JOURNAL OF FINANCIAL INTERMEDIATION **7,** 220–239 (1998)
ARTICLE NO. JF980244

Trading System and Market Integration*

Alexander Kempf

Chair of Finance, University of Mannheim, 68131 Mannheim, Germany
E-mail: kempf@bwl.uni-mannheim.de

and

Olaf Korn

Centre for European Economic Research (ZEW), P.O. Box 103443, 68034 Mannheim, Germany
E-mail: korn@zew.de

Received December 2, 1996

In this paper we investigate empirically the relative advantages of floor and screen trading systems. We judge the systems by their ability in providing a high degree of market integration. The main result is that a closer integration of underlying and derivative markets occurs when both instruments are screen traded, but the difference is significant only for short return intervals. In active trading periods the superiority of screen systems is even more pronounced. *Journal of Economic Literature Classification Numbers:* G15, G20. © 1998 Academic Press

I. INTRODUCTION

Current financial markets are undergoing dramatic changes. New markets have emerged all over the world and account for a significant share of total trading volume (Sarkar and Tozzi, 1998). Existing exchanges cooperate

* We are grateful to two anonymous referees, Maureen O'Hara (the editor), Horst Bienert, Reto Francioni, Peter Reichling, Hartmut Schmidt, and participants of the CBOT 9th Annual European Futures Research Symposium, the 7th Symposium on Money, Finance, Banking, and Insurance, the 3rd Annual DGF Meeting, the 6th AFIR International Colloquium, and the SBF-Paris Bourse conference on Organization and Quality of Equity Markets for helpful comments. We thank the Deutsche Börse AG, the German Finance Database, Karlsruhe, and the German Finance Database, Mannheim, for providing the data. All remaining errors are our own.

1042-9573/98 $25.00
Copyright © 1998 by Academic Press
All rights of reproduction in any form reserved.

and adjust their trading structure to become more attractive for investors. For example, the German Futures and Options Exchange (DTB) and the Swiss Options and Financial Futures Exchange (SOFFEX) are developing the common trading platform EUREX. In a global alliance, these exchanges cooperate with the Chicago Board of Trade (CBoT). The London International Financial Futures and Options Exchange (LIFFE) has recently announced important reforms of their trading systems. But what is the right way to go about this?

One of the most controversial issues concerning the trading system is whether to establish screen trading or floor trading markets. Several authors attribute a higher liquidity to floor markets, especially in active periods. Massimb and Phelps (1994) state that more locals exist on floor markets than in computer markets, leading to a higher liquidity. Beneviste *et al*. (1992) argue that liquidity is higher in floor markets as dealers can distinguish between informed and liquidity traders more accurately when facing them. Advocates of screen trading emphasize that electronic systems are superior due to lower trading costs, faster order execution, accelerated information dissemination, anonymity of trading, and the possibility of investors being able to trade in many markets simultaneously (Harris, 1990; Grünbichler *et al*., 1994; Massimb and Phelps, 1994). In addition, they stress that the current trend from floor trading to screen trading markets (Domowitz, 1993; Grünbichler *et al*., 1994) demonstrates the superiority of computerized systems.

Since there are theoretical arguments in favor of both systems, one needs to address the question of superiority in empirical studies. There are three lines of research in the literature. The first one focuses on whether floor trading or screen trading leads to higher market liquidity (Shyy and Lee, 1995; Fremault Vila and Sandmann, 1996; Pirrong, 1996; Kofman and Moser, 1996; Breedon and Holland, 1998). These papers provide conflicting results. The second line of research addresses the question of whether floor trading or screen trading results in a faster transmission of information (Grünbichler *et al*., 1994; Shyy and Lee, 1995; Kofman and Moser, 1996; Sandmann and Fremault Vila, 1996; Breedon and Holland, 1998). Again, the results are mixed. The final line of research investigates whether the trade execution system of a computerized market leads to a higher trader and customer surplus in comparison with a floor market. Based on a simulation study, Domowitz (1990) reports slightly better performance of the computerized GLOBEX system.

In this paper, we contribute to the discussion of whether floor trading or screen trading is superior by focusing on a new criterion. Our main question is: Which trading system performs better in the sense that it provides a higher degree of integration between markets?[1] The degree of market integration is of considerable interest for both investors and exchanges. For example, closely integrated markets offer hedging opportunities and allow investors to split orders so reducing market impact costs. These new trading opportunities could attract additional investors to integrated markets and lead to higher trading volume and liquidity. From the point of view of an exchange, the results of market integration are highly favorable.

We address our main question by analyzing the integration between the German stock index DAX and DAX futures. The corresponding markets are ideally suited for our purpose as the stocks included in the DAX are simultaneously floor and screen traded. This allows us to study the integration between spot and futures markets for different spot trading systems. Although one expects a close integration between underlying (DAX index) and derivate (DAX futures) markets due to arbitrage trading, the trading system probably effects the degree of integration. Arbitrage trading is limited by market frictions[2] (trading costs, order execution lags, and delayed information dissemination) and market frictions are determined—among other factors—by the trading system.

It has been argued that computerized exchanges perform well in normal situations but not in periods of high volatility. In these active periods, trading volume tends to turn from the computerized system toward a traditional floor market or broker systems. One reason could be that knowledge of the counterparty of a trade is more important in times of high information intensity (Franke and Hess, 1997). Another possible reason is that posting limit orders in an electronic order book provides a free option to other traders, which is especially valuable in volatile periods (Copeland and Galai, 1983). In floor markets this problem is less important, since a quote is valid only as long as the "breath of the trader is warm." Such effects could also influence market integration. It is therefore important to check the robustness of the results for periods of high market activity and volatility.

The remainder of the paper is organized as follows. In Section II the concept of market integration is formalized and different measures of market integration are discussed. Section III contains a description of the market microstructure and Section IV introduces the data set. In Section V the different measures of market integration are used to test whether the trading system has an impact on market integration. Section VI provides

[1] Financial markets are integrated if investors consider the instruments traded in these markets as substitutes and, consequently, prices tend to fluctuate together. A more precise definition of market integration is given in Section II.

[2] The optimal arbitrage trading strategy in the presence of market frictions is discussed, for example, in Brennan and Schwartz (1990), Holden (1990), Tuckman and Vila (1992), and Kumar and Seppi (1994).

our integration results for active and inactive trading periods. Section VII summarizes the main findings and concludes.

II. MEASUREMENT OF MARKET INTEGRATION

Two markets are integrated if the prices in these markets fluctuate together. This idea of price comovement can be formalized by means of the correlation between the returns in each market. As Stoll and Whaley (1990) show, perfect market integration implies that the return in one market is perfectly correlated with the simultaneous return in the other market. This leads directly to our first measure of market integration.

Measure 1. Market integration can be measured by the correlation coefficient between simultaneous returns in the markets. The higher the correlation coefficient, the stronger the market integration.

A second measure of market integration is adopted from a paper by Chen and Knez (1995). Their basic idea is that closely integrated markets should assign similar prices to similar payoffs. They argue that the more strongly the markets are integrated, the smaller the differences in risk-adjusted returns per time interval. Chen and Knez (1995) formalize this idea as follows:

Measure 2. Market integration can be measured by the minimum squared distance between stochastic discount factors in the markets (Chen and Knez, (1995)).[3] The smaller the distance, the stronger the market integration.[4]

The return correlations and the Chen–Knez measure reflect the trading decisions of all market participants, although these trading decisions are not modeled explicitly. Therefore, Measures 1 and 2 have the desirable characteristic that they do not rely on the validity of an underlying trading model. The disadvantage of both measures, however, is that they give no insight on why integration is dependent on the trading system. Are differences caused by arbitrageurs or by other investors?

The measures discussed next allow such a refined view on market integration but they rely on trading models. They concentrate on the impact of arbitrage trading on market integration. Since the focus of our paper is on the integration between a futures contract and its underlying, arbitrageurs

[3] A more formal definition of the Chen–Knez measure is given in Section V, where the implementation of the measure is discussed.

[4] In fully integrated markets, the risk-adjusted returns are equal and the markets are perfect substitutes for investors.

are supposed to have a major impact on market integration. Arbitrageurs could build up opposite positions in the spot and futures markets at time t, carry these positions until maturity of the futures contract at T, and gain riskfree arbitrage profits, $|X(t, T)|$. Therefore, the trading decision of arbitrageurs is based on the mispricing $X(t, T)$ between spot and futures markets.[5]

Measure 3. The spot-future market integration can be measured by the absolute mispricing between spot and futures markets, $|X(t, T)|$. The smaller the absolute mispricing, the stronger the market integration.[6]

This measure of arbitrage-induced market integration is based on attainable profits $|X(t, T)|$ of arbitrageurs following a simple cash-and-carry trading strategy in the absence of market frictions. Attainable arbitrage profits, however, just indicate arbitrage opportunities. They do not reveal whether arbitrageurs actually trade and maintain market integration. To overcome this disadvantage, the individual-arbitrage-trading model has to be extended to an equilibrium approach which provides insights into the impact of arbitrage trading on observable prices.

Garbade and Silber (1983) develop such an equilibrium model of futures and spot markets. They show that the arbitrage induced market integration can be measured by the overall price adjustment in response to a mispricing. The strength of this price adjustment is expressed by the parameter $\mu \in [0, 1]$ in the equilibrium mispricing process derived within the model

$$\Delta X^*(t, T) = -\mu X^*(t-1, T) + u(t). \tag{1}$$

The asterisk indicates that mispricing is calculated from the logarithmic spot and futures prices. The change in mispricing is given as $\Delta X^*(t, T) \equiv X^*(t, T) - X^*(t-1, T)$ and $u(t)$ denotes an error term. Here, μ is the mean reversion parameter of the mispricing process.[7] It serves as the fourth measure of market integration.

Measure 4. The spot-future market integration can be measured by the mean reversion of the mispricing between spot and futures markets. The higher the mean reversion parameter μ, the stronger the market integration.[8]

[5] A precise definition of mispricing for the markets under study is given in Section IV.

[6] In perfectly integrated markets, $X(t, T) = 0$ holds for all t, $0 \leq t \leq T$.

[7] If μ is greater than zero, the spot and futures markets are cointegrated in the notion of Engle and Granger (1987). Cointegration between the price series should exist for two markets which are integrated in an economic sense.

[8] In perfectly integrated markets, the measure is not defined, since in those markets $X(t, T) = 0$ holds for all t, $0 \leq t \leq T$.

In Sections V and VI the four market integration measures are estimated. Measure 1 and Measure 2 record the overall integration between spot and futures markets by reflecting the trades of all market participants. Measure 3 and Measure 4 provide additional insights by catching only the market integration resulting from arbitrage trading. Based on the different measures, we will first test whether spot-futures' market integration depends on the trading system, then examine whether any discrepancy in market integration results from differences in arbitrage trading, and finally determine whether the results differ for active and inactive trading periods.

III. MARKET MICROSTRUCTURE

This study is based on data of the German stock index DAX and DAX futures. The index consists of 30 major German stocks, selected with respect to high market capitalization, high turnover, and early availability of opening prices. The DAX is a capital-weighted performance index which is adjusted for price changes due to subscription rights, stock splits and dividends. The adjustment for dividends is a specific feature of the DAX. It is obtained by reinvesting the total amount of dividend payments in the dividend-paying stock. Thus, if a dividend is paid, the number of shares in the index basket increases, while the total value of the portfolio underlying the DAX remains unchanged.[9] The stocks underlying the DAX index (DAX stocks) are the most liquid stocks traded in Germany, accounting for about 85% of total trading volume in all German stocks. They are floor traded at eight regional German stock exchanges as well as screen traded in the electronic IBIS system.[10] About 35% of the trading in DAX stocks is executed via the IBIS system and most of the remainder via the Frankfurt Stock Exchange, the largest of the regional exchanges. For the period used in this study (June 1995 to March 1996), the total turnover in DAX stocks was DM 1053.143 million at the Frankfurt Stock Exchange and DM 516.036 million in the IBIS system.

At the floor of the Frankfurt Stock Exchange, trading takes place between 10:30 a.m. and 1:30 p.m.[11] The traders can be divided into three groups. First, there are bank employees, trading on behalf of the bank or for a customer. Second, there are floor brokers who trade for their own benefit

[9] See Grünbichler and Callahan (1994) for a more detailed description of the dividend adjustment procedure.

[10] In November 1997 the IBIS system was superseded by the new electronic trading system Xetra. Xetra is an extension of IBIS, which will finally allow for electronic trading of most German stocks and bonds.

[11] See Bühler and Kempf (1995) for a brief description of the FLOOR trading system in Frankfurt and the DAX futures trading system.

and who are permitted to buy and sell any stock, although they generally specialize in certain market segments. Finally, there are official brokers, appointed by the government, who are legally restricted in trading. Their function in the market is to provide a continuous auction in the most liquid stocks (including all DAX stocks) as well as a noon auction in all stocks. The minimum transaction size in a continuous auction is 50 shares, while odd lots are executed at the noon auction. Official brokers run the limit order book. The order book is not open to the public but official brokers announce the best bid and ask prices and the quoted quantities. Thus, they act as typical auctioneers and are paid by a fixed brokerage fee of the trade volume (0.06%). Once a trade is carried out, it is immediately submitted to the settlement system and processed to the DWZ (Deutsche Wertpapier-daten-Zentrale), the German securities clearing service. Transactions are settled within two working days.

IBIS is a fully computerized trading system[12] with trading hours ranging from 8:30 a.m. to 5:00 p.m. All members of German stock exchanges may participate in the IBIS system. IBIS is an anonymous system, where trading takes place via computer terminals in continuous auctions. The order book is open, but participants cannot identify the trader submitting the order. IBIS was designed to serve primarily the needs of institutional investors. Therefore, the minimum transaction size (100 shares) is larger than on the floor. Once a transaction on IBIS is carried out, trade data are automatically transmitted to the German securities clearing service DWZ. Transactions are settled within two working days.

DAX futures are screen traded at the German Futures and Options Exchange (DTB). The DTB runs a fully automated trading system. The trading period ranges from 8:30 a.m. to 5:00 p.m. Index futures are traded in a continuous auction market where market participants trade for their own benefit or on the behalf of customers. Each trader submits orders anonymously via a trading terminal to the exchange where the orders are automatically matched. Orders which are not carried out immediately are put into an open order book. The minimum transaction size is one futures contract which amounts to DM 100 per index point.

IV. DATA

The spot data set consists of all DAX levels reported from the Frankfurt Stock Exchange and from the IBIS system over the sample period 16/6/1995 to 14/3/1996. This is the time interval between the maturity dates of

[12] Schmidt and Iversen (1992) give a brief description of the IBIS system. A more detailed description can be found in Deutsche Börse AG (1993).

the June 95 and the March 96 futures contracts.[13] Both FLOOR-DAX and IBIS-DAX are computed once a minute from the most recent transaction prices of the constituent stocks.

The futures data set contains all time-stamped bid and ask quotes for the futures contract with the shortest time to maturity. The futures midquote is calculated as the arithmetic mean of bid and ask futures quotes, and the effective midquote is assigned to each DAX value. Thus, we construct a futures time series with minute-by-minute observations.

For each trading day we concentrate on the time of day at which all three markets are open (10:30 a.m. to 1:30 p.m.). To avoid possible biases at the beginning of a trading session, observations within the first 15 min after the opening of the Frankfurt Stock Exchange are excluded from the data set. In summary, for each of 184 trading days and each of the three markets, minute-by-minute observations within the time window 10:45 a.m. to 1:30 p.m. are used.

To identify periods with different degrees of trading activity, we calculate the total number of trades in the futures market for each of the 184 trading days. These numbers range from 656 to 5448 trades with a median of 2846. All days with a total number of trades less than the 25% quantile (2392 trades) are classified as periods of low trading activity. Days with higher total number of trades than the 75% quantile (3443 trades) are considered as periods of high market activity.[14]

The mispricing $X(t, T)$ is defined as the difference between a spot-equivalent portfolio value $F(t, T)$ and the index value $S(t)$. Index values are directly available from the data set. To obtain spot-equivalent portfolio values, all futures midquotes $f(t, T)$ are corrected for the net holding costs of the corresponding index portfolio using the following formula:

$$F(t, T) \equiv f(t, T) \cdot e^{-r(t,T)\cdot(T-t)}. \tag{2}$$

In (2), $r(t, T)$ denotes the annual riskless rate of return for an investment from time t to T, and $T - t$ is the time to maturity of the futures contract, measured in years. For the calculation of the spot-equivalent futures price in (2), daily money market rates with maturities of one day, one month and three months are used. Matching maturities are achieved by linear interpolation of the nearest available rates. Dividends have no influence

[13] The Floor-DAX data were provided by the Deutsche Börse AG. The IBIS-DAX, the futures data, and the interest rate data were supplied by the German Finance Database, Karlsruhe/Mannheim.

[14] As an alternative, the one-minute return volatility within a day could be used to identify active and inactive periods. Volatility and number of trades show a correlation of 0.72 and lead to a very similar classification of trading days, however.

on the net holding costs in (2) since the DAX index is corrected for dividend payments.[15]

Finally, we construct the continuously compounded one-minute returns in both markets as well as the ordinary and logarithmic mispricing series:

$$\Delta S^*(t) \equiv \ln[S(t)] - \ln[S(t-1)] \tag{3}$$

$$\Delta F^*(t, T) \equiv \ln[F(t, T)] - \ln[F(t-1, T)] \tag{4}$$

$$X(t, T) \equiv F(t, T) - S(t) \tag{5}$$

$$X^*(t, T) \equiv \ln[F(t, T)] - \ln[S(t)]. \tag{6}$$

Overnight returns are discarded; i.e., each observation in the return series refers to a one-minute return. Given the data, the highest possible observation frequency is one minute. This frequency is used in the study since longer time periods may not be suitable to capture the impact of arbitrage trading on market integration. As a sensitivity check we repeated our calculations for different return intervals.

It is important to note that both FLOOR-DAX and IBIS-DAX are computed from the most recent *transaction* prices of the constituent stocks. Since the constituent stocks are not traded simultaneously, the reported index value will not in general equal the true equilibrium price. Infrequent trading introduces a spurious positive autocorrelation into observed index returns, caused by delayed trading of some of the component stocks. As Miller *et al.* (1994) show, infrequent trading may lead to a mean reversion of the mispricing and therefore influence integration Measure 4.

Table I provides the autocorrelations ($\hat{\rho}$) of FLOOR-DAX and IBIS-DAX returns with lags of up to ten minutes. The first few autocorrelations are significantly positive (up to 0.4). This result is a strong indication of stale prices in the index, since the autocorrelation in futures returns, which are not spurious due to infrequent trading, is close to zero for all lags.[16]

The problem of stale prices could be remedied when midquote based indices were used instead of transaction price based indices. As such data are not available for the DAX, one has to correct observed index values for staleness in order to obtain a proxy of the unobservable true index value.

We follow the approach to Jokivuolle (1995), who suggests a simple model of the relation between true and observed index values. In this model the log of the true index can be identified as the permanent component

[15] See Bühler and Kempf (1995) for a derivation of the no-arbitrage relation between DAX and DAX futures.

[16] There is no infrequent trading effect in index futures, as the future trades as a single instrument. None of the first 20 autocorrelation coefficients differ from zero at a 1% significance level. The largest of these coefficients takes a value of 0.03.

TABLE I
Autocorrelations of One Minute DAX Returns for Several Lags

Lag	No. obs.	FLOOR-DAX $\hat{\rho}$	FLOOR-DAX Stdv.	FLOOR-DAX t-value	IBIS-DAX $\hat{\rho}$	IBIS-DAX Stdv.	IBIS-DAX t-value
1	30176	0.391**	0.011	35.87	0.387**	0.014	27.64
2	29992	0.281**	0.015	18.49	0.238**	0.009	25.06
3	29808	0.221**	0.009	25.46	0.173**	0.009	18.43
4	29624	0.157**	0.008	19.81	0.124**	0.008	17.71
5	29440	0.118**	0.008	15.51	0.092**	0.009	10.41
6	29256	0.079**	0.007	10.64	0.057**	0.010	5.76
7	29072	0.049**	0.007	6.63	0.026*	0.012	2.09
8	28888	0.029**	0.007	3.96	0.001	0.013	0.06
9	28704	0.017*	0.008	2.22	−0.013	0.015	−0.89
10	28520	0.012	0.007	1.77	−0.006	0.009	−0.68

Note. This table shows the estimated return autocorrelations ($\hat{\rho}$), their standard deviations (Stdv.), and the t-values for different lags. The continuously compounded returns are calculated using (3) from index levels based on last transaction prices from the Frankfurt floor (FLOOR-DAX) and the IBIS system (IBIS-DAX). Available observations between 16/6/1995 and 14/3/1996 are used. The calculations do not use lagged observations, which belong to a different trading day. This explains the different numbers of observations (No. obs.) referring to different time lags. The standard deviations are based on the method of Diebold (1988) to correct for ARCH-effects.

* Significant at the 5% level.
** Significant at the 1% level.

in the Beveridge–Nelson (1981) decomposition of the observed logarithmic index series. In order to perform the decomposition, observed returns have to be fitted to a time-series model.[17] AR(4) models are adapted to both the FLOOR-DAX and the IBIS-DAX return series. The number of lags results from the Information Criterion of Schwarz (1978). As a result of the correction procedure we obtain a proxy of the true index level. It reflects the (unobservable) DAX index based on transaction prices of simultaneously traded stocks. Thus, we have valid index and futures prices for each minute. Significant serial correlation remains neither in the FLOOR-DAX nor in the IBIS-DAX returns. In the remaining part of the paper we refer to true index values whenever index levels or index returns are mentioned.

V. MAIN RESULTS

The first measure of market integration suggested in Section II is the correlation coefficient between the contemporaneous returns in both markets. Table II reports the simultaneous and lagged correlations between

[17] The calculations were carried out as suggested by Newbold (1990).

TABLE II
Results for Measure 1 Based on One Minute Return Intervals

Lag	No. obs.	FLOOR			IBIS			FLOOR-IBIS		
		$\hat{\rho}_F$	Stdv.	*t*-value	$\hat{\rho}_I$	Stdv.	*t*-value	$\hat{\rho}_F - \hat{\rho}_I$	Stdv.	*t*-value
−5	28704	0.016*	0.008	2.12	0.026**	0.008	3.35	−0.010	0.011	−0.91
−4	28888	0.024**	0.008	3.06	0.025**	0.008	3.07	−0.001	0.011	−0.09
−3	29072	0.021**	0.007	2.82	0.026**	0.008	3.15	−0.005	0.011	−0.45
−2	29256	0.047**	0.008	6.05	0.049**	0.008	5.56	−0.002	0.011	−0.18
−1	29440	0.059**	0.008	7.56	0.066**	0.009	7.02	−0.007	0.012	−0.58
0	29624	**0.109****	0.008	13.18	**0.276****	0.012	22.82	**−0.167****	0.014	−11.93
1	29440	0.290**	0.011	26.60	0.375**	0.013	29.07	−0.085**	0.017	−5.01
2	29256	0.222**	0.009	25.26	0.113**	0.009	12.53	0.109**	0.013	8.38
3	29072	0.113**	0.008	14.14	0.033**	0.008	4.32	0.080**	0.011	4.69
4	28888	0.042**	0.008	5.52	0.010	0.008	1.26	0.052**	0.011	4.73
5	28704	0.022**	0.007	2.91	−0.001	0.008	2.19	0.023*	0.011	2.09

Note. This table shows lagged and contemporaneous correlations between DAX and futures returns for a one minute return interval. Values for both FLOOR-DAX ($\hat{\rho}_F$) and IBIS-DAX ($\hat{\rho}_I$) are presented together with the standard deviations (Stdv.) and the *t*-values. Positive lags refer to a lead of the futures market while negative ones refer to a lead of the spot market. Available observations between 16/6/1995 and 14/3/1996 are used. The calculations do not use lagged observations which belong to a different trading day. This explains the different numbers of observations (No. obs.) referring to different time lags. The standard deviations are based on the method of Diebold (1988) to correct for ARCH-effects. The main results are shown in columns 9 to 11 where differences between FLOOR-DAX correlations and IBIS-DAX correlations are provided.

* Significant at the 5% level.

** Significant at the 1% level.

futures and spot returns for both FLOOR-DAX ($\hat{\rho}_F$) and IBIS-DAX ($\hat{\rho}_I$) based on one-minute return intervals. The numbers in the first column refer to the time period (in minutes) by which spot returns lag futures returns. Non-zero coefficients for positive lags indicate a lead of the futures market while for negative lags they express a lead of the spot market.

Integration Measure 1 is given for IBIS and FLOOR data in the row corresponding to lag 0, which reflects the correlation between contemporaneous returns. For both markets, the measures are significantly above zero but smaller than one. As is to be expected, there is market integration, although it is not perfect. The IBIS correlation of 0.276 lies markedly above the FLOOR correlation of 0.109. The difference between the correlation coefficients shown in column 9 of Table II is highly significant, as can be seen from the corresponding *t*-value of −11.93. This finding suggests that screen trading leads to higher market integration than floor trading.

The results for the lagged correlations give some hint about the information flow between spot and futures markets. For both IBIS and FLOOR, the highest correlation coefficient is obtained between spot returns and futures returns of the previous period (lag 1). This indicates a lead of the futures market; i.e., new information is incorporated more quickly in the futures market than in the spot market. With only a delay of one or two minutes, prices in the spot market adjust to this information. Similar results

TABLE III
Results for Measure 1 Based on Different Return Intervals

Return interval (in minutes)	No. obs.	FLOOR			IBIS			FLOOR-IBIS		
		$\hat{\rho}_F$	Stdv.	*t*-value	$\hat{\rho}_I$	Stdv.	*t*-value	$\hat{\rho}_F - \hat{\rho}_I$	Stdv.	*t*-value
1	29624	0.109**	0.008	13.18	0.276**	0.012	22.82	−0.167**	0.014	−11.93
2	14720	0.277**	0.015	19.10	0.479**	0.017	27.85	−0.202**	0.022	−9.18
3	9752	0.406**	0.018	22.68	0.611**	0.023	26.11	−0.205**	0.029	−7.07
4	7360	0.523**	0.026	20.11	0.685**	0.028	24.46	−0.162**	0.038	−4.26
5	5888	0.580**	0.029	20.00	0.744**	0.035	21.26	−0.164**	0.045	−3.64
6	4784	0.647**	0.029	22.23	0.772**	0.033	23.39	−0.125**	0.044	−2.84
7	4232	0.692**	0.037	18.70	0.799**	0.039	20.49	−0.107*	0.054	−1.98
8	3680	0.736**	0.039	18.87	0.816**	0.039	20.92	−0.080	0.055	−1.45
9	3128	0.736**	0.036	20.56	0.831**	0.038	21.87	−0.105*	0.052	−2.02
10	2944	0.752**	0.043	17.49	0.842**	0.045	18.71	−0.090	0.062	−1.45
20	1472	0.841**	0.067	12.55	0.901**	0.073	12.34	−0.060	0.102	−0.59

Note. This table shows contemporaneous correlations between DAX and futures returns for several return intervals. Correlations for both FLOOR-DAX ($\hat{\rho}_F$) and IBIS-DAX ($\hat{\rho}_I$) are presented together with standard deviations (Stdv.) and *t*-values. Available observations (No. obs.) between 16/6/1995 and 14/3/1996 are used. The main results are shown in columns 9 to 11 where differences between FLOOR-DAX correlations and IBIS-DAX correlations are given.

* Significant at the 5% level.

** Significant at the 1% level.

are well documented in the literature for different indices and sample periods, as for example in Kawaller *et al.* (1987), Stoll and Whaley (1990), and Chan (1992).

Since strong lead–lag structures are observed for both pairs of markets, one would suspect that differences in contemporaneous return correlations are dependent on the chosen return interval. How differences in market integration depend on the time interval used to calculate returns is an important question. When investors judge the relevance of any difference in market integration, they will look at integration measures which correspond to their investment horizons. These time horizons may differ substantially among investors. Table III reports integration measures calculated over return intervals of up to 20 min.

The table shows that the correlation between spot and futures markets increases with the return interval. This is true for both IBIS- and FLOOR-DAX. Integration Measure 1 is higher for IBIS-DAX in all cases, although statistically significant differences can be observed just up to seven minutes. This suggests that there is stronger integration between the two screen trading markets, though considerable differences due to the trading system are obtained only for short time periods of a few minutes.

The second measure of market integration is the one proposed by Chen and Knez (1995). It measures the minimum squared distance between stochastic discount factors of two markets. An admissible stochastic discount factor is defined as a random variable d with finite variance, such that the price $\pi(p)$ of a portfolio with payoff p can be expressed as the expected value of its state-by-state discounted payoff:[18]

$$\pi(p) = E(p \cdot d). \tag{7}$$

If there are two sets of admissible stochastic discount factors D_{F} and D_{S} for the futures and spot markets, the integration measure g is defined as

$$g(D_{\mathrm{F}}, D_{\mathrm{S}}) \equiv \min_{d_{\mathrm{F}} \in D_{\mathrm{F}}, d_{\mathrm{S}} \in D_{\mathrm{S}}} E((d_{\mathrm{F}} - d_{\mathrm{S}})^2). \tag{8}$$

The smaller this measure is, the more integrated the two markets are. In economic terms the Chen–Knez measure expresses how compatible the pricing rules in the two markets are with each other.

The implementation of the integration measure follows the first algorithm proposed by Chen and Knez (1995). We calculate series of one-minute gross returns $(1 + \Delta F^*, 1 + \Delta S^*)$ for futures and spot markets, which serve as the column vectors X_{F} and X_{S} of basis payoffs associated with a price of 1. To start the algorithm, one needs to know one discount factor. In our application, which is a special case with only one asset traded in each market,[19] initial values d_{S}^* and d_{F}^* are obtained as

$$d_{\mathrm{S}}^* = X_{\mathrm{S}} \left(\frac{1}{N} X_{\mathrm{S}}' X_{\mathrm{S}} \right)^{-1} \tag{9}$$

$$d_{\mathrm{F}}^* = X_{\mathrm{F}} \left(\frac{1}{N} X_{\mathrm{F}}' X_{\mathrm{F}} \right)^{-1}, \tag{10}$$

where N is the number of entries in X_{S} and X_{F}. It can be seen that d_{S}^* and d_{F}^* solve the sample counterpart of (7). Once the element d_{F}^* of D_{F} is available, the minimum squared distance between d_{F}^* and the set D_{S} is calculated as[20]

$$g(d_{\mathrm{F}}^*, D_{\mathrm{S}}) = \left(\frac{1}{N} X_{\mathrm{S}}' d_{\mathrm{F}}^* - 1 \right) \left(\frac{1}{N} X_{\mathrm{F}}' X_{\mathrm{F}} \right)^{-1} \left(\frac{1}{N} X_{\mathrm{S}}' d_{\mathrm{F}}^* - 1 \right). \tag{11}$$

[18] For an interpretation of stochastic discount factors see for example Brennan (1979).

[19] Of course there are many individual stocks trading in the spot markets, although we focus on the DAX index as a single instrument. The "asset" traded in the second market (futures market) is the spot equivalent portfolio of futures and bonds.

[20] Alternatively we could start the algorithm with $d_{\mathrm{S}}^* \in D_{\mathrm{S}}$ and minimize $g(d_{\mathrm{S}}^*, D_{\mathrm{F}})$.

TABLE IV
Results for Measure 2

No. obs.	FLOOR			IBIS			FLOOR-IBIS		
	$\hat{g}_F 10^{-12}$	Stdv.	t-value	$\hat{g}_I 10^{-12}$	Stdv.	t-value	$(\hat{g}_F - \hat{g}_I)10^{-12}$	Stdv.	t-value
29624	2.519	10.599	0.20	1.566	8.506	0.18	0.954	13.590	0.07

Note. The table shows the Chen–Knez (1995) measure of market integration between DAX and futures. Measures for both FLOOR-DAX ($\hat{g}_F$) and IBIS-DAX ($\hat{g}_I$) are displayed together with the standard deviations (Stdv.) and the t-values. Available observations (No. obs.) between 16/6/1995 and 14/3/1996 are used. Standard errors are calculated from the asymptotic distribution derived by Hansen *et al.* (1995). The main results are shown in columns 8 to 10. Column 8 reports differences in the Chen–Knez measure for floor and screen trading systems.

* Significant at the 5% level.

** Significant at the 1% level.

The element of D_S which leads to the minimum distance in (11) is denoted by d_S^{**}. It takes the value

$$d_S^{**} = d_F^* - X_S\left(\frac{1}{N}X_S'X_S\right)^{-1}\left(\frac{1}{N}X_S'd_F^* - 1\right). \tag{12}$$

Given the stochastic discount factor d_S^{**} for the spot market, the whole procedure is reversed and the minimum squared distance between d_S^{**} and D_F is obtained. Chen and Knez (1995) suggest iterating this process until the changes in the integration measure are negligible.[21]

The main question of this study is to see whether the integration measures are different for FLOOR-DAX and IBIS-DAX. This requires some indication about the sampling variation of integration Measure 2. Unfortunately, such statistical inferences have not yet been developed. However, Hansen *et al.* (1995) provide the asymptotic distribution of the minimum squared distance between a given discount factor and the set of all admissible discount factors for a market. This refers to the first step of the algorithm of Chen and Knez (1995), where the distance between d_F^* and D_S is minimized. In our application the algorithm converged almost directly after the first step; i.e., any further iterations had almost no effect on the estimated measures.[22] Therefore, we apply the standard errors of Hansen *et al.* (1995). As a check, we additionally constructed standard errors from repeated calculations of the integration measures based on bootstrapped gross returns. The resulting standard errors are very close to the asymptotic ones.

Table IV shows the resulting integration measures between spot and

[21] The above procedure describes the calculation of the weak integration measure of Chen and Knez. They also propose a strong measure which restricts the sets of admissible stochastic discount factors to nonnegative ones. In the present application all elements of the discount factors turned out to be positive, thus the weak and strong measures coincide.

[22] After the first iteration, the measures did not change by more than 10^{-17} for the next 50 iterations.

futures markets for both the FLOOR-DAX and the IBIS-DAX. As column 8 indicates, the integration measure for the IBIS-DAX takes a smaller value than the corresponding one for the FLOOR-DAX. However, as the measures are very small compared to their sampling variation, no statistically significant difference in integration is observed. For both markets, the measure indicates almost perfect integration. The same result holds for a return interval of 5 min. Thus, in contrast to Measure 1, the Chen–Knez measure does not support the hypothesis that screen trading leads to higher market integration than floor trading.

A possible explanation of this finding is that Measure 2 is not directly related to observed prices or returns. Instead, it selects from two large sets of admissible stochastic discount factors those elements which are closest. It seems plausible that for instruments as similar as DAX and DAX futures some very similar pricing rules (and discount factors) exist, which are consistent with the prices in both markets.

It is interesting to note that a focus on the specific discount factors d_F^* and d_S^* from (9) and (10), which are directly related to the gross returns, leads to statistically significant differences on a one percent significance level. The IBIS-DAX discount factor is closer to the DAX futures discount factor than the corresponding one of the FLOOR-DAX. This supports the hypothesis that screen trading is superior to floor trading. In this respect the results are consistent with those for Measure 1.

Measure 3 and Measure 4 are applied to investigate whether the differences between IBIS and FLOOR market integration can be attributed to the trading of arbitrageurs. As our third measure, the absolute mispricing is used, which determines the size of arbitrage opportunities. From all mispricing observations, the mean absolute mispricing for FLOOR and IBIS data is estimated.

Table V summarizes the results. Overall, the mean absolute mispricing is smaller than two index points, which is less than 0.1% of the index level. In the floor market the absolute mispricing is about a quarter of an index point higher than in the screen market. This difference between the estimates for either pair of markets is statistically different from zero at 5% level. Thus, the screen trading market offers less potential arbitrage profits than the floor trading market.[23] This result is not sensitive to the observation

[23] The absolute mispricing measures possible arbitrage profits only in the absence of transaction costs and other market frictions. There are no short sales restrictions and very small transaction costs in DAX futures. However, there are notable transaction costs and short sale restrictions in the spot market, but these occur in the floor trading system and in the IBIS system. Short sales restrictions might explain why for both pairs of markets mispricing is positive in only 42% of all cases. For these cases the average mispricing is 1.22 (IBIS) and 1.42 (FLOOR) index points. Even when the analysis is confined to positive mispricing, which cannot be attributed to short sales restrictions, the difference between FLOOR-DAX and IBIS-DAX mispricing stays about the same as for the whole sample.

TABLE V
Results for Measure 3

No. obs.	FLOOR		IBIS		FLOOR-IBIS		
	$\lvert X_F \rvert$	Stdv.	$\lvert X_I \rvert$	Stdv.	$\lvert X_F \rvert - \lvert X_I \rvert$	Stdv.	t-value
29808	1.70	0.078	1.46	0.064	0.24*	0.101	2.38

Note. This table shows the average absolute mispricing between DAX and DAX futures in index points. The (signed) mispricing is defined as $X(t, T) \equiv F(t, T) - S(t)$. The average is calculated over all available observations (No. obs.) for the period 16/6/1995–14/3/1996. Results for both FLOOR-DAX ($\lvert X_F \rvert$) and IBIS-DAX ($\lvert X_I \rvert$) are displayed. Standard deviations (Stdv.) are calculated by the method of Newey and West (1987) with 120 lags, as the absolute mispricing shows a strong positive autocorrelation. The main results are shown in columns 6 to 8. Column 6 reports differences in the integration measure for floor and screen trading systems.

* Significant at the 5% level.

** Significant at the 1% level.

frequency. Again it suggests the superiority of screen trading with respect to market integration.

The last measure of market integration focuses on the dynamics of the mispricing series. It determines how quickly the mispricing reverts to zero. The integration measure μ is estimated from (1) as given in Section II. Model (1) was used by Dickey and Fuller (1979) to devise a test for the presence of a unit root in the time series, i.e., a test whether the parameter μ equals zero.[24] The unit root hypothesis is important, as one needs to reject it to apply standard inference techniques for the comparison between the $\hat{\mu}$-values of IBIS and FLOOR. Therefore, unit root tests for both mispricing series were carried out. Instead of the Dickey and Fuller (1979) procedure, the test of Phillips and Perron (1988) was used.[25] The latter test requires weaker assumptions concerning the error terms $u(t)$, allowing for heteroscedasticity and autocorrelation. Results are reported in Table VI. The mispricing series of both IBIS and FLOOR show highly significant test statistics, which suggest that both series are mean reverting.

A comparison between the integration measures $\hat{\mu}_F$ and $\hat{\mu}_I$ points into the same direction as Measure 3. The mean reversion parameter for the IBIS mispricing series takes a higher value than the corresponding one for the FLOOR. The two values are significantly different at a five percent level. Therefore, the higher degree of market integration between screen

[24] If the parameter μ were equal to zero the prices could move arbitrarily far apart from each other without being forced to come closer together again. This is hardly compatible with any economic notion of market integration.

[25] Critical values for both tests can be found in standard Dickey–Fuller tables, for instance in Banerjee *et al.* (1993).

TABLE VI
Results for Measure 4

	FLOOR			IBIS			FLOOR-IBIS		
No. obs.	$\hat{\mu}_F$	Stdv.	Phillips–Perron test statistic	$\hat{\mu}_I$	Stdv.	Phillips–Perron test statistic	$\hat{\mu}_F - \hat{\mu}_I$	Stdv.	*t*-value
29624	0.073	0.004	−36.95**	0.085	0.004	−42.73**	−0.0122*	0.0061	−1.97

Note. This table shows the mean reversion coefficients of the mispricing processes for FLOOR ($\hat{\mu}_F$) and IBIS ($\hat{\mu}_I$) together with the standard deviation (Stdv.). The mean reversion parameters are estimated from (1) using all available observations (16/6/1995–14/3/1996). Phillips–Perron test statistics for the hypotheses $\mu_F = 0$ and $\mu_I = 0$ are also provided. Twenty lags are used in the test. The main results are shown in columns 8 to 10. Column 8 reports differences in the integration measure for floor and screen trading system.
* Significant at the 5% level.
** Significant at the 1% level.

trading markets as compared with floor trading markets can—at least to some degree—be accounted to increased arbitrage trading.[26]

VI. RESULTS FOR ACTIVE AND INACTIVE TRADING PERIODS

As earlier empirical studies (Pirrong, 1996; Franke and Hess, 1997) report that the relative merits of both systems depend on the trading activity, we provide separate results for active and inactive periods. Table VII shows

TABLE VII
Integration Measures for Periods of High and Low Market Activity

	All trading days (Floor − IBIS)			High activity (Floor − IBIS)			Low activity (Floor − IBIS)		
	Measure	Stdv.	*t*-value	Measure	Stdv.	*t*-value	Measure	Stdv.	*t*-value
Measure I $\hat{\rho}_F - \hat{\rho}_I$	−0.167**	0.014	−11.93	−0.207**	0.029	−7.14	−0.115**	0.024	−4.79
Measure II $(\hat{g}_F - \hat{g}_I)10^{-12}$	0.954	13.590	0.07	3.992	53.990	0.07	−0.3816	13.416	−0.03
Measure III $\lvert X_F\rvert - \lvert X_I\rvert$	0.24*	0.101	2.38	0.34	0.211	1.61	0.23	0.220	1.05
Measure IV $\hat{\mu}_F - \hat{\mu}_I$	−0.0122*	0.0061	−1.97	−0.0168	0.0154	−1.09	−0.0015	0.0062	0.24

Note. This table shows the differences between integration measures for the floor and IBIS markets together with their standard deviations (Srdv.) and *t*-values. The measures are calculated with data from all trading days between 16/6/1995 and 14/3/1996 (all trading days), the 46 days with the highest number of trades in the futures market (high activity) and the 46 days with the lowest number of trades in the futures market (low activity). The data frequency is one minute.
* Significant at the 5% level.
** Significant at the 1% level.

[26] For 5-min return intervals the integration measures are increased for both markets, but the difference ($\hat{\mu}_F - \hat{\mu}_I = -0.016$) is still about the same. For a 10-min frequency $\hat{\mu}_F - \hat{\mu}_I = 0.011$. None of these differences are statistically significant.

the differences between the FLOOR-DAX and IBIS-DAX integration measures for those periods. The "High Activity" period contains the 46 days with the highest number of trades in the futures markets. For the "Low Activity" period we used the 46 days with the lowest number of trades. Columns 2–4 repeat the results for the whole data set to facilitate a comparison.

Overall, the table provides no indication that the results are sensitive to the trading activity. Especially, we find no support for the hypothesis that floor trading is preferable in high trading periods. The difference in return correlations in favor of screen trading markets becomes even higher for the most active trading days. The Chen–Knez measure shows no significant difference in either case. As in Measure 1, the differences in Measures 3 and 4 are larger (in absolute value) for high activity periods than for low activity ones, still indicating a higher degree of market integration for the IBIS-DAX. Although the differences lose their statistical significance, this is probably an effect of the lower number of observations (a quarter of the original sample), which reduces the power of the tests. Taking all into account, we find no support for the hypothesis that a floor market leads to a higher degree of market integration in periods of high trading activity than a computerized market. On the contrary, the screen market even improves relative to the floor market in these periods. Overall, the IBIS electronic trading system seems to be quite robust to changes in the trading intensity.

VII. CONCLUSION

One of the most controversial questions concerning the design of exchanges is whether a screen trading system or a floor trading system is preferable. The current paper contributes to this discussion by looking at a new criterion, the ability to ensure a high degree of market integration between the underlying security and its derivative.

The main result of our empirical study is that markets are more closely integrated when both instruments are screen traded. This observed discrepancy in market integration can partly be attributed to differences in arbitrage trading. In addition, we find that the trading system leads to differences in market integration but only for short time intervals. This is consistent with a delayed information flow and order execution lags in the floor market, which cease to be observable for intervals of more than a few minutes. Our last result is that for periods of high and low trading activity the relative performance of screen and floor trading systems in respect to market integration hardly differs from the overall results.

Finally we have come to the conclusion that in order to achieve a high degree of integration between spot and futures markets, it seems more advisable to trade both instruments on a screen system, than to have one floor traded and one screen traded.

REFERENCES

Banerjee, A. J., Dolado, J., Galbraith, J. W., and Hendry, D. F. (1993). "Co-integration, Error-Correction and the Econometric Analysis of Non-stationary Data," Oxford Univ. Press, Oxford.

Beneviste, L., Marcus, A., and Wilhelm, W. (1992). What's special about the specialist? *J. Finan. Econ.* **32,** 61–86.

Beveridge, S., and Nelson, C. R. (1981). A new approach to decomposition of economic time series into permanent and transitory components with particular attention to measurement of the business cycle, *J. Monet. Econ.* **7,** 151–174.

Breedon, F. J., and Holland, A. (1988) "Electronic versus Open Outcry Markets: The Case of the Bund Futures Contract." Discussion Paper No. 76, Bank of England.

Brennan, M. J. (1979). The pricing of contingent claims in discrete time models, *J. Finance* **34,** 53–68.

Brennan, M. J., and Schwartz, E. S. (1990) Arbitrage in stock index futures, *J. Business* **63,** 7–31.

Bühler, W., and Kempf, A. (1995). DAX index futures: Mispricing and arbitrage in German markets, *J. Futures Markets* **15,** 833–859.

Chan, K. (1992). A further analysis of the lead-lag relationship between the cash market and stock index futures market, *Rev. Finan. Stud.* **5,** 123–152.

Chen, Z., and Knez, P. J. (1995). Measurement of market integration and arbitrage, *Rev. Finan. Stud.* **8,** 287–325.

Copeland, T. E., and Galai, D. (1983). Information effects on the bid-ask spread, *J. Finance* **38,** 1457–1469.

Dickey, D. A., and Fuller, W. A. (1979). Distribution of the estimators of autoregressive time series with a unit root, *J. Amer. Statist. Assoc.* **74,** 427–431.

Diebold, F. X. (1988). "Empirical Modeling of Exchange Rate Dynamics," Springer-Verlag, Berlin.

Domowitz, I. (1990). Mechanics of automated trade execution systems, *J. Finan. Intermed.* **1,** 167–194.

Domowitz, I. (1993). A taxonomy of automated trade execution systems, *J. Int. Money Finance* **12,** 607–631.

Deutsche Börse AG (1993). Integrated Stock Exchange and Information System IBIS, Frankfurt.

Engle, R. F., and Granger, C. J. W. (1987). Cointegration and error correction: Representation, estimation and testing, *Econometrica* **55,** 251–276.

Franke, G., and Hess, D. (1997). "Information Diffusion in Electronic and Floor Trading," Discussion Paper, University of Konstanz.

Fremault Vila, A., and Sandmann, G. (1996). "Floor Trading Versus Electronic Screen Trading: An Empirical Analysis of Market Liquidity in the Nikkei Stock Index Futures Markets," Discussion Paper, London School of Economics.

Garbade, K. D., and Silber W. L. (1983). Price movement and price discovery in futures and cash markets, *Rev. Econ. Statist.* **65,** 289–297.

Grünbichler, A., and Callahan, T. W. (1994). Stock index futures arbitrage in Germany: The behavior of DAX index futures prices, *Rev. Futures Markets* **13,** 661–686.

Grünbichler, A., Longstaff, F. A., and Schwartz, E. S. (1994). Electronic screen trading and the transmission of information: An empirical examination. *J. Finan. Intermed.* **3,** 166–187.

Hansen, L. P., Heaton, J., and Luttmer, E. (1995). Econometric evaluation of asset pricing models, *Rev. Finan. Stud.* **8,** 237–274.

Harris, L. P. (1990). ''Liquidity, Trading Rules, and Electronic Trading Systems,'' Monograph Series in Finance and Economics, Vol. 1990-4.

Holden, C. (1990). ''Intertemporal Arbitrage Trading: Theory and Empirical Tests,'' Discussion Paper #474, Indiana University.

Jokivuolle, E. (1995). Measuring true stock index value in the presence of infrequent trading, *J. Finan. Quant. Anal.* **30,** 455–464.

Kawaller, I. G., Koch, P. D., and Koch, T. W. (1987). The temporal price relationship between S&P500 futures and the S&P500 index, *J. Finance* **42,** 1309–1329.

Kofman, P., and Moser, J. (1996). ''Spreads, Information Flows and Transparency across Trading Systems,'' Discussion Paper, Monash University.

Kumar, P., and Seppi, D. J. (1994). Information and index arbitrage, *J. Business* **67,** 481–509.

Massimb, M. C., and Phelps, B. D. (1994). Electronic trading, market structure and liquidity, *Finan. Anal. J.* **50,** 39–50.

Miller, M. H., Muthuswamy, J., and Whaley, R. E. (1994). Mean reversion of Standard & Poor's 500 index basis changes: Arbitrage-induced or statistical illusion? *J. Finance* **49,** 479–513.

Newbold, P. (1990). Precise and efficient computation of the Beveridge–Nelson decomposition of economic time series, *J. Monet. Econ.* **26,** 453–457.

Newey, W., and West, K. (1987). A simple positive semi-definite, heteroscedasticity and autocorrelation consistent covariance matrix, *Econometrica* **55,** 703–708.

Phillips, P. C. B., and Perron, P. (1988). Testing for a unit root in time series regression, *Biometrica* **75,** 335–346.

Pirrong, G. (1996). Market liquidity and depth on computerized and open outcry trading systems: A comparison of DTB and LIFFE Bund contracts, *J. Futures Markets* **16,** 519–543.

Sandmann, G., and Fremault Vila, A. (1996). ''Stochastic Volatility, Error Correction and Dual Listing in Futures Markets,'' Discussion Paper, London School of Economics.

Sarkar, A., and Tozzi, M. (1998). Electronic trading on futures exchanges, *Federal Reserve Bank of New York, Current Issues in Economics And Finance* **4,** 1–5.

Schmidt, H., and Iversen, P. (1992). Automating German equity trading: Bid–ask spreads on competing systems, *J. Finan. Services Res.* **6,** 373–397.

Schwarz, G. (1978). Estimating the dimension of a model, *Ann. Statist.* **6,** 461–464.

Shyy, G., and Lee, J. H. (1995). Price transmission and information asymmetry in Bund futures markets: LIFFE vs. DTB, *J. Futures Markets* **15,** 87–99.

Stoll, H. R., and Whaley, R. E. (1990). The dynamics of stock index and stock index futures returns, *J. Finan. Quant. Anal.* **25,** 441–468.

Tuckman, B., and Vila, J-L. (1992). Arbitrage with holding costs: A utility-based approach, *J. Finance* **47,** 1283–1302.