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**Working Paper**

# Discovering the best: Informational efficiency and liquidity of alternative trading mechanisms in experimental asset markets

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# Discovering the best: Informational efficiency and liquidity of alternative trading mechanisms in experimental asset markets

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Abstract:

This paper reports the results of 18 experimental asset markets with 262 subjects that explore the effects of liquidity and aggregation of information. The main focus lies on the comparison of different trading mechanisms of stock exchanges. Compared to most of financial markets experiments, reality is met by introducing long-living assets and integrating all subjects in a multi-period decision-making process.

In accordance with the evidence from the empirical research in real financial markets, our results show that the continuous auction achieves the highest informational efficiency. Dealer markets do the worst; call markets (batch trading) reach an intermediate position. A comparable result is achieved regarding the liquidity of the trading mechanisms.

For both success factors of real stock exchanges our results show a strong tendency that continuous trading outperforms the other market structures, at least in the framework of the present measurement and on the chosen abstraction level. This does not exclude for the practice to offer a combination with call markets in certain titles and at certain times, particularly, if the here met assumptions of an open market access and information symmetry between the investors do not apply in full extent.

JEL Classification: D44, G12, G14

Key Words: Market Microstructure, Experimental Asset Markets, Market Efficiency, Informational Efficiency, Liquidity, Call Markets, Continuous Auction, Dealer Markets, Auctions

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# 1 Introduction

In economic literature the allocation of financial resources is regarded as the outstanding function of a financial market. The market prices from the balance of supply and demand determine the expected return (supply) as well as the expected capital costs (demand), that influence the profitability of investment projects.

The willingness of the investors to acquire assets essentially depends on their maturity and on their liquidability. These on the other hand is determined largely by the pricing and the tradeability. Therefore, the allocative function gets essential support through the informational and valuation efficiency of the prices that are generated by the financial markets (cf. Fama 1970 as well as the discussion in Bienert 1996). The allocation of financial resources into the most favorable use relies on the condition that the market prices reflect the currently available information of the economic subjects.

The tradeability takes shape through the concept of the liquidity. Liquidity is defined as the possibility to buy (or to sell) an asset immediately and anytime in large or small quantities without any additional charge or price increase (or reduction). So, two time dimensions (immediacy and market willingness) and two price dimensions (inferior price influence of minimum lot and block orders) are made clear besides the resiliency (cf. Bernstein 1987, Schmidt/Iversen 1991, Kempf 1998).

Both aspects, informational efficiency and liquidity, are key factors in valuing the performance of financial markets (cf. e.g. Oehler 2000a). The academic research within the market microstructure paradigm as well as the adjustment of real market designs in a growing competition between international stock exchanges were enforced by the crucial question which organizational structure survives and outperforms the competitors. There are two central issues in the debate over the last two decades: the consequences of computerization of the trading process (cf. e.g. Franke/Hess 2000) and the quality of different trading mechanisms. The latter topic is addressed in this paper.

Figure 1 shows the principal alternatives of a market structure (see e.g. Schmidt/Küster Simic 2000 for an overview).

The first criterion, the privilege to generate the market clearing price, i.e. the kind of matching the orders, determines two main designs: the dealer market and the auction market. The dealer market is shortly characterized as a market where special market participants, the so-called market makers, supply liquidity. Market makers have the duty to continuously quote bid and ask prices, the so-called bid-ask spread. This provides the possibility for an immediate order execution on the quoted prices (hence, quote driven). The bid-ask spread compensates the market makers´ costs for inventory, adverse selection and others.

Please insert Figure 1 around here

The second criterion, the number of market makers in a dealer market, leads to the differentiation in a monopolistic and a multi-dealer environment. On the other hand, an auction market collects the orders of the investors and generates the market clearing price (hence, order driven) either every time if the supply and the demand fit together (continuous trading/auction) or only at discrete times (batch trading/auction). The latter alternative usually generates the market price on a level where the highest turnover is possible. In comparison to the continuous auction the call auction may lead to a better price discovery through the large number of orders that are executed at one time. But this advantage in informational efficiency will be compensated by the lack of immediacy, i.e. the time component of liquidity.

An additional criterion, the investors´ access privilege to the price generating process, distinguishes between an open market without any access restriction, e.g. like most of the proprietary trading systems, and the agency auction where intermediaries control the orderflow.

The two success factors, liquidity and informational efficiency, are not independent from each other. An informationally efficient market implies that price changes only occur if new information arrive which signal the change in the fundamental value of an asset. Therefore, these price changes are permanent.

On the other hand, liquid markets are able to compensate price changes rapidly. The (ostensible) problem is solved by the argument that only temporary deviations of some transaction prices from the market clearing price intended by the concept. From that point of view, price changes potentially contain an information-induced and a liquidity-induced component (cf. Schmidt 1970, 70-73, Amihud/Mendelson 1986 and 2000, Hu 1997, Kempf/Uhrig 1996).

But in the (extreme) case of rational investors in a pareto-optimal environment informational efficiency leads to illiquid markets because from every transaction only one side, the initiator, benefits from the contract (cf. Milgrom/Stockey 1982). This puzzle can only be solved if the assumptions are reduced. Under the (realistic) presumption that not all traders in the market are fully rational, noise traders, i.e.

investors who trade on ostensible informations, cause deviations from the (true) market clearing price: "What´s needed for a liquid market causes prices to be less efficient" (Black 1986, 532).

We have to draw two conclusions from this short discussion: Under the assumption of real markets with noise traders a trade-off between liquidity and informational efficiency is more likely. First, this means that a higher degree of information aggregation not necessarily leads to a higher liquidity level. Beyond this, the claim for an informational efficiency as high as possible is not equivalent to an optimum for the whole market because of costs for transaction and adverse selection (cf. Grossman/Stiglitz 1980). Second, it cannot necessarily be expected that one trading mechanism dominates all other.

Having these arguments in mind we now discuss the previous research on trading mechanisms, both the empirical and the experimental results.

The paper is organized as follows. Section 2 sheds some light on the previous research on the topic. Section 3 describes the experimental design and procedures pertaining to market environments, market institutions, information structure and subjects. In section 4 we develop a set of testable hypotheses that motivate the data analysis. Section 5 presents the results and section 6 concludes.

## 2 Related research

Most theoretical research on market microstructure only models one trading mechanism at once. Comparisons of such and statements to the superiority of alternatives are rarely be found. A secondary-analytic comparison of the results of the research to call markets (see e.g. Mendelson 1982, Ho/Schwartz/Whitcomb 1985, Rustichini/Satterthwaite/Williams 1994), to continuous trading (see e.g. Friedman 1984 and 1991, Easley/Ledyard 1993, Glosten 1994), and to dealer markets (see the survey by O´Hara 1995) deals with the problem of different assumptions and frameworks. Nevertheless, the following statements can be derived.

The call auction shows advantages in the information processing, especially when the information is asymmetrically distributed among the investors. Moreover, the transaction costs are rather low, however, high waiting costs originated by the not-continuous trade may attend. It can therefore be shown that investors with information advantages have less interest in call markets. On the other hand, the continuous auction dominates especially when immediacy is a principal trade motivation. This conflict of interests led to the argument going back to Pagano/Röell (1992) that both kinds of auctions can also exist parallel. Besides the coexistence of parallel markets, also the solution of the integration of a call auction into a continuous auction is observed more frequently in the reality. It can be shown that a suitable market structure is created exactly when different trade motives occur (cf. Admati/Pfleiderer 1988, Pagano/Röell 1990 und 1992). However, the coexistence or integration of both trading mechanisms lead among others to higher overheads and to the splitting of a given orderflow.

The few studies that perform a comparison of market structures directly achieve similar results in principle, which should be addressed shortly. The model of Mendelson (1982 and 1987) states that especially in markets of inferior liquidity, so-called thin markets, the call auction is advantageous and has a weak superiority in comparison to a dealer market.

In the model of Wilson (1987) it is shown that the continuous auction is in tendency superior also in thin markets, however with symmetrical information distribution.

In the specific framework of a market with information privileges for some investors (insiders; cf. Kyle 1985) as well as generally in the models with information asymmetry of Pagano/Röell (1992 and 1996) it can be shown, that the call auction dominates the continuous trading. This is valid regarding both factors, informational efficiency and liquidity. However, such models use also intermediaries which are quite similar to market makers (cf. Madhavan 1992).

Altogether, the advantage of the call market more clearly existing with asymmetrical information only proves to be ostensible if one considers that the demand for immediacy, i.e. the time component of liquidity, is not modeled. In the comparison between the two basic market structures, the dealer market and the auction market (see Fig. 1 No.s 1 and 2), the last-named alternative dominates in the results of the theoretical work.

Induced through the theoretical models an extensive empirical research about topics of the market microstructure has established, especially to the quality of single trading mechanisms, from which the essential results should be presented shortly.[1]

[1] Studies are not taken into account that conduct the comparison between market structures very indirectly by using the decision of investors for a location or relocation, e.g. with a questionnaire, because numerous further influential factors make the data very

One group of empirical work measures differences in the price volatility to draw conclusions on the advantageousness of trading mechanisms indirectly. Mostly, the two alternatives of auction markets, batch trading and continuous trading, are compared. The basic idea of this method is that risk averse investors prefer markets, whose organization structure leads to a low volatility. In order to solve the problem of several parallel influential factors the studies are conducted with two time series of the same market (e.g. the open and the close prices). However, only a market microstructure-induced effect is separated from a information-induced one, further factors are disregarded through the assumptions of rational behavior (see e.g. Amihud/Mendelson 1987, Pagano/Röell 1990, Stoll/Whaley 1990). Altogether the newer results, especially for the German market, show that the original interpretation of the differences found between the parallel time series cannot be attributed to general or specific differences of trading mechanisms (cf. Theissen 1998, 261).

Most empirical studies were conducted concerning the success factor liquidity. Accordingly, the theoretical and empirical results give high evidence for the bid-ask spread as the most valid measure of liquidity, whereas the liqidity rate, the so-called market coefficient or the Roll measure (cf. Roll 1984) only cover some aspects or leads to diverging interpretations for different market structures (cf. Kempf 1998, Theissen 1999). For call auctions the explicit bid-ask spread does not exist. Therefore, the implicit measure, defined by Friedman (1993a, 1993b), is used instead of the Roll measure because the latter is not valid (cf. Theissen 1999, 233).

The implicit bid-ask spread is defined as the difference between the very best rejected (not executed) bid and the very best rejected ask. This concept is based on the consideration that a bid which is additionally reaching the market would be executed at exactly the price which is carried by the lowest limited and not executed ask. The same is valid for an additionally executed ask. "This provides an implicit measure of transaction costs that is valid across institutions" (Friedman 1993a, 423).

Probably due to the measurement problems substantially more often studies on the comparison of the continuous auction and dealer markets are conducted (see e.g. Pagano/Röell 1990, Lee 1993, Schmidt/Iversen 1993, Bessembinder/Kauffmann 1996, Huang/Stoll 1996, Keim/Madhavan 1996, Schmidt/Oesterhelweg/Treske 1996). Independently from the chosen method these papers find out that the continuous auctions show a higher liquidity than the dealer markets.

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noisy (see e.g. Schiereck 1995, Schmidt/Oesterhelweg/Treske 1996) or by using the revenues of the access intermediaries, e.g. broker, dealer (see e.g. Stoll 1993 und 1995).

The comparison between batch trading and continuous auction does not yield any clear results (cf. Haller/Stoll 1989, Pagano/Röell 1990, Stoll/Whaley 1990), because the used Roll measure is not applicable for call markets in its interpretation as transaction cost difference (cf. Theissen 1999, 233). The direct measurement under the assumption that the entire order book is known (price of an additional order) fails because of the non-availability of the corresponding data (cf. Mendelson 1982, Schmidt/Oesterhelweg/Treske 1996). Amihud/Mendelson/Lauterbach (1997) determine in a study on the introduction of the continuous trading on the stock exchange Tel Aviv that positive abnormal returns emerge that are attributed to a higher liquidity. Furthermore, they show an increase in the informational efficiency.

Studies on the second success factor, the informational efficiency, are hardly available because the necessary benchmark, the fundamental or "true" value of the assets, cannot be observed in reality. Therefore, the indirect measurement is based on the analysis of parallel markets. Either the innovation of a market form is analyzed additionally (cf. Amihud/Mendelson/Lauterbach 1997) or earnings announcements in parallel but differently organized markets are examined (cf. Greene/Watts 1996). Whereas the first-named study states an improvement of the information processing after the introduction of the continuous trading, the results of the second study can be interpreted in the sense that a call market does better than a continuous auction in direct comparison with a dealer market.

Overall, however, all studies suffer from the fact that clear and direct statements about the informational efficiency can hardly be derived because the fundamental value of an assets is not known in reality. Also, the empirical studies on liquidity indicate that the data situation of real financial markets does not allow any systematic comparison of the central market structures.

The two basic problems of field studies, the not-controllable conditions and the lacking observableness and availability of important variables, can be overcome by the analysis in experimental asset markets. Here, a variation of the different market structures is possible. It can be traded an identical asset under different trading mechanisms. In addition, both the true value as well as the information structure are observable, i.e. the information given to and signaled from all traders. Finally, all transactions and further data can be documented so that the implicit bid-ask spread from the complete order book of a call market can be calculated, for example (see e.g. Duxbury 1995, Oehler 1995, Sunder 1995, Bossaerts/Plott 2000).

Thus, it is feasible to analyze selectively the efficiency of information processing, i.e. to compare the (endogenous) prices from the experimental market with the (exogenous) fundamental value of the asset generated by a random draw from a known distribution or given by the experimenter, respectively. Just as well the degree of liquidity can be measured in different market environments. All data are available to compute the explicit and the implicit spread without any problems of e.g. different transactions costs.[2]

There is a growing body of studies in experimental financial market research in the last two decades. Starting from a basic design in the 1980s (cf. Plott/Sunder 1982) which is used by most of the experimenters in an auction framework, nowadays multi-period and large-scale market experiments (cf. e.g. Bossaerts/Plott 2000 for large-scale markets, Smith/Suchanek/Williams 1988, van Boening/Williams/LaMaster 1993, Heilmann/Läger/Oehler 2000a for multi-period markets) as well as the design of dealer markets (cf. e.g. Friedman 1993b, Lamoureux/Schnitzlein 1996, Krahnen/Weber 1999, Theissen 1999) complete the experimental tools.

Plott/Sunder design their markets as a continuous auction with a stochastic dividend process which leads to private values of the asset in the same period because all subjects are divided in two or more groups of traders which receive different payoffs. The endowment will be reinitialized after one or two trading periods, i.e. the holdings are liquidated and all investors start with a new endowment in the next period. This method allows to control for a special kind of learning, i.e. the amount of time the subjects need to reach the market equilibrium. In addition, the private valuation makes it feasible to measure the allocative efficiency.

With reference to our topic, the comparison of trading mechanisms, the results of the experimental studies (cf. e.g. Plott/Sunder 1982 and 1988, Friedman 1993a, Schiereck 1997) are somewhat ambiguous because of the differences in the information structure.

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[2] A third application of experimental financial markets lies in an analysis of the consequences of privileges for some traders. There are two topics in this experimental research which both lead off to much from the focus in our paper. First, the improvement of market transparency like an orderbook transparency is mostly analyzed in one trading regime and more seldom a comparison is done (cf. e.g. Flood/Huisman/Koedijk/Mahieu/Röell 1997, Flood/Huisman/Koedijk/van Dijk/van Leeuwen 1998, Bloomfield/O´Hara 1999 and 2000 for quote disclosure (ex ante transparency), cf. e.g. Oehler/Unser 1998 for trade disclosure (ex post transparency)). Second, the endowment with information privileges like insider information or selective transparency only for some traders, sometimes done with a comparison of different market structures (cf. e.g. Friedman 1993b, Nöth/Weber 1996, Nöth 1998, Krahnen/Weber 1999, Heilmann/Läger/Oehler 2000a for insider trading, cf. e.g.

But the findings show the tendency that in the case of higher degrees of informational asymmetry the call market creates a better informational efficiency and higher liquidity than the continuous auction.

For real asset markets the assumption of stationary replication, i.e. the reinitialization at every period, seems to be unsuitable (cf. Theissen 1998, 166). A dynamic portfolio adjustment and an endogenous expectation formation on the prices are not possible. Beyond it, the advantage that the replication of periods with the same subjects lower the research costs is quite ostensible because the trading periods are not (statistically) independent (cf. Friedman 1993a, Theissen 1999). So, it is necessary to conduct more experiments in order to generate enough data points (cf. Oehler/Unser 1998).

As a consequence, multi-period designs are developed which contain long-living assets and which provide investors with common-value assets. In comparison to the former framework the drawback that the trading motivation by the private dividend payoffs vanishes, is compensated by the fact that, like in real markets that "only" the heterogenity of risk aversion (cf. Unser 2000) in relation to the endowment trigger orders (portfolio changes). The experimental results of the studies which use the more realistic framework (cf. Smith/Suchanek/Williams 1988, van Boening/Williams/LaMaster 1993) show the tendency that the continuous auction dominates the call auction concerning to informational efficiency and liquidity.[3]

In addition, the above cited studies which compare dealer markets with continuous auctions generate no unambiguous results. Whereas the findings from a private-value design by Friedman (1993b) demonstrate that dealer markets have lower informational efficiency and liquidity, the results from a common-value design by Krahnen/Weber (1999) and Theissen (1999) with heterogenous information in the sequel, i.e. all traders receive signals of identical ex ante quality and different ex post realization, show a weak superiority of dealer markets. But the results from the different market maker designs in Krahnen/Weber are somewhat inconsistent and not fully explainable (Theissen 1998, 288).

Summing up the discussion of the previous research there is a quite clear tendency that in environments with information symmetry continuous trading (No. 2ab in Fig. 1)

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Friedman 1993b, Syha 1999, Gerke/Bienert/Syha 2001 for selective orderbook transparency).

[3] The contradictory result from Schnitzlein (1996) lacks on some methodological problems because he e.g. measures liquidity in a not appropriate way (cf. Theissen 1999, 235).

is superior to batch trading (No. 2aa) and the latter dominates dealer markets (No. 1a or 1b) regarding informational efficiency and liquidity.

Under asymmetrically distributed information, the results are not unambiguous. Whereas most studies can show a dominance of auction markets markets over dealer markets, no order can be found for the two alternatives of the call market and the continuous trading.

The following experimental analysis therefore should provide a clarification. The focus of the study lies on a symmetrical information framework with heterogeneous risk attitudes of the investors.

# 3 Experimental design

In our experiments investors trade long-living stocks, i.e. the stocks are not liquidated at the end of a trading period. The market prices were determined by the trading actions of the subjects but the fundamental information structure about the stocks was generated by a binomial process described in more detail below. As known by the investors the true or fundamental value of a stock is used for the incentive procedure (payment) at the end of each experimental session.

## 3.1 Information structure, subjects, and procedures

The fundamental value of the traded stocks follows a binomial process with a positive drift. This can be fully described by five parameters:

- Start value $v_1$, the fundamental value of the first period.
- Probability $p$ for an upward movement in the next period.
- Probability $q = 1 - p$ for a downward movement in the next period.
- Increment $u$ of an upward step.
- Increment $d$ of a downward step. Both increments were of equal size.

Before the experiments were started, the values of the parameters were fixed and valid for all experiments.[4] In the following, the construction of the binomial process

[4] In the call market experiments, the path of the realized fundamental values was identical in all 6 experiments (parallel sessions). This was not possible for the continuous trading and dealer market experiments, where we used a set of five and six different paths, respectively. It is unlikely that participants knew the path because the experiments were organized at (geographical) different places.

shall be explained briefly. By using the following values of the five parameters, the binomial process can be described as shown in Figure 2.

| **Parameters of the binomial process** | **Values** |
|---|---|
| $v_1$ | 1,000 |
| $p$ | 60% |
| $q$ | 40% |
| $u$ | 1.2 |
| $d$ | 0.8 |

*Please insert Figure 2 around here*

In period 2 there are two possible values for the fundamental value: it can increase or decrease. If it increases, it changes from $v_1 = 1{,}000$ to $v_2^u = v_1 \cdot u = 1{,}000 \cdot 1.2 = 1{,}200$ with a probability of $p = 60\%$. However, if the fundamental value decreases it changes from $v_1 = 1{,}000$ to $v_2^d = v_1 \cdot d = 1{,}000 \cdot 0.8 = 800$ for what the probability amounts to $1 - p = q = 40\%$. Now randomly either event “up” or “down” takes place. On the basis of the resulting (realized or drawn) fundamental value $v_2$, two different values are possible within the subsequent period and so on.

The role of the fundamental value in these experiments is twofold. On the one hand, it is used for the valuation of the portfolios of the participants. On the other hand, the participants get information about the fundamental value by its expected value of the next period: $\mathrm{E}_t(v_{t+1}) = p \cdot u \cdot v_t + q \cdot d \cdot v_t$. This information was given to the participants at the beginning of every trading period. Before the beginning of the first trading period participants got the parameter values of the binomial process, too. Thus, not only the entire illustration of Figure 2 was comprehensible but also $\mathrm{E}_t(v_T)$, i.e. the expected value of the fundamental value of the 17th period ($v_T$), was determinable for each investor. The remuneration of the participants depended on $v_T$ (see below). The expected value of $v_T$ in period $t$ emerges from the affiliated fundamental value as follows: $\mathrm{E}_t(v_T) = v_t \cdot 1.04^{(17-t)}$.[5]

[5] However, the design of an long-living asset and 16 consecutive trading periods impedes learning processes, on principle, since no stationary decisional situation is granted. A theoretical consideration on the structure of a participant’s rational calculation and on the

Considering the incentive structure, i.e. the payment on the last fundamental value, our experiments have the property that the discovery of the path within the binomial tree illustrates the worthiness of the stocks relative to investors' reference points. Since consecutive rises on the path reduce the probability that a low prior level is reached again, stock owners should be *least* eager to sell. Similarly, if the path reaches a high level (e.g. period 9 or 11 in Figure 2) the probability that a high-level purchase price is recovered during the remaining periods is quite low, and the investor should be eager to sell the stock. Thus, a disposition effect is clearly a mistake in this setting.

Each subject was endowed with 50 stocks and 35,000 currency units.[6] Short selling and borrowing was allowed up to the initial endowment. The subjects were rewarded depending on their success which was measured by their final holdings (cash or debts plus portfolio valued with $v_T$ ). Using this kind of remuneration, all participants knew that a liquidation of their shares at the end of the experiment was not necessary. The final holding was transformed from currency units into Euro by a pre-known divisor. The average payoff was 17.2 € (median: 16.2 € with a range from 5.5 € to 48.8 € [7]). The average time demanded for one experiment was approximately three hours.

The experiments were conducted with graduate students of the University of Hagen and the Bamberg University. All participants had basic knowledge on financial markets and were well-trained statistically. Each subject took part only once.[8] All participants received a set of written instructions at least two weeks before the experiment started (available from the authors). All questions were answered in this pre-period.

### 3.2 Trading mechanisms

Our experiments were run as computerized market experiments. In each of the experiments between 12 and 18 investors formed the market and 16 trading periods were executed. In every market one asset was traded. The following table shows the

size of the market-clearing price is only to indicate under the assumption of risk neutrality. $\mathrm{E}_t(v_T)$ can be interpreted as an asset value of a risk-neutral investor.

[6] Only market makers were endowed differently, cf. Section 3.2).

[7] Losses appeared; nevertheless, there were no negative €-amounts in the final settlement of the accounts of the presented experiments, since the initial endowment with cash and assets was assumed to be given (donated) and the realized losses did not lead to a complete asset deterioration. Basically, the participants had to assume on the basis of the written and oral instructions that losses could have been charged to them.

[8] The only exception are the 18 market makers in the dealer market design. They were chosen from experienced subjects who already took part in one of the continuous trading experiments.

number of experiments and the number subjects for each of the three trading mechanisms.

| Trading mechanism | No. of experiments | No. of subjects |
|---|---|---|
| Call market | 6 | 78 |
| Continuous trading | 6 | 82 |
| Dealer market | 6 | 102 |

The details of these three designs are described in the following.

In a *call market* (CM) buy and sell orders for an asset are collected over a fixed period of time (trading period) and then executed at the clearing price. There is one call in each trading period.

Similar to the main stock markets the clearing price is determined such that the trading volume (number of stocks) is maximized. In the case that not every order can be served at the market price the following rationing rule is applied: limited bids exceeding the clearing price as well as limited asks below this price are served preferentially. At the limit from which a total execution is no longer possible it will be rationed out proportionally with the weighted order size. The subjects can submit one limited bid and/or ask - within the scope of the given budget restrictions - at every auction. Unlimited orders can be mimiked by choosing a high bid or a low ask. After the clearing price has been determined, the quote (with rationing information if necessary) and the underlying aggregated and anonymized orders are announced to the participants. In case of order execution the participants receive an execution notice.

In *continuous trading* (CT) investors can enter new orders at any time during a trading period. There are no restrictions concerning the limit of a new order[9] or the number of orders. Order execution follows price and time priority. The following information from the electronic trading system is available to the subjects: the currently best bid and ask, the order book of the period (anonymous), the subject's orders in the period, the subject's current position in cash and stocks, and the prior transaction prices and volumes in the period. This list is also anonymous, i.e. the subjects involved

[9] The only restrictions are based on the existing orders of an investor. Subjects are forced to keep a spread in their orders, i.e. their lowest non-executed ask has to be higher than their highest non-executed bid.

in the transactions cannot be identified by the other traders in the market. To submit a new order subjects have to enter the number of stocks and a bid or ask. As long as an order has not been executed the subject can cancel her order. If the new order can be matched with existing orders in the order book the transaction takes place. If not, the order is added to the order book.

There are three market makers in each *dealer market* (DM). Only these market makers are allowed to submit limit orders. The other subjects can only accept the prices quoted by the dealers. At any point in time during a period a bid and ask of each of the market makers has to be available. The following information from the electronic trading system is available to the subjects: the currently best bid and ask, the prior bids and asks in the period of each market maker, the subject's current position in cash and stocks, the prior transaction prices and volumes in the period. This list is anonymous, i.e. the subjects involved in the transactions cannot be identified by the other traders in the market. To accept an order the subjects have to name the market maker and enter the corresponding bid or ask and the number of shares. The maximum number of stocks in a single transaction is set to ten. Immediately after a transaction the dealer involved in the transaction has to confirm the existing bid and ask or has to enter a new quote. The market makers receive the same information as the others. The initial endowment of the market makers is higher than that of the other traders. They are endowed with 100 shares and 70,000 currency units. Short selling and borrowing was allowed again up to their initial endowment.

# 4 Hypotheses

Two main aspects are focussed in our research: informational efficiency and liquidity under different trading mechanisms.

Regarding to the previous theoretical, empirical and experimental research, particularly in a symmetric information environment, we expect markets with continuous trading (**CT**) to be the most efficient. Two aspects support this view. Firstly, this mechanism allows subjects to trade assets in "quasi-continuous" time. Secondly, trades can follow each other in a fast pace. These two conditions ensure a quick and thorough incorporation of (new) information into prices. Call markets (**CM**) offer much less ideal conditions to the subjects and should therefore also be less efficient.

Dealer markets (**DM**) seem to be, concerning the trading conditions for the subjects, somewhere inbetween **CT** and **CM**. But although trading can take place more often than in **CM**, the fact that the market makers are involved in every single transaction should significantly lower the speed of aggregation of new information.

With these results in mind, our working hypotheses are the following:

**Hypothesis *Tm.Inf1*:**

**Continuous trading (CT) is the trading mechanism with the *highest* informational efficiency.**

**Hypothesis *Tm.Inf2*:**

**Dealer market (DM) is the trading mechanism with the *lowest* informational efficiency.**

The above mentioned reasons for higher efficiency in **CT** still hold true when looking at the liquidity. We therefore expect **CT** to offer the highest liquidity to subjects. At the other end of the range there should be **CM**, due to offering only limited possibilities to the subjects to trade actively, i. e. fast and often. This is equivalent to the previous experimental research with a common-value design (see section 2) which suggests a weak superiority of dealer markets.

Consequently, our working hypotheses are:

**Hypothesis *Tm.Liq1*:**

**Continuous trading (CT) is the trading mechanism with the *highest* liquidity.**

**Hypothesis *Tm.Liq2*:**

**Call market (CM) is the trading mechanism with the *lowest* liquidity.**

# 5 Results

## 5.1 Aggregation of information

The implemented information structure and payment system is based on an investment behavior that is oriented on the binomial tree. Every realization ("draw") means an adjustment to the fundamental value that is decisive for the later payoff $v_T$. According to this, the measurement of the Root Mean Squared Error (*RMSE*), which is common in literature, is used in a standardized form (with medians, cf. table 1.1) as a measure of the quality of aggregation (cf. e. g. Friedman 1993a, Schiereck 1997 concerning the use in stock market experiments). The standardization which guarantees a comparability of individual trading periods and complete experiments takes place by the use of $\mathrm{E}_t(v_T)$. For the calculation of the used measure the following is valid:[10]

$$RMSE_j = \xi_{0,5}(RMSE_{t,j}^{std}) \quad \text{with} \quad RMSE_{t,j}^{std} = \frac{\sqrt{\frac{1}{c_{t,j}}\sum_{i=1}^{c_{t,j}}(p_{i,t,j} - \mathrm{E}_t(v_T))^2}}{\mathrm{E}_t(v_T)}$$

with $j$ Experiment number
**CM**: $j = 1,\ldots,6$
**CT**: $j = 1,\ldots,6$
**DM**: $j = 1,\ldots,6$

$t$ Period index, $t = 1,\ldots,16$

$p_{i,t,j}$ $i$th determined price for period $t$ in experiment $j$
**CM**: $i = 1 \ \forall t,j$
**CT**, **DM**: $i > 1 \ \forall t,j$

$\mathrm{E}_t(v_T)$ Expected value of the payoff $v_T$ in period $t$

$c_{t,j}$ Number of the price determinations in period $t$
**CM**: $c_{t,j} = 1 \ \forall t,j$
**CT**, **DM**: $c_{t,j} > 1 \ \forall t,j$

$\xi_{0,5}$ denote the median procedure.

Table 1.1 presents the total results, table 1.2 describes the detailed results for each data point (single markets).

*Please insert table 1.1 and 1.2 around here*

---

[10] Additionally we performed the same calculations using the "Mean Relative Error" (*MRE*): $MRE_j = \xi_{0,5}(MRE_{t,j}) \quad \text{with} \quad MRE_{t,j} = \frac{\frac{1}{c_{t,j}}\sum_{i=1}^{c_{t,j}}|p_{i,t,j} - \mathrm{E}_t(v_T)|}{\mathrm{E}_t(v_T)}$.

Results are similar to the results presented in this paper. Please note that for **CM**, *RMSE* and *MRE* are identical because of $c_{t,j} \equiv 1$:

$$\frac{\sqrt{\frac{1}{1}\sum_{i=1}^{1}(p_{i,t,j} - \mathrm{E}_t(v_T))^2}}{\mathrm{E}_t(v_T)} = \frac{\frac{1}{1}\sum_{i=1}^{1}|p_{i,t,j} - \mathrm{E}_t(v_T)|}{\mathrm{E}_t(v_T)} = \frac{|p_{t,j} - \mathrm{E}_t(v_T)|}{\mathrm{E}_t(v_T)}.$$

Overall, the levels of informational efficiency between the three trading mechanisms seem to be quite similar.

**CT** is the most efficient environment (25.9%). **CM** holds the second place (27.5%) and **DM** shows the lowest informational efficiency (30.2%). This holds true if we look at the single data points except for the first one for the comparison of CM and DM (see table 1.2).

So, hypothesis *Tm.Inf1* and hypothesis *Tm.Inf2* cannot be rejected. But applying the usually non-parametric Wilcoxon rank sum test the differences are not significant on a 10% level (see the following table).

| **Trading mechanism** | **Level of significance** (Wilcoxon rank sum test) |
|---|---|
| **CT** ↔ **CM** | 29.44% |
| **CT** ↔ **DM** | 12.01% |

## 5.2 Liquidity

For the calculation of the measure for liquidity, the bid-ask spread in standardized form (Average Relative Spread, *ARS*), the following is valid:

$$ARS_j = \xi_{0,5}(ARS_{t,j}) \quad \text{with} \quad ARS_{t,j} = \frac{\frac{1}{cs_{t,j}}\sum_{i=1}^{cs_{t,j}} s_{i,t,j}}{\mathrm{E}_t(v_T)}$$

with $j$ Experiment number
**CM**: $j = 1,\ldots,6$
**CT**: $j = 1,\ldots,6$
**DM**: $j = 1,\ldots,6$

$t$ Period index, $t = 1,\ldots,16$

$s_{i,t,j}$ $i^{\text{th}}$ spread for period $t$ in experiment $j$:

**CM**: $s_{i,t,j} = Ask_{t,j}^{rej} - Bid_{t,j}^{rej} \quad (i = 1 \;\; \forall t, j)$

$Ask_{t,j}^{rej}$ = Best rejected ask of period $t$ in experiment $j$

$Bid_{t,j}^{rej}$ = Best rejected bid of period $t$ in experiment $j$

**CT**, **DM**: $s_{i,t,j} = Ask_{i,t,j} - Bid_{i,t,j} \quad (i > 1 \;\; \forall t, j)$

$\mathrm{E}_t(v_T)$ Expected value of the payoff $v_T$ in period $t$

| | |
|---|---|
| $cs_{t,j}$ | Number of spreads in period *t*: |
| | **CM**: $cs_{t,j} = 1 \ \ \forall t, j$ |
| | **CT**, **DM**: $cs_{t,j} > 1 \ \ \forall t, j$ |
| $\xi_{0,5}$ | denote the median procedure. |

For call markets (subtype 2aa in figure 1) Friedman (1993a) formulates roughly the bid-ask spread as the difference between the particularly best rejected (not executed) bid and the particularly best rejected ask. We calculate the spreads in **CM** this way[11] (i.e. $s_{i,t,j} = Ask_{t,j}^{rej} - Bid_{t,j}^{rej}$). This concept is based on the consideration that an additional bid reaching the market would be executed at exactly the price which is carried by the lowest limited and not executed ask. The same is valid for an additionally executed ask.

Table 2.1 shows the descriptive results, table 2.2 the detailed results for each data point (single markets).

*Please insert table 2.1 and 2.2 around here*

Hypothesis *Tm.Liq1* cannot be rejected: The **CT** spreads are the smallest, **CT** is the most liquid trading mechanism. This result is highly significant (see the following table).

| **Trading mechanism** | **Level of significance** (Wilcoxon rank sum test) |
|---|---|
| **CT** ↔ **CM** | 0.11% |
| **CT** ↔ **DM** | 0.76% |

But it is quite interesting to see that the most illiquid trading mechanism is **DM** (9.3%) and not **CM** (6.1%). Hence, Hypothesis *Tm.Liq2* has to be rejected. This holds true for the single markets (table 2.2) except of the first two data points.

For the subjects, the **DM** mechanism is more related to **CT** than it is to **CM**. Therefore our results concerning the illiquidity of the **DM** mechanism have to be

[11] Cf. Heilmann/Läger/Oehler 2000a, 368–369, for detailed discussion of the use of the implicit spread in call markets.

explained by the behavior of the market makers rather than of the subjects. The spreads are set by the market makers and they coherently tried to maximize their profits per transaction ("high-margin strategy") by setting wide spreads. They did not follow a strategy to lower the spreads in order to increase overall profits due to a higher turnover.

The results for **DM** are similar to the results reported by Theissen who documents 12%.[12] But his results reported for **CM** and **CT** are different. There, clearly **CM** is the most liquid mechanism (1.8%) whereas **CT** is only number two (4.7%). Possible explanations for the different results lie in the chosen design. Theissen uses an stationary-replication design (see above section 2) which does not consider any problem of portfolio changes over time and other time-dependent decisions of investors. Additionally, the quite complex information structure may let to some complications in understanding the experimental procedures. The most convincing reason for the differing results in both studies is the fact that Theissen induces a strong asymmetric information distribution (see above section 2) whereas we use a symmetric approach. Corresponding to the previous theoretical, empirical and experimental research both results support the hints from the findings there. Under an (strong) asymmetric environment call markets outperform continuous trading and within a symmetric information environment continuous auctions show superiority.

## 6 Summary and conclusion

This study reports the results of 18 experimental asset markets. The experiments are done to compare three principal trading mechanisms which are focused in financial markets literature with both a theoretical and a empirical perspective. The information structure and the payment system that was implemented in the environment allow us to analyze both success factors in international competition of stock exchanges, the informational efficiency and the liquidity of the three fundamental market structures.

Corresponding to the theoretical research and to field studies, the informational efficiency of continuous auctions shows a weak superiority to call markets and a stronger performance in comparison to dealer markets.

Regarding to the second criterion, the liquidity, continuous trading offers substantially higher liquidity compared to dealer markets and call markets. Dealer

[12] Cf. Theissen 1999, p. 251. He also used *ARS* to measure liquidity.

markets perform worst. These findings are equivalent to observations in reality and central theoretical proposals.

The used market designs delivered a richness of data both for further studies on the aggregate level as well as for research on the individual level. Among others, there are two promising tracks for future work with our stock exchanges in the laboratory. Firstly, the comparison of the trading mechanisms was enriched by the introduction of some information privileges. A series of experiments, similar to the markets presented here, was conducted with insiders. The information privilege consists of the fact that these subjects get the new information one period earlier than all other traders. First results indicate a tendency of call markets to widen the bid-ask spread in order to avoid disadvantages from adverse selection.

Secondly, the market experiments shall be used in further analyses in the sense of the behavioral-finance paradigm (cf. Oehler 2000c) for the explanation of the results in the aggregate. It still has to be clarified whether individual participants or groups reveal intentionally or unintentionally their trading strategies through their orders and what they reach with it. First results indicate that e. g. uninformed traders want to sell an asset very quickly compared to a rational behavior when its price has risen recently. On the other hand, they do not want to sell an asset over a long period of time when its price has sunk before. This is an indication for the disposition effect (cf. Heilmann/Läger/Oehler 2000b). In contrast to theoretical considerations, this phenomenon does not lead to a close-down of the whole market caused by a reluctance to trade. The market participants rather seem either to use different reference points in their evaluation or not all investors are affected by the disposition effect in the same intensity.

## References


Admati, A. / Pfleiderer, P., A Theory of Intraday Patterns, Review of Financial Studies (1), 1988, 3–40

Amihud, Y. / Mendelson, H., Asset Pricing and Bid-Ask Spread, Journal of Financial Economics (17), 1986, 223–249

Amihud, Y. / Mendelson, H., Trading Mechanisms and Stock Returns: An Empirical Investigation, Journal of Finance (42), 1987, 533–553

Amihud, Y. / Mendelson, H., The Liquidity Route to a Lower Cost of Capital, Journal of Applied Corporate Finance (12), Winter, 2000, 8–25

Amihud, Y. / Mendelson, H. / Lauterbach, B., Market Microstructure and Securities Values: Evidence from the Tel Aviv Stock Exchange, Journal of Financial Economics (45), 1997, 365–390

Bernstein, P. L., Liquidity, Stock Markets, and Market Makers, Financial Management (16), 1987, 54–62

Bessembinder, H. / Kauffman, H., A Comparison of Quotations, Trading Costs, and Volatility for NYSE and NASDAQ-listed Stocks, NYSE Working Paper 96-03, 1996

Bienert, H., The Market Process of Stock Exchanges [Der Marktprozeß an Aktienbörsen], Gabler, Wiesbaden, 1996

Black, F., Noise, Journal of Finance (41), 1986, 529–543

Bloomfield, R. / O'Hara, M., Market Transparency: Who Wins and Who Loses?, Review of Financial Studies (12), 1999, 5–35

Bloomfield, R. / O'Hara, M., Can Transparent Markets Survive?, Journal of Financial Economics (55), 2000, 425–459

Bossaerts, P. / Plott, C. R., Basic Principles of Asset Pricing Theory: Evidence from Large-Scale Experimental Financial Markets, CEPR Discussion Paper No. 2578, 2000

Cohen, K. J. / Maier, S. F. / Schwartz, R. A. / Whitcomb, D. K., Transaction Costs, Order Placement Strategy, and the Existence of the Bid-Ask Spread, Journal of Political Economy (89), 1981, 287–305

Duxbury, D., Experimental Asset Markets within Finance, Journal of Economic Surveys (9), 1995, 331–371

Easley, D. / Ledyard, J., Theories of Price Formation and Exchange in Double Oral Auctions, in: Friedman, D. / Rust, J. (eds.), The Double Auction Market, Addison–Wesley, Reading, MA, 1993, 63–97

Fama, E. F., Efficient Capital Markets, Journal of Finance (25), 1970, 383–417

Flood, M. / Huisman, R. / Koedijk, K. G. / Mahieu, R. J. / Röell, A., Post-Trade Transparency in Multiple Dealer Financial Markets, Working Paper, Maastricht University, 1997

Flood, M. / Huisman, R. / Koedijk, K. G. / van Dijk, M. A. / van Leeuwen, I. W., The More You See, the Less You Get: Price-Competing Insiders under Different Trading Mechanisms, Working Paper, Maastricht University, 1998

Franke, G. / Hess, D., Information Diffusion in Electronic and Floor Trading, Journal of Empirical Finance (7), 2000, 455–478

Friedman, D., On the Efficiency of Experimental Double Auction Markets, American Economic Review (74), 1984, 60–72

Friedman, D., A Simple Testable Model of Double Auction Markets, Journal of Economic Behavior and Organization (15), 1991, 47–70

Friedman, D., How Trading Institutions Affect Financial Market Performance: Some Laboratory Evidence, Economic Inquiry (31), 1993a, 410–435

Friedman, D., Privileged Traders and Asset Market Efficiency: A Laboratory Study, Journal of Financial and Quantitative Analysis (28), 1993b, 515–534

Gerke, W. / Bienert, H. / Syha, C., Impact of the Orderbook Privilege in an Experimental Stock Exchange [Auswirkungen des Orderbuchprivilegs an einer experimentellen Aktienbörse], Zeitschrift für betriebswirtschaftliche Forschung (53), 188–215

Glosten, L. R., Insider Trading and the Role of the Monopoly Specialist, Journal of Business (62), 1989, 211–235

Glosten, L. R., Is the Electronic Open Limit Order Book Inevitable?, Journal of Finance (49), 1994, 1127–1161

Greene, J. / Watts, S., Price Discovery on the NYSE and the NASDAQ: The Case of the Overnight and Daytime News Releases, Financial Management (25), 1996, 19–42

Grossmann, S. J. / Stiglitz, J. E., On the Impossibility of Informationally Efficient Markets, American Economic Review (70), 1980, 393–480

Haller, A. / Stoll, H., Market Structure and Transaction Costs: Implied Spreads in the German Stock Market, Journal of Banking and Finance (13), 1989, 697–708

Harris, L. E., Liquidity, Trading Rules, and Electronic Trading Systems, New York Salomon Center (ed.), Monograph in Finance and Economics, 1990-4, New York, 1990

Heilmann, K. / Läger, V. / Oehler, A., Aggregation of Information, Insider Trading, and Liquidity in Experimental Call Markets [Informationsaggregation, Insiderhandel und Liquidität in experimentellen Call Markets], Zeitschrift für Bankrecht und Bankwirtschaft (12), 2000a, 361–371

Heilmann, K. / Läger, V. / Oehler, A., The Disposition Effect—Evidence on the Investors' Aversion to Realize Losses, Proceedings of the 25th Annual Colloquium, IAREP, Wien 2000b

Ho, T. S. / Schwartz, R. A. / Whitcomb, D. K., The Trading Decision and Market Clearing under Transaction Price Uncertainty, Journal of Finance (40), 1985, 21–42

Hu, S.-Y., Trading Turnover and Expected Stock Returns: The Trading Frequency Hypothesis and Evidence from the Tokyo Stock Exchange, Discussion Paper, University of Chicago, 1997

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

Keim, D. / Madhavan, A., Transaction Costs and Investment Style: An Inter-Exchange Analysis of Institutional Equity Trades, Working Paper, 1996,

Kempf, A., What do Liquidity Measures Measure? [Was messen Liquiditätsmaße?], Die Betriebswirtschaft (58), 1998, 299–311

Kempf, A. / Uhrig, M., The Impact of Liquidity on Bond Prices, Working Paper 96-06, Universität Mannheim, 1996

Krahnen, J. P. / Weber, M., Does Information Aggregation Depend on Market Structure? Market Makers vs. Double Auction, Zeitschrift für Wirtschafts- und Sozialwissenschaften (119), 1999, 1–22

Kyle, A., Continuous Auctions and Insider Trading, Econometrica (53), 1985, 1315–1335

Lamoureux, C. G. / Schnitzlein, C. R., When it´s not the Only Game in Town. The Effect of Bilateral Search on the Quality of a Dealer Market, Journal of Finance (52), 1996, 683–712

Lee, C., Market Integration and Price Execution for NYSE-listed Securities, Journal of Finance (48), 1993, 1009–1038

Madhavan, Trading Mechanisms in Securities Markets, Journal of Finance (47), 607–641

Mendelson, H., Market Behavior in a Clearinghouse, Econometrica (50), 1982, 1505–1524

Mendelson, H., Consolidation, Fragmentation, and Market Performance, Journal of Financial and Quantitative Analysis (22), 1987, 189–207

Milgrom, P. / Stockey, N., Information, Trade and Common Knowledge, Journal of Economic Theory (26), 1982, 17–27

Nöth, M., Information Aggregation and Insider Detection in Financial Markets [Informationsaggregation und Insidererkennung in Finanzmärkten], Gabler, Wiesbaden, 1998

Nöth, M. / Weber, M., Insider Detection in Experimental Markets [Insidererkennung in experimentellen Märkten], Zeitschrift für betriebswirtschaftliche Forschung (48), 1996, 959–982

Oehler, A., Explaining the Behavior of Private Investors [Die Erklärung des Verhaltens privater Anleger], Schäffer-Poeschel, Stuttgart, 1995

Oehler, A., Competition of Stock Exchanges—An Economic Analysis [Wertpapierbörsen im Wettbewerb – eine ökonomische Analyse], Sparkasse (117), 2000a, 351–357

Oehler, A., A Stock Exchange in the Laboratory?—Results of Experimental Financial Market Research for the Design of Stock Exchanges [Börse im Labor? – Ergebnisse experimenteller Finanzmarktforschung für die Ausgestaltung von Börsen], Kurzbericht, Bamberg 2000b

Oehler, A., Behavioral Finance—Theoretical, Empirical and Experimental Results under Conditions of Markets [Behavioral Finance – Theoretische, empirische und experimentelle Befunde unter Marktrelevanz], Bankarchiv, No. 11, 2000c, 978–989

Oehler, A. / Unser, M., Transparency and Call Markets, Working Paper, Bamberg, 1998

O´Hara, M., Market Microstructure Theory, Basil Blackwell, Oxford, 1995

Pagano, M. / Röell, A., Trading Systems in European Stock Exchanges: Current Performance and Policy Options, Economic Policy (10), 1990, 63–115

Pagano, M. / Röell, A., Auction and Dealership Markets? – What is the Difference?, European Economic Review (36), 1992, 613–623

Pagano, M. / Röell, A., Transparency and Liquidity: A Comparison of Auction and Dealer Markets with Informed Trading, Journal of Finance (51), 1996, 579–611

Plott, C. R. / Sunder, S., Efficiency of Experimental Security Markets with Insider Information, Journal of Political Economy (90), 1982, 663–698

Roll, R., A Simple Implicit Measure of the Bid/Ask Spread in an Efficient Market, Journal of Finance (39), 1984, 1127–1139

Rubio, G. / Tapia, M., Adverse Selection, Volume and Transactions Around Dividend Announcements in a Continuous Auction System, European Financial Management (2), 1996, 39–67

Rustichini, A. / Satterthwaite, M. A. / Williams, S. R., Convergence to Efficiency in a Simple Market with Incomplete Information, Econometrica (62), 1994, 1041–1063

Schiereck, D., Institutional Investors´s Decisions for a Stock Exchange [Internationale Börsenplatzentscheidungen institutioneller Investoren], Gabler, Wiesbaden, 1995

Schiereck, D., Information Aggregation and Anonymity in Experimental Call Markets [Informationsaggregation und Anonymität in experimentellen Call-Märkten], Zeitschrift für Wirtschafts- und Sozialwissenschaften (117), 1997, 365–390

Schmidt, H., Stock Exchange Organization for the Protection of the Investors [Börsenorganisation zum Schutz der Anleger], Mohr, Tübingen 1970

Schmidt, H., Report of Study "Advantages and disadvantages of an integrated market compared with a fragmented market", Commission of the European Communities, Collection Studies: Competition – Approximation of legislation Series no. 30, Brussels, March 1977

Schmidt, H. / Iversen, P., Bid-Ask-Spreads of German Blue Chips in IBIS and Matis [Geld-Brief-Spannen deutscher Standardwerte in IBIS und Matis], Zeitschrift für Bankrecht und Bankwirtschaft (3), 1991, 209–226

Schmidt, H. / Iversen, P. / Treske, K., Floor or Computer? [Parkett oder Computer?], Zeitschrift für Bankrecht und Bankwirtschaft (5), 1993, 209–221

Schmidt, H. / Küster Simic, A. K., The Theory of the Bid-Ask-Spread in Auction Markets: The Influence of Order Book Transparency on the Trading Uncertainty [Zur Theorie der Geld-Brief-Spanne auf Anlegerauktionsmärkten: Der Einfluß der Orderbuchtransparenz auf die Abschlußunsicherheit], Kredit und Kapital, Sonderheft 15, 2000, 137-172

Schmidt, H. / Oesterhelweg, O. / Treske, K., German Stock Exchanges on a Performance Test: IBIS and BOSS-CUBE [Deutsche Börsen im Leistungsvergleich: IBIS und BOSS-CUBE], Kredit und Kapital (29), 1996, 90–122

Schnitzlein, C. R., Call and Continuous Trading Mechanisms Under Asymmetric Information: An Experimental Investigation, Journal of Finance (51), 1996, 613–636

Sunder, S., Experimental Asset Markets: A Survey, in: Kagel, J. H. / Roth, A. E. (eds.), Handbook of Experimental Economics, University Press, Princeton, NJ, 1995, 445–500

Schwartz, R. A., Reshaping the Equity Markets, New York, 1991

Schwartz, R. A., Technology Impacts on the Equity Markets, Bundesverband der Börsenvereine an deutschen Hochschulen (BVH) e.V. (Hrsg.), Aktienkultur – Perspektiven für den Finanzplatz Deutschland, Rieger, Wolfratshausen, 1997, 109–134

Smith, V. L. / Suchanek, G. L. / Williams, A. W., Bubbles, Crashes, and Endogenous Expectations in Experimental Spot Asset Markets, Econometrica (56), 1988, 1119–1151

Stoll, H. R., Equity Trading Costs In-the-Large, Journal of Portfolio Management (19), 1993, 41–50

Stoll, H. R., The Importance of Equity Trading Costs: Evidence from Securities Firms´ Revenues, in: Schwartz, R. A. (ed.), Global Equity Markets: Technological, Competitive, and Regulatory Challenges, Chicago, 1995

Stoll, H. R./ Whaley, R., Stock Market Structure and Volatility, Review of Financial Studies (3), 1990, 37–71

Syha, C., Orderbook Transparency and Investor Behavior [Orderbuchtransparenz und Anlegerverhalten], Gabler, Wiesbaden, 1999

Theissen, E., Organizational Structures of Securities Trading, Call Market, Continuous Auction and Dealer Markets, Gabler, Wiesbaden, 1998

Theissen, E., Liquidity Measurement in Experimental Stock Markets [Liquiditätsmessung auf experimentellen Aktienmärkten], Kredit und Kapital (32), 1999, 225–264

Unser, M., Lower partial moments as measures of perceived risk: An experimental study, Journal of Economic Psychology (21), 2000, 253–280

Van Boening, M. V. / Williams, A. W. / LaMaster, S., Price Bubbles and Crashes in Experimental Call Markets, Economics Letters (41), 1993, 179–185

Wilson, R., On Equilibria of Bid-Ask Markets, in: Feiwel, G. (ed.), Arrow and the Ascent of Economic Theory, Essays in Honour of Kenneth G. Arrow, MacMillan Press, Basingstoke, 1987

## Appendix

### Figure 1: Main designs of financial markets

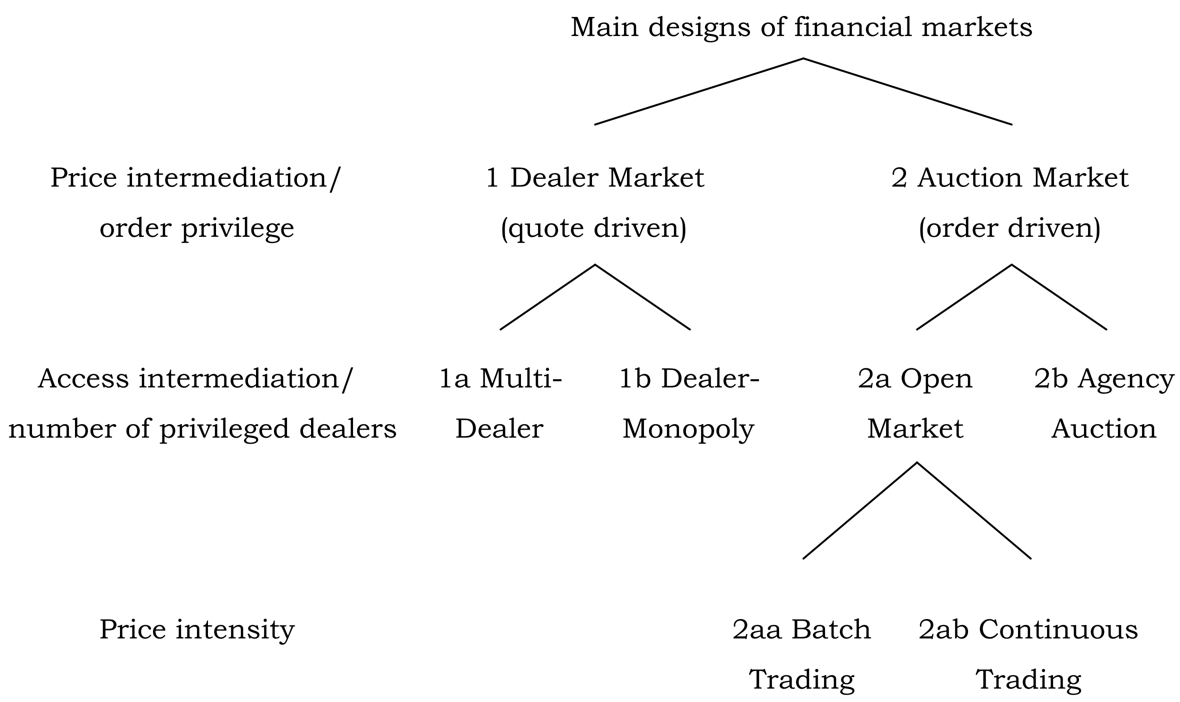

**Figure 2: Generating the fundamental asset value with a binomial tree**

| Parameters | |
|---|---|
| ***v*** 1 | 1,000 |
| ***p*** | 0.60 |
| ***q* (=1–*p*)** | 0.40 |
| ***u*** | 1.20 |
| ***d*** | 0.80 |

| P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P13 | P14 | P15 | P16 | [P17] | prob.(*) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | 18,488 | 0.0% |
| | | | | | | | | | | | | | | | 15,407 | | |
| | | | | | | | | | | | | | | 12,839 | | 12,326 | 0.3% |
| | | | | | | | | | | | | | 10,699 | | 10,271 | | |
| | | | | | | | | | | | | 8,916 | | 8,559 | | 8,217 | 1.5% |
| | | | | | | | | | | | 7,430 | | 7,133 | | 6,848 | | |
| | | | | | | | | | | 6,192 | | 5,944 | | 5,706 | | 5,478 | 4.7% |
| | | | | | | | | | 5,160 | | 4,953 | | 4,755 | | 4,565 | | |
| | | | | | | | | 4,300 | | 4,128 | | 3,963 | | 3,804 | | 3,652 | 10.1% |
| | | | | | | | 3,583 | | 3,440 | | 3,302 | | 3,170 | | 3,043 | | |
| | | | | | | 2,986 | | 2,867 | | 2,752 | | 2,642 | | 2,536 | | 2,435 | 16.2% |
| | | | | | 2,488 | | 2,389 | | 2,293 | | 2,202 | | 2,113 | | 2,029 | | |
| | | | | 2,074 | | 1,991 | | **1,911** | | **1,835** | | 1,761 | | **1,691** | | **1,623** | 19.8% |
| | | | **1,728** | | 1,659 | | **1,593** | | **1,529** | | **1,468** | | **1,409** | | **1,353** | | |
| | | **1,440** | | **1,382** | | **1,327** | | 1,274 | | 1,223 | | **1,174** | | 1,127 | | 1,082 | 18.9% |
| | **1,200** | | 1,152 | | **1,106** | | 1,062 | | 1,019 | | 978 | | 939 | | 902 | | |
| **1,000** | | 960 | | 922 | | 885 | | 849 | | 815 | | 783 | | 751 | | 721 | 14.2% |
| | 800 | | 768 | | 737 | | 708 | | 679 | | 652 | | 626 | | 601 | | |
| | | 640 | | 614 | | 590 | | 566 | | 544 | | 522 | | 501 | | 481 | 8.4% |
| | | | 512 | | 492 | | 472 | | 453 | | 435 | | 417 | | 401 | | |
| | | | | 410 | | 393 | | 377 | | 362 | | 348 | | 334 | | 321 | 3.9% |
| | | | | | 328 | | 315 | | 302 | | 290 | | 278 | | 267 | | |
| | | | | | | 262 | | 252 | | 242 | | 232 | | 223 | | 214 | 1.4% |
| | | | | | | | 210 | | 201 | | 193 | | 186 | | 178 | | |
| | | | | | | | | 168 | | 161 | | 155 | | 148 | | 142 | 0.4% |
| | | | | | | | | | 134 | | 129 | | 124 | | 119 | | |
| | | | | | | | | | | 107 | | 103 | | 99 | | 95 | 0.1% |
| | | | | | | | | | | | 86 | | 82 | | 79 | | |
| | | | | | | | | | | | | 69 | | 66 | | 63 | 0.0% |
| | | | | | | | | | | | | | 55 | | 53 | | |
| | | | | | | | | | | | | | | 44 | | 42 | 0.0% |
| | | | | | | | | | | | | | | | 35 | | |
| | | | | | | | | | | | | | | | | 28 | 0.0% |

**(*)** probability of this fundamental asset value in period 17, calculated in period 1

| | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P13 | P14 | P15 | P16 | [P17] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **fundamental asset values** | 1,000 | 1,200 | 1,440 | 1,728 | 1,382 | 1,106 | 1,327 | 1,593 | 1,911 | 1,529 | 1,835 | 1,468 | 1,174 | 1,409 | 1,691 | 1,353 | 1,623 |
| **delivered expected fund. values $E_t(v_{t+1})$** | 1,040 | 1,248 | 1,498 | 1,797 | 1,438 | 1,150 | 1,380 | 1,656 | 1,987 | 1,590 | 1,908 | 1,526 | 1,221 | 1,465 | 1,758 | 1,407 | |
| **expected asset values for the payoff $E_t(v_T)$** | 1,873 | 2,161 | 2,494 | 2,877 | 2,213 | 1,703 | 1,964 | 2,267 | 2,615 | 2,012 | 2,321 | 1,786 | 1,374 | 1,585 | 1,829 | 1,407 | |

**Table 1.1: Results on information aggregation – overview**

The table shows the results of the RMSE measure on the aggregation of information for the three market environments: CM, CT, and DM.

For interpretation: the best value (highest efficiency) is reached when the measure's value amounts to 0%. It is valid[13]: $RMSE = \xi_{0,5}(RMSE_j)$.

We use medians instead of means in the averaging procedure to give not too much weight to outliers (cf. Nöth 1998). Additionally, the Wilcoxon rank sum test uses this measure. Results calculated with the mean are quite similar.

| | Trading mechanism | | |
|---|---|---|---|
| | CM | CT | DM |
| RMSE | 27.8% | 25.9% | 30.2% |

Standardized

**Table 1.2: Results on information aggregation – details**

The table shows the results of the RMSE measure on the aggregation of information for the three market environments: CM, CT, and DM.

As supplement to table 1.1, table 1.2 shows the results for each single experiment (data point).

| Trading mechanism | $RMSE_j$ (j = 1 … 6) | | | | | |
|---|---|---|---|---|---|---|
| CM | 24.2% | 24.4% | 26.0% | 29.6% | 30.9% | 33.3% |
| CT | 21.5% | 24.3% | 24.8% | 26.9% | 28.8% | 32.3% |
| DM | 14.6% | 28.5% | 29.2% | 31.1% | 35.5% | 35.5% |

Standardized

[13] For the definition of $RMSE_j$ see above, this section.

**Table 2.1: Results on liquidity – overview**

The table shows the results of the bid-ask-spread as the liquidity measure for the three trading mechanisms (averaged relative spread on the basis of $E_t(v_T)$): CT, CM, and DM.

It is valid[14]: $ARS = \xi_{0,5}(ARS_j)$

We use medians to give not too much weight to outliers (cf. Nöth 1998). Additionally, the Wilcoxon rank sum test uses this measure. Results calculated with means are quite similar.

| | Trading mechanism | | |
|---|---|---|---|
| | CM | CT | DM |
| ARS | 6.1% | 2.4% | 9.3% |

Standardized

**Table 2.2: Results on liquidity – details**

The table shows the results of the bid-ask-spread as the liquidity measure for the three trading mechanisms (averaged relative spread on the basis of $E_t(V_t)$): CM, CT, and DM.

As supplement to table 2.1, table 2.2 shows the results for each single experiment (data point).

| Trading mechanism | $ARS_j$ (j = 1 … 6) | | | | | |
|---|---|---|---|---|---|---|
| CM | 5.0% | 5.5% | 5.6% | 6.7% | 7.0% | 9.6% |
| CT | 2.1% | 2.1% | 2.3% | 2.6% | 3.0% | 3.6% |
| DM | 2.4% | 4.8% | 6.7% | 11.8% | 18.1% | 25.3% |

Standardized

[14] For the definition of $ARS_j$ see above, this section.