day. Analogously, transaction return 2 is computed using the and the second and the third price from the continuous market, and so on. The numbers in the table are the 1994 grand mean of the absolute transaction returns of the stocks within a given group.

Table 4: Mean absolute transaction returns before the close on IBIS

	Group				
Transaction return	1	2	3	4	5
–4	0.0541	0.0742	0.1065	0.1644	0.2342
–3	0.0551	0.0764	0.1091	0.1549	0.2204
–2	0.0596	0.0840	0.1104	0.1600	0.2239
–1	0.0583	0.0851	0.1182	0.1535	0.2148
0	0.0645	0.0978	0.1383	0.1603	0.2375

Transaction return 0 denotes the return computed from the last but one and the last price of each day recorded on IBIS. Analogously, transaction return –1 is computed using the last but two and the last but one price, and so on. The numbers in the table are the 1994 grand mean of the absolute transaction returns of the stocks within a given group.

The volatility of interval returns decreases in intervals 6 and 7. Around the opening of the FSE (interval 9) we find a sharpe increase in volatility when mean absolute returns almost double compared to interval 7 or 8. It is interesting to note that mean absolute returns in interval 9 are much higher on IBIS than on the FSE and that this interval is the one with the highest volatility of the day.

After the three hour period when the FSE and IBIS are open simultaneously there is a noteable decrease in IBIS volatility until interval 23. This volatility movement is parallel to the decrease in trading activity documented in figure 1. Volatility then does not vary much, with the exception of an increase in intervals 24 and 25. A possible explanation for this movement is that the period of lower trading activity on the DTB is over, and as a consequence there are more trades and higher volatility on IBIS.

Like on the FSE there is something like a day-end effect on IBIS, since mean absolute returns go up in interval 34 and are larger than in the preceding intervals. The same pattern can be found for mean absolute transaction returns in table 4. Execept for group 4 the last transaction of the day always has the largest absolute value among the last five returns.[21]

The intraday pattern of volatility on IBIS is consistent with our findings for trading activity. Also with respect to volatility IBIS seems to be influenced by the other two large markets, the DTB and the FSE.

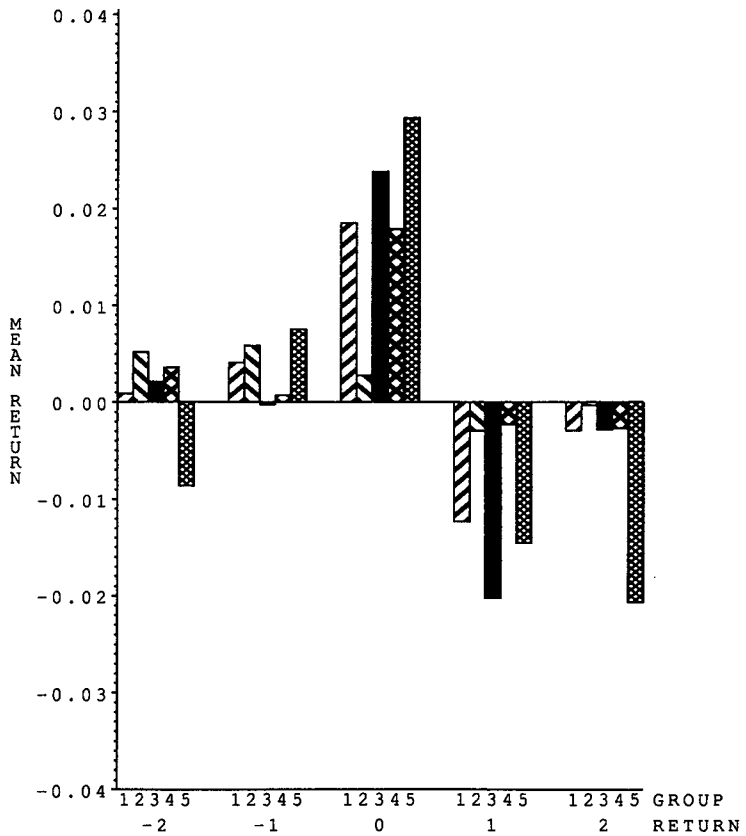
5.3 Batch Auctions on the FSE

The three batch auctions are a unique feature of floor trading on the German stock market. The relative share of trading volume in these auctions is quite large as shown by SCHMIDT, OESTERHELWEG and TRESKE (1995) who find that the opening auction, the noon auction and the auction at the close account on average for 9, 7, and 13% of the daily trading volume, respectively. The following paragraphs contain an analysis of the FSE price behavior around the noon auction as well as an investigation of IBIS prices around the auction periods on the FSE.

FSE Prices around the Noon Auction

An interesting fact about the FSE transaction returns at noon is depicted in figure 3. Here return 0 involves the last FSE price before the noon auction and the auction price itself. The other transaction returns are compouted in an analogous manner.

Figure 3: Transaction returns on the FSE around the auction



The means for return 0 are positive for all five groups whereas they are all negative for return 1.[22] A reversal in consecutive transaction returns is expected on a non-dealer market (as shown theoretically by HO, SCHWARTZ and WHITCOMB (1985), and empirically by STOLL and HALLER (1989)), but reversals on the FSE seem to be much more pronounced around the noon auction than over the rest of the day. To investi-gate this hypothesis the following regression was run for each individual stock i:

$$r_{i,j} = \alpha_i + \beta_i r_{i,j-1} + \gamma_i D_{j-1} r_{i,j-1} + \varepsilon_{i,t} \qquad (4)$$

Here $r_{i,j}$ denotes transaction return j for stock i. The dummy variable D_{j-1} was set equal to 1, if transaction return j – 1 was computed using the price recorded immediately before the noon auction price and the noon auction price itself. Otherwise D_{j-1} was set to zero. The first and the last transaction return were excluded for each day in the sample period and each stock to avoid a possible bias in the estimation due to effects around the open or the close. The expected sign of both β_i and γ_i is negative, and the estimate for γ_i measures the additional (negative) autocorrelation of transaction returns around the noon auctions.
Equation (4) was estimated using the generalized method of moments (GMM). Since the system is exactly identified the parameter estimates are identical to those produced by OLS. However, the standard errors will be appropriately adjusted for potential autocorrelation and heteroskedasticity of the error term.

Table 5: Estimation results for the model

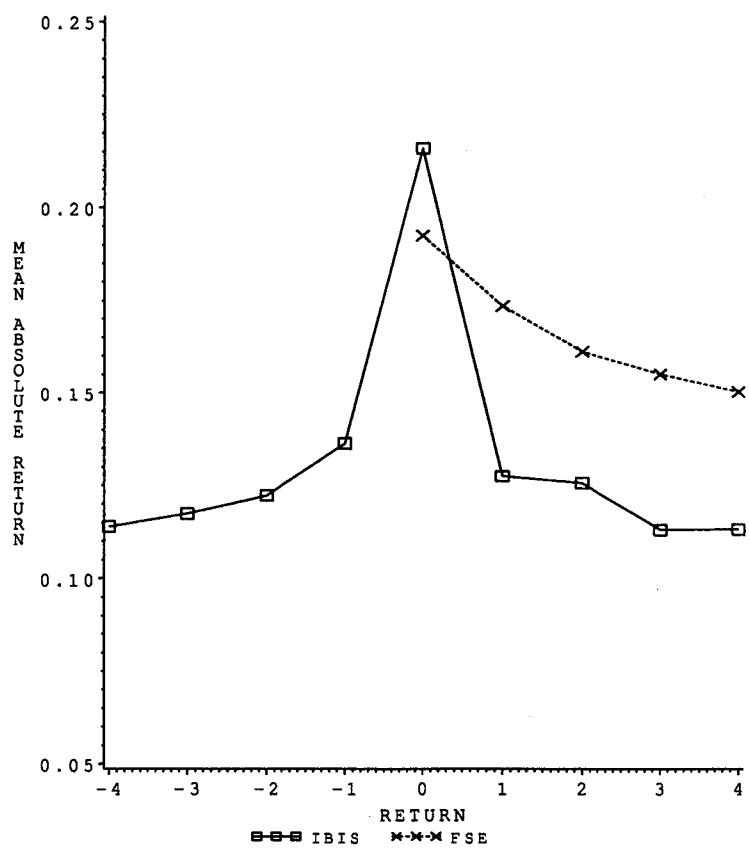
$$r_{i,j} = \alpha_i + \beta_i r_{i,j-1} + \gamma_i D_{j-1} r_{i,j-1} + \varepsilon_{i,t}$$

Group	$\bar{\beta}$	$\bar{\gamma}$
1	–0.1235 (4)	–0.0491 (2)
2	–0.1245 (5)	–0.1909 (3)
3	–0.0841 (4)	–0.1639 (3)
4	–0.0740 (4)	–0.1120 (2)
5	–0.0791 (5)	–0.1120 (1)

The variables in the regression are defined as follows: $r_{i,j}$ is the j th transaction return for stock i and D_{j-1} is a dummy variable which is set to one if return j – 1 is computed using the last price from the continuous market and the noon auction price, and to zero otherwise. The model was estimated using GMM. The numbers in parentheses denote the number of significant t-statistics for the given coefficient in the respective group.

The results are shown in table 5. The entries show the averages $\bar{\beta}$ and $\bar{\gamma}$ for the five groups as well as the number of signifikant t-statistics for the two coefficients. Overall the results are as expected. The autocorrelation coefficient is generally negative for transaction returns and return reversals are larger around the noon auction than for the rest of the day. The *t*-statistics show that this increase is signifikant for 11 of the 30 stocks. A possible interpretation is that there are order imbalances at the noon auction and that the Kursmakler takes the other side of the market to provide additional liquidity. If he charges an implicit fee for this service this could result in larger return reversals. On the other hand the larger reversals around the noon auction could also indicate that the quality of the noon auction price in terms of its

Figure 4: Mean absolute transaction returns on IBIS around the opening on the FSE



informational content is worse than that of the prices from the continuous market. The auction price would then differ to some degree from the true value which is represented by the prices from the continuous market. In this case there would be a clear market structure effect on price behavior.

IBIS Price Behavior around FSE Auctions

It is also interesting to investigate the behavior of IBIS volatility around the batch auctions on the FSE. Again we use mean absolute transaction returns for this purpose.

Figure 4 shows the volatility of transaction returns on IBIS around the opening of the FSE. The mean absolute transaction return from the last IBIS price before the opening of the FSE to the first price after this event (transaction return 0) is considerably larger than all the earlier or later transaction returns in the morning. The statistic of the Friedman test is highly significant for all five groups. Part of this effect may be due to the much larger time span between the two consecutive trades for return 0 compared to the other returns shown in table 6.[23] For all five groups this time period is about twice as long as that of the preceding returns. Afterwards the time between two successive trades is even shorter than before the open.

Furthermore, the mean absolute return from the last IBIS price before the opening of the FSE to the Frankfurt opening price is much larger than the average absolute return from the opening price to the next IBIS price (see table 7). Again the Wilcoxon sign test rejects the null hypothesis of equal means at low levels of significance. This special behavior of IBIS prices is observable during all three FSE auctions of the day, but with a decreasing tendency. The same tests as above were conducted for the noon and the afternoon auctions, and the statistics were in general signifikant for the noon auction but no longer for the auction at the close.

Another interesting observation is that the signs of the IBIS transaction returns following the opening auction on the FSE seem to depend on the amount of the 'price correction' from the last IBIS price to the opening price on the FSE. A sequence of transaction returns with equal signs is called a run.[24] The daily observations of this price correction for the individual stocks were grouped into three categories: the highest and the lowest decile and the

Table 6: Mean absolute transaction returns and length of return intervals on IBIS around the open of the FSE

	Group				
Transaction return	1	2	3	4	5
–2	0.0586/4:05	0.0814/6:41	0.1213/11:22	0.1587/22:06	0.2358/22:13
–1	0.0611/4:12	0.0872/7:37	0.1279/13:55	0.1683/24:57	0.2597/27:51
0	0.0891/8:52	0.1338/16:36	0.2175/28:48	0.2998/46:01	0.4362/43:42
1	0.0605/2:24	0.0885/4:15	0.1223/7:50	0.1783/16:43	0.2417/17:41
2	0.0596/2:08	0.0895/4:50	0.1184/8:10	0.1641/15:15	0.2494/17:47

Transaction return 0 denotes the return computed each day from the last IBIS price before the opening price on the FSE is set and the first price thereafter. Transaction return –1 is computed using the last but one and the last IBIS price before the opening of the FSE. Analogously, transaction return 1 is computed from the first and the second IBIS price following the opening on the FSE. The entries in the table are the 1994 grand mean of the absolute transaction returns of the stocks within a given group and the length of the average time span between the two transactions used to compute the returns (measured in minutes and seconds).

Table 7: Mean absolute differences between FSE and IBIS prices around the FSE opening auction

	Group				
	1	2	3	4	5
IBIS – FSE	0.1215	0.1720	0.2607	0.3530	0.5398
FSE – IBIS	0.0977	0.1276	0.1860	0.2504	0.3042

IBIS – FSE is the average absolute difference between the latest (log) IBIS price recorded before the opening transaction on the FSE and the FSE opening price. FSE – IBIS is the analogous number for the opening price on the FSE and the next following IBIS price.

remaining group which contained 80% of the observations. Afterwards the number of positive and negative runs of length k (k = 3,4,5) were counted for these three groups. The results are qualitatively similar for all five groups of stocks so that they are only presented for group 1. If the occurence of a run was indeed independent of the amount of the price correction we would expect to find 10% of the positive and the negative runs as well as 10% of all the other observations in the decile with the largest positive observations. However, the results indicate that this is not the case. For group 1 the upper decile contains about 27% of all positive runs of length 3, 23% of those of length 4 and 15% of the positive runs of length 5. On the other we observe only 1% of the negative runs of length 3 and none of length 4 or 5, respectively, in this decile. The findings for negative runs are almost symmetric. The decile with the 10% lowest price corrections contains 25, 30, and 18% of the negative runs of length 3, 4, and 5, and only 1, 3, and 1% of the positive runs, respectively.[25] Overall the FSE seems to be the leading market during the opening period.

6. Summary and Conclusions

This study investigates intraday trading on the FSE and on IBIS. The results for the floor market on the FSE are mostly consistent with the findings for other markets. We observe U-shaped patterns for both the frequency of transactions and the volatility of returns. Transaction returns around the noon auction are not significantly more volatile than other returns. However, there is some return effect in that return reversals are more pronounced here than for the rest of the trading day. Furthermore we find a continuous decline in volatility on the FSE after the opening. This finding provides strong support for the hypothesis that return volatility is primarily induced by the information flow rather than by market structure.

For the computer trading system IBIS we do not observe similar patterns in volatility or transaction frequency. Furthermore, although there is a quite long period of IBIS trading before the floor market opens on the FSE, the informative content of the prices generated during this period seems to be low. This can be seen from the fact that transaction return volatility at the open on the FSE is just as high as the opening volatility on IBIS. IBIS prices seem to be influenced especially by auction prices from the floor in Frankfurt. Price movements on IBIS after an auction on the FSE tend to have the same direction as the price difference between the two markets at the time of the auction. In general the IBIS results together with the findings for the FSE seem to contradict the hypothesis of BROCK and KLEIDON (1992). These authors argue that it is mainly the trading halt between the close on the previous day and the

following opening that causes higher volume and higher volatility at the open.

A possible direction for further research is to focus on the stationarity of the price discovery process over the trading day. Given the results of this study it seems likely that some events on one market have a higher impact on a second market than others. An example for this hypothesis is given by the finding that especially the opening auction price from the FSE seems to be important for the behavior of prices on IBIS.

Appendix

Table A.1: Stocks in the DAX index (1994)

Firm Name	Symbol	Firm Name	Symbol	Firm Name	Symbol
Allianz	ALV	Deutsche Babcock	DBC	Mannesmann	MMW
BASF	BAS	Deutsche Bank	DBK	Metallgesellschaft	MET
Bayer	BAY	Dresdner Bank	DRB	Preussag	PRS
Bayerische Hypo	BHW	Henkel	HEN3	RWE	RWE
Bayerische Vereinsbank	BVM	Hoechst	HFA	Schering	SCH
BMW	BMW	Karstadt	KAR	Siemens	SIE
Commerzbank	CBK	Kaufhof	KFH	Thyssen	THY
Continental	CON	Linde	LIN	VEBA	VEB
Daimler - Benz	DAI	Lufthansa	LHA	VIAG	VIA
Degussa	DGS	MAN	MAN	Volkswagen	VOW

Table A.2: Classification of DAX stocks in 1994 according to DM trading volume on the FSE

Class	Volume*	TBTK†	TBTI~	TBTI‡	Stocks
1	105.866	2:49	1:45	2:19	ALV, BAY, DAI, DBK, SIE, VOW
2	32.025	3:37	3:46	4:54	BAS, CBK, DRB, HFA, MMW, VEB
3	19.844	5:51	6:34	8:44	BHW, BMW, BVM, RWE, SCH, THY
4	11.572	7:15	14:35	19:46	KAR, KF , LIN, MAN, PRS, VIA
5	6.408	7:48	15:10	19:24	CON, DBC, DGS, HEN3, LHA, MET

*: Average annual trading volume in billions of DM.
†: Mean time in minutes between two consecutive transactions on the FSE.
~: Mean time in minutes between two consecutive transactions on IBIS during trading time of the FSE.
‡: Mean time in minutes between two consecutive transactions on IBIS when FSE is closed.

Footnotes

[1] See, for example, MCINISH and WOOD (1990), LOCKWOOD and LINN (1990) and CHEN, ELLIS and WOOD (1994).

[2] Intraday studies of the German market focussing on different aspects than the ones presented here were provided by BAMBERG and RÖDER (1996), and RÖDER (1996), who investigate expiration day effects and intraday volatilities, and SCHMIDT, IVERSEN and TRESKE (1991) who investigate bid-ask spreads and implied transaction costs.

[3] The following description draws heavily on DBAG (1995).

[4] Besides the Kursmaklers there are also the so-called Freimaklers who are not involved in the process of setting official prices.

[5] If a market participant submits an order for 130 shares 100 of these shares will be traded in the continuous market and the remaining 30 shares will be traded at the noon auction.

[6] For a detailed description of IBIS see DBAG (1993).

[7] Today all stocks included in the DAX-100 index as well as some other liquid stocks are traded on IBIS.

[8] The stocks in the DAX are weighted according to the nominal value of their equity. A special characteristic of the DAX is that it is a performance index, i.e. the index is computed as if dividends were reinvested into the index portfolio.

[9] There is no obligation, however, to post a quote upon a trader's request.

[10] Again, these trading times represent the situation over the sample period. As of May 22, 1995, all equity and index derivatives can be traded from 9:00 a.m. to 5 p.m.

[11] See table A. 1 in the appendix for a list of the DAX stocks.

[12] Prices on the German floor markets carry a flag indicating whether there was excess supply or demand at the given price. In 1994 supply did not exactly equal demand in only 0.12 percent of all the observations in our sample.

[13] This result could be a hint that IBIS is the 'true' underlying market for the derivatives traded on the DTB. Relative to the 'important' stocks the stocks which are not underlyings for stock options on the DTB (and which also do not have much weight in the DAX) are traded much less frequently on IBIS than on the FSE.

[14] The F-test furthermore assumes normality of the underlying variable. Since absolute returns are by definition always non-negative this assumption is automatically violated. The Levene test which is the k-sample analogue of the nonparametric Kruskal-Wallis test does not rely on distributional assumptions but is also not able to test against a specific monotonicity alternative.

[15] Mean returns were analyzed as well, but no distinct patterns were found. Since the hypotheses presented in section 2 do not make any predictions about mean interval or transaction returns, the results are not shown here.

[16] Furthermore, the volume in shares is generally smaller on IBIS. This implies that the average trade size is smaller on IBIS than on the FSE.

[17] The pattern is almost identical for the five groups of stocks. However, the stocks in group 5 seem to exhibit a significantly higher intraday volatility than the stocks in the other groups. A large portion of the difference between group 5 and the other stocks is due to the return behavior of MET. Taking this firm out of the sample yields much smaller differences in volatility, but the qualitative results still remain the same.

[18] The Friedman test rejected the null hypothesis of equal mean absolute transaction returns around the noon auction for groups 1 and 2. A detailed investigation of the ranks of the absolute transaction returns showed that the return involving the noon auction price was not the reason for these rejections.

[19] The Wilcoxon sign test for equality of mean absolute returns for the last trade compared to the immediately preceding trage yields a significant statistic for all five groups.

[20] The Page test rejects the null hypothesis of equal mean absolute returns against the alternative of a decreasing volatility at the 1% level.

[21] In the case of interval returns the statistics for the Wilcoxon sign test are significant for groups 1, 2, 3, and 5. For transaction returns we obtain significance for groups 1 to 3.

[22] Significantly positive means are found for groups 1, 3, and 5 for return 0, significantly negative means are observable for groups 1 and 3 for return 1.

[23] All these results are consistent with the sharp decrease in number of trades on IBIS immediately before the opening of the FSE.

[24] See FAMA (1965) for a first analysis of runs in stock returns and their implications for market efficiency.

[25] In general the directions of the last IBIS price change before the opening on the FSE and the first IBIS price change afterwards have the same sign as the difference between the last IBIS price before the FSE open and the FSE opening price.

References

ADMATI, A. and P. PFLEIDERER (1988): "A Theory of Intraday Trading Patterns: Volume and Price Variability", Review of Financial Studies 1, pp. 3–40.

AMIHUD, Y. and H. MENDELSON (1991): "Volatility, Efficiency, and Trading: Evidence from the Japanese Stock Market", Journal of Finance 46, pp. 1765–89.

AMIHUD, Y., H. MENDELSON and M. MURGIA (1990): "Stock Market Microstructure and Return Volatility – Evidence from Italy", Journal of Banking and Finance 14, pp. 423–40.

BAMBERG, G. and K. RÖDER (1996): "Intraday-Volatilität und Expiration-Day-Effekte am deutschen Aktienmarkt", Kredit und Kapital 29, pp. 244–76.

BROCK, W. A. and A. W. KLEIDON (1992): "Periodic Market Closure and Trading Volume", Journal of Economic Dynamics and Control 16 , pp. 451–89.

CHEN, R., D. M. ELLIS and R. A. WOOD (1994): "The Empirical Distribution of Intradaily Stock Return Volatility", Working paper, Texas A&M University.

DEUTSCHE BÖRSE AG (DBAG) (1993): Integrated Stock Exchange Trading And Information System IBIS, Frankfurt.

DEUTSCHE BÖRSE AG (DBAG) (1995): FWB Frankfurter Wertpapierbörse Monatsstatistik Juni 1995, Frankfurt.

FAMA, E. F. (1965): "The Behavior of Stock Returns", Journal of Business 38, pp. 34–105.

GERETY, M. S. and J. H. MULHERIN (1994): "Price Formation on Stock Exchanges: The Evolution of Trading within the Day", Review of Financial Studies 7, pp. 609–29.

HARRIS, L. (1986): "A Transaction Data Study of Weekly and Intradaily Patterns in Stock Returns", Journal of Financial Economics 16, pp. 99–117.

HARRIS, L. (1989): "A Day-End Transaction Price Anomaly", Journal of Financial and Quantitative Analysis 24, pp. 29–45.

HO, T., R. A. SCHWARTZ and D. K. WHITCOMB (1985): "The Trading Decision and Market Clearing under Transaction Price Uncertainty", Journal of Finance 40, pp. 21–42.

JAIN, P. C. and G. JOH (1988): "The Dependence between Hourly Prices and Trading Volume", Journal of Financial and Quantitative Analysis 23, pp. 269–83.

JONES, C. M., G. KAUL and M. L. LIPSON (1994): "Transactions, Volume, and Volatility", Review of Financial Studies 7, pp. 631–51.

KYLE, A. S. (1985): "Continuous Auctions and Insider Trading", Econometrica 53, pp.1315–35.

LOCKWOOD, L. J. and S. C. LINN (1990): "An Examination of Stock Market Return Volatility During Overnight and Intraday Periods", 1964–1989, Journal of Finance 45, pp. 591–601.

LÜDECKE, T. (1995): "Struktur und Qualität von Finanzmärkten – eine theoretische und empirische Analyse", Ph.D. Dissertation, University of Karlsruhe.

MCINISH, T. H. and R. A. WOOD (1990): "A Transactions Data Analysis of the Variability of Common Stock Returns during 1980–1984", Journal of Banking and Finance 14, pp. 99–112.

PAGE, E. B. (1963): "Ordered Hypothesis for Multiple Treatments: A Significance Test for Linear Ranks", Journal of the American Statistical Association 58, pp. 216–30.

RÖDER, K. (1996): "Intraday-Volatilität und Expiration-Day-Effekte bei DAX, IBIS-DAX und DAX-Future", Arbeitspapiere zur Mathematischen Wirtschaftsforschung No. 134, Universität Augsburg.

SCHMIDT, H., P. IVERSEN and K. TRESKE (1991): "Parkett oder Computer?", Zeitschrift für Bankrecht und Bankwirtschaft 3, pp. 209–21.

SCHMIDT, H., O. OESTERHELWEG and K. TRESKE (1995): "Investor Acceptance of Call Market Trading in Germany", Working paper, University of Hamburg.

STOLL, H. R. and A. HALLER (1989): "Market Structure and Transaction Costs", Journal of Banking and Finance 13, pp. 697–708.

STOLL, H. R. and R. E. WHALEY (1990): "Stock Market Structure and Volatility", Review of Financial Studies 3, pp. 37–71.

THEISSEN, E. (1995): "Market Structure, Overnight Volatility and Pre-Trading Price Information: An Empirical Examination for the German Stock Market", Working paper, University of Frankfurt.

WOOD, R. A., T. H. MCINISH and J. K. ORD (1985): "An Investigation of Transactions Data for NYSE Stocks", Journal of Finance 40, pp. 723–41.