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Electronic Screen Trading and the Transmission of Information: An Empirical Examination*

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We examine the lead–lag relation between intraday spot and futures prices for a stock index where the component stocks are floor traded while the futures contract is screen traded. We find that futures prices lead spot prices by nearly 20 min. This is much longer than in markets where both the index and index futures are floor traded. We show that this lead–lag relation is unlikely to be an artifact of differences in liquidity between the spot and futures markets. These results are consistent with the hypothesis that screen trading accelerates the price discovery process. *Journal of Economic Literature* Classification Numbers: F33, G15, G20, O31.

I. INTRODUCTION

One of the most important and controversial trends affecting many financial markets is the current movement away from traditional floor-trading markets toward electronic screen-trading markets. In a screen-trading market, participants enter quotes and orders into a computer net-

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work, which then automatically matches orders and confirms trades.[1] Despite ongoing opposition to screen trading, the April 1991 issue of *Futures* reports that 34% of the respondents to a recent survey expect the current open-outcry system for futures trading to be gone by 1999, and 68% expect 24-hour screen trading to be fully implemented before the end of the century.[2] Screen-trading markets are already in place in Australia, Austria, Canada, Finland, Germany, Japan, New Zealand, Sweden, Switzerland, and the United States.

The most controversial aspect of screen trading is that it eliminates the need for a trading floor. Advocates of screen trading argue that it reduces the costs of trading, which enhances the price discovery process. In contrast, critics of screen trading claim that by eliminating the economic role played by floor traders and/or specialists, the market provides less liquidity and immediacy. The relative benefits and costs of electronic screen trading continue to be a key issue facing policy makers, regulators, exchanges, and market participants.[3]

This paper uses a unique new data set to explore the issue of whether information is actually incorporated into prices more rapidly in a continuous screen-trading market than in a floor-trading market. This is done by examining the lead–lag relation between intraday returns on the German stock index (DAX), whose component stocks are all floor traded, and returns on the screen-traded DAX index futures.

A number of important results about screen trading emerge from this analysis. We find that the DAX index futures price consistently leads the DAX index by 15–20 min. This lead–lag relation is much longer and more unidirectional than in markets where both the index and the index futures are floor traded. This lead–lag relation cannot be entirely due to differences in liquidity, since the average time between trades in the futures market is only about 2 min less than the average time between trades for the typical firm in the DAX index. Although there may be other reasons for the long lead–lag relation between the futures and spot prices, these

[1] It is the automatic order-matching feature that differentiates electronic screen-trading markets from more traditional markets like NASDAQ in which computers assist traders by providing dealer-quote screens or functioning as electronic "bulletin boards." Examples of various types of electronic screen-trading systems are described in Amihud and Mendelson (1985), Cohen and Schwartz (1989), Domowitz (1989), Miller (1990), Domowitz (1990), Bollerslev and Domowitz (1991), Huang and Stoll (1991), Harris (1992), and Biais *et al.* (1992). Domowitz (1992) provides a valuable taxonomy of over 50 existing and planned automated market structures.

[2] Glosten (1991) develops a model of an electronic limit order book and argues that its immunity to competition makes its survival inevitable.

[3] Miller (1990) and Harris (1990) provide excellent discussions of the potential costs and benefits of electronic screen trading.

results appear consistent with the hypothesis that screen trading accelerates the price discovery process.

We also examine the lead–lag relation between squared DAX index futures and DAX index returns. This allows us to test whether the lead–lag relation differs when large returns are given more weight. We find that the lead–lag relation for squared returns is virtually the same as before. These results contrast with those of Chan *et al.* (1991), who find no evidence of a unidirectional lead–lag relation between squared futures and index returns when both are floor traded.

Finally, we compute French and Roll (1986) variance ratios to examine the hypothesis that screen-traded futures prices are less noisy than floor-traded spot prices. We find that the variance ratio for the DAX futures is much closer to 1 than that for the DAX index. This result is consistent with the notion that prices in screen-trading markets are less noisy signals of actual values than prices in floor-trading markets.

The remainder of this paper is organized as follows. Section II discusses electronic screen trading and its potential effects on the lead–lag relation between spot and futures prices. Section III describes the microstructure of the DAX spot and futures markets. Section IV describes the intraday data used in the empirical analysis. Section V presents the empirical results for the lead–lag relation between futures and index prices. Section VI examines the lead–lag relation between squared futures and index returns. Section VII reports the variance ratio tests. Section VIII summarizes the results and makes concluding remarks.

II. SCREEN TRADING AND THE LEAD-LAG RELATION

In studying how rapidly screen trading incorporates information into prices, the ideal situation would be to focus on a security that was simultaneously traded in a floor-trading market and a screen-trading market. A simple examination of the lead–lag relation between the two markets would provide direct evidence about the differences between the two types of market structures.[4]

Few, if any, securities are traded in both floor-trading and screen-trading markets. There are securities, however, for which this ideal situation is closely approximated. For example, there are securities that are floor traded in the spot market and screen traded in the futures market. Since the spot and futures prices are linked by the no-arbitrage relation,

[4] A number of recent papers have focused on the relation between market structure and security prices in other markets. For example, see Amihud and Mendelson (1987), Grossman and Miller (1988), Stoll and Whaley (1990b), Amihud *et al.* (1990), Bollerslev and Domowitz (1991), Madhavan (1992), and Fishman and Longstaff (1992).

the intraday lead–lag relation between floor-traded spot prices and screen-traded futures prices should also provide direct evidence about the speed at which information is incorporated into prices.

Of these cash market/futures market combinations, the most liquid and actively traded is the German stock index (DAX), which is floor traded at the Frankfurt Stock Exchange (FSE) and screen traded on the computerized German Futures and Options Exchange (DTB).[5] Accordingly, we focus on the lead–lag relation between the prices emerging from these two markets.

In this section, we review the reasons why there may be a lead–lag relation between stock index and stock index futures prices even when both are floor traded. We then consider the implications of the screen-trading literature for how the lead–lag relation may differ when index futures are screen traded instead of floor traded.

The Lead–Lag Relation

Absent market frictions and transaction costs, the no-arbitrage condition between spot and futures markets requires that intraday stock index and index futures prices move in lockstep.[6] With frictions, however, Stoll and Whaley (1990a) argue that there are several reasons why there may be a lead–lag relation between the futures and spot markets. For example, infrequent trading in the component stocks of the index may create a spurious lead–lag relation in the data. Similarly, bid–ask spreads may induce negative serial correlation into the spot price, which could also result in a spurious lead–lag relation. Stoll and Whaley (1990a) show that these two problems can be avoided by using an ARMA model to filter out the effects of infrequent trading and bid–ask spreads on the index returns.

Differences in liquidity between the spot and futures markets could also induce a lead–lag relation. For example, if the average time between trades for the component firms of the index is longer than the average time between trades for the futures contract, information will be impounded in futures prices more rapidly on average than in spot prices. This could induce a lead–lag relation between spot and futures prices. It is important to stress that it is the difference in the liquidity of the spot and futures markets that creates the lead–lag relation—the lead–lag relation is a function of the relative liquidity of the markets, rather than their absolute liquidity.

Black (1975), Anthony (1988), Stoll and Whaley (1990a), Stephan and

[5] Other floor-trading spot/screen-trading futures market combinations include the Swiss stock market and the SOFFEX as well as the Swedish stock market and the OM Sweden exchange. These markets either are too illiquid, or do not have transaction data available.

[6] This will only be strictly true if dividends and interest rates are not stochastic.

Whaley (1990), and Miller (1990) argue that market frictions such as transaction costs, capital requirements, and short-selling restrictions may make it optimal for some to trade in the derivatives market rather than the spot market. Furthermore, Grossman and Miller (1988) and Miller (1990) show that futures markets may provide more immediacy to traders than does the spot market. An important implication is that informed traders may find that they can act on their private information more rapidly, and at a lower cost, in the futures market than in the spot market. This would result in a lead–lag relation between futures and spot prices since new information would appear first in the futures market and then be transmitted to the spot market.

Subrahmanyam (1991) and Chan (1992) also show that the adverse-selection costs faced by discretionary liquidity traders may be minimized by trading in the futures market rather than the spot market. This result, in conjunction with the implications of Kyle (1985) and Admati and Pfleiderer (1988), in which informed traders tend to use the camouflage provided by liquidity traders, also suggests that informed traders may choose the futures market rather than the spot market. Again this implies that the transmission of information may be from the futures market to the spot market.

In some situations, however, informed traders may choose to trade in the spot market rather than in the futures market. For example, Subrahmanyam (1991) and Chan (1992) show that if an informed trader has firm-specific information, it may be optimal to trade the shares of the firm directly rather than trading the index futures. Thus, for some types of information, the transmission of information may run from the spot to the futures market. As discussed by Chan *et al.* (1991), this raises the possibility of a bidirectional lead–lag relation in the data.

Screen Trading and the Transmission of Information

There are several ways in which electronic screen trading might affect the lead–lag relation between futures and spot prices. First, Harris (1990) argues that electronic trading lowers the fixed costs of running an exchange. In a competitive environment, this could translate into lower trading costs for market participants. If trading costs are lower in an electronic screen-trading futures market than in a floor-trading futures market, informed traders may find it possible to trade on the basis of less-significant pieces of information. The effect of this would be to accelerate the price discovery process in the futures market and lengthen the lead between futures and spot prices.

A second feature of screen trading is that it reduces the time required to physically process an order, route it to the market, and execute the trade. For example, Grossman (1990) states that "Computerized trading has considerably increased the efficiency of executing portfolio trading strategies by speeding up the process of information collection, demand execution (analysis) and order execution. On a real time basis, prices can be collected, trading instructions generated and orders communicated." This aspect of electronic screen trading should also lengthen the lead between futures and spot prices.

A third property of screen trading is that price information is captured and disseminated more rapidly. The reason for this is simply that orders and trades are already in the information system in a screen-trading market. In contrast, price information must be entered into the reporting system in a floor-trading market. Hasbrouck and Sosebee (1992) present evidence showing that the average reporting lag for trades on the NYSE is approximately 20 s and can be as long as 120 s.[7] By eliminating the reporting lag, price data from a screen-trading market should reflect the actual information in the market more rapidly. This feature should also lengthen the lead between futures and spot prices.

A fourth consideration is that screen-trading markets can convey more information to market participants than floor-trading markets. For example, as will be described in the next section, the screen-trading DAX index futures market allows each market participant to see all of the orders in the system.[8] By being able to condition trades on the entire limit order book, traders may be able to aggregate and interpret information more rapidly.[9] The effect of making the futures limit order book visible to all traders should be to lengthen the lead–lag relation between futures and spot prices.

Finally, screen-trading markets may not be as transparent as floor-trading markets in the sense that traders may not know with whom they are trading. In contrast, traders in a floor-trading market such as the S & P 500 index futures pit can observe the identities and trading activities of all other traders.[10] A number of studies have examined the effects of market transparency or trader anonymity on security prices. These studies include Miller (1990), Harris (1990), Roell (1990), Admati and Pfleiderer

[7] Most trades on the NYSE are reported by floor reporters. Floor reporters stand outside the specialist's post and report the trades as called out by the specialist or by the seller. Reporting a trade involves first manually filling out a card and then feeding the card into a reader near the specialist's post.

[8] Not all electronic screen-trading markets have this feature. See the discussion in Miller (1990), and Domowitz (1990).

[9] Glosten (1991) shows that an open electronic limit order book has the effect of maximizing the resilience of prices to severe adverse-selection problems.

[10] This information is not perfect, however, since traders may not know whether other traders are trading for their own accounts or filling customers orders (with the exception of traders standing on the top step who trade exclusively for customers). See the discussion about dual trading in Fishman and Longstaff (1992).

(1990), Madhavan (1992), Fishman and Longstaff (1992), Forster and George (1992), Grossman (1992), and Harris (1992). A common theme in many of these studies is that informed traders prefer to trade in markets that are opaque. The intuition for this is simply that anonymity allows informed traders to trade more aggressively without revealing their information to other traders. The anonymity provided by screen trading may induce informed traders to trade more frequently in the DAX index futures market than in the spot market, thereby increasing the lead–lag relation between futures and spot prices.

These features of electronic screen-trading all suggest that the lead–lag relation between DAX index futures and spot prices should be longer than in other markets in which both the stock index and stock index futures are floor traded. Factors which might tend to make the DAX index futures and spot market lead–lag relation shorter include the possibility that screen-trading markets may be less liquid. This possibility is discussed by Miller (1990) who argues that by eliminating the role of the floor trader, screen-trading markets have fewer traders who are willing to provide immediacy to the market by absorbing order imbalances. Similarly, Miller and Upton (1989) point out that by providing quotes in an electronic screen market, traders provide a free option to the market and risk having quotes "picked off" by traders with better information. If screen-trading markets are less liquid, the lead–lag relation between the futures and spot market may be reduced or disappear altogether.

In summary, the literature suggests that the effect of screen trading should be to lengthen the lead–lag relation between futures and spot prices. This effect, however, will be mitigated if screen trading reduces the liquidity of the stock index futures market relative to that of the underlying stock index market. Whether the lead–lag relation is increased or decreased by electronic screen trading is ultimately an empirical question.

III. MARKET MICROSTRUCTURE

In this section, we begin by describing the DAX index and the microstructure of the German spot market. We then give a brief description of the DAX index futures market and discuss how the electronic screen-trading system operates. Finally, we consider several institutional differences between German and U.S. markets.

The DAX Index and the Frankfurt Stock Exchange

The DAX index is a value-weighted index of the 30 largest firms traded on the Frankfurt Stock Exchange (FSE). This floor-trading stock exchange is the largest in Germany and second only to the London Stock Exchange in Europe. The FSE lists approximately 900 firms with an aggregate market capitalization of about $350 billion at the end of 1990. Table I shows that the 10 largest firms in the DAX represent nearly two-thirds of the total market capitalization of the index.

There are three basic types of traders at the FSE, a floor-trading market. The first type consists of commercial banks that handle all customer orders and are comparable to the commission house brokers at the NYSE. Banks are allowed to trade for their own accounts as well. Commissions are fixed at the FSE.

The second category of traders consists of the independents or freie makler. These traders are comparable to the independent floor brokers and registered competitive traders at the NYSE. Freie makler trade for their own accounts and compete with other traders in arranging trades. As in the U.S., freie makler do not have access to the limit order book.

The third type of traders is the auctioneers or kursmakler. Their role is similar to that of an NYSE specialist. The kursmakler are allowed to hold some inventory and have primary responsibility for the opening auction, which parallels the opening procedure at the NYSE. Similarly to a NYSE specialist, a kursmakler is only allowed to trade for his own account if necessary to clear submitted orders. Kursmakler are officially appointed by the FSE.

At the end of 1991, the FSE had 230 members, of which 139 were banks, 40 kursmakler, and 51 freie makler. This number is not fixed. The FSE is open Monday through Friday from 10:30 AM to 1:30 PM. The pattern of trading at the FSE parallels that at the NYSE. Orders are brought to the floor by the commercial banks who function as brokers. The orders are then presented to the kursmakler who enters the orders into the order book. Trades are executed when buy and sell orders are crossed by the kursmakler. If an order cannot be crossed, the kursmakler may choose to take the other side of the trade at some price. The freie makler compete with the kursmakler by providing quotes to brokers at which they are willing to cross customer orders. The German spot market is best described as a continuous auction.[11]

The FSE is a fairly liquid market. Table I shows that the average time until opening for the 30 stocks in the DAX index is 3.12 min. Table I also reports the average time between trades for the firms in the DAX index. On average, the firms in the DAX index trade every 4.94 min.

[11] The FSE also holds a midday auction for small investors with orders of less than 50 shares. Some of these orders can be prematched off the trading floor. All of these smaller orders, however, must be executed at the midday auction prices, see Pallman (1992).

TABLE I
AVERAGE TIME IN MINUTES UNTIL OPENING AND AVERAGE TIME IN MINUTES BETWEEN TRADES FOR DAX FUTURES, THE 10 LARGEST FIRMS IN THE DAX INDEX, AND THE DAX INDEX

Future/stocks	Average time to open	Average time between trades	Index weight
DAX futures	2.20	2.98	—
Allianz	4.89	6.10	10.50
Daimler	2.05	4.34	10.03
Siemens	2.17	3.31	9.83
Deutsche Bank	3.35	3.31	8.61
Bayer	2.20	3.54	5.74
RWE	2.76	5.49	5.09
VEBA	2.59	4.71	4.75
Hoechst	4.81	4.71	4.47
BASF	4.76	4.42	4.45
Dresdner Bank	3.25	6.77	3.79
Remaining 20 firms	4.56	6.38	34.74
All DAX index firms	3.12	4.94	100.00

Note. Index weight is the percentage weight that the component stock has in the capitalization-weighted DAX index at the end of the November 1990 to September 1991 sample period. Statistics for the 20 remaining firms and the DAX index are capitalization-weighted averages of the statistics for the individual firms. Two hundred four trading days in the sample.

The DAX Index Futures Market

DAX index futures are screen traded on the computerized German Futures and Option Exchange (DTB). The microstructure of this market is considerably different from that of more traditional floor-trading futures markets such as the Chicago Board of Trade (CBOT) and the Chicago Mercantile Exchange (MERC). Recall that at the CBOT and the MERC, trading takes place in an octagonal trading pit where traders negotiate face to face. There are two general types of floor traders in these markets. Floor brokers do not trade for their own account but bring customer orders to the floor. Professional traders serve as providers of liquidity and immediacy by trading for their own accounts.

In contrast, the DTB is a fully computerized exchange with an automatic order matching system. The center of the exchange is a network of Digital 9000 computers which is accessible by traders through directly linked terminals or through networked personal computers. Trading on the DTB first started on January 26, 1990 with options on 14 stocks. DAX index futures began trading at the DTB on November 19, 1990. Since that time, the DTB has become the third most active European futures exchange, with over 3.7 million futures contracts traded during 1991. The DTB is also the most active European stock options exchange, with over 9 million option contracts traded during 1991. The average daily trading volume for the DAX index futures was 5,046 contracts during 1991.

The DTB is a dealer market where virtually all participants serve as market makers who pay lower fees and transaction costs in exchange for providing liquidity to the market. The current costs of becoming a full clearing member of the exchange is approximately $200,000. Annual fees are roughly $60,000. Market makers get a 50% reduction on the annual fees. Currently, there are about 77 members of the exchange.

A typical trading day begins with a pretrading period from 9:30 to 10:30 A.M. during which dealers enter orders and quotes into the electronic order book. During this period, dealers are allowed to change and cancel their quotes and orders. Quotes are based on a minimum size of five contracts with limits on absolute spreads. During the pretrading period the system transmits price indications to the market. At the 10:30 AM opening, orders are automatically matched through a single call auction. The market makers are not allowed to change their order books during the opening. After the opening, contracts are traded on a continuous basis until the close of the market at 4:00 PM.

The trading screen provides a significant amount of information about current prices and trading activity. Traders can observe the current price of the component stocks in the DAX, the current level of the DAX, and the current inside quotes and orders for each futures contract. A subscreen provides complete information to the traders about all of the quotes and limit orders the system along with the associated size of the quote or order. Thus, all traders have equal access to the electronic limit order book. The trading system also has a screen that allows traders to see the last traded price, the size of the last trade, and the highest and lowest prices during the current trading day. In addition, traders have screens that allow them to review their own orders and quotes or to request quotes from market makers. Market makers are only obligated to provide quotes on request.

The trading screen does not identify the source of the price quotations or the limit orders in the system. Thus, market participants do not know with whom they are trading. This feature makes this market less transparent than the traditional open-outcry futures exchange where each trader can see the activities of all of the other traders in the pit. The system, however, does provide information to traders about aggregate market participation. Specifically, the trading screen gives the total number of traders who are currently receiving price information on their trading screens, as well as the total number of traders who are currently logged on to the trading screen. This information, along with the current inventory of limit orders and price quotes, gives the trader some sense of the depth and activity of the market.

All quotes and orders are prioritized by price. If two orders or quotes are at the same price, priority is given to the first entered into the system. Market orders have priority over limit orders. Once an order is executed by the system, the clearing process begins immediately by sending a confirmation notice directly to the screens of the parties involved in the trade.

Institutional Differences

Our primary objective is to examine the lead–lag relation between DAX index and index futures prices. To put our results in perspective, however, we compare them with those reported by other researchers for markets where both the index and the index futures are floor traded. In particular, we contrast our results with those reported in the literature for the S & P 500 index and index futures lead–lag relation. Accordingly, it is important to consider whether there are significant institutional differences between the German and U.S. markets that might affect the comparisons.

Although there are a number of ways in which German and U.S. markets differ, the earlier discussion suggests that the basic microstructure of the German cash market is largely comparable to that of the NYSE. The major difference between countries, of course, is that DAX index futures are screen traded at the DTB while S & P 500 index futures are floor traded at the MERC. There are several other potentially important institutional differences, however, which are described below.

One difference is that the kursmakler at the FSE have no affirmative obligation. In contrast, specialists at the NYSE have the obligation to trade in a way that guarantees price continuity, provides market depth, and minimizes order imbalances even if the specialist has to trade at adverse prices. This institutional difference could have some affect on the length of the lead–lag relation in the German markets. Note, however, that the kursmakler are active market participants and are involved in nearly 50% of the trades executed. We will examine the potential effects of this institutional difference by testing whether the lead–lag relation changes when greater weight is placed on larger price movements.

Order routing is a critical factor for trading strategies such as index arbitrage. The NYSE provides a computerized order-routing system called the Designated Order Turnaround (DOT) system. The major advantage of this system is that market orders involving baskets of stocks are routed directly to the specialist display book. The FSE has no direct counterpart to the DOT system. On the other hand, the DAX only includes 30 stocks. This makes it easier for market orders involving many of the component DAX stocks to be executed rapidly. Again, examining whether the lead–lag relation changes when greater weight is placed on larger price movements can provide diagnostic evidence about the effect of this institutional difference. This is because this difference is most likely to matter during periods of large price movements which are typically accompanied by high trading volume.

Finally, selling stock short is much more difficult in the German than in the U. S. stock market. Since German banks are not allowed to lend their customers' securities, a short seller must borrow the security directly from its legal owner. This institutional difference will not affect the length of the lead–lag relation, however, if there are investors who can sell stock from their current inventories. Given the large portfolio holdings of many major German institutional investors, it is unlikely that short selling restrictions would have a significant effect on the lead–lag relation.

IV. THE DATA

The database of time-stamped DAX index quotes was provided to us by the FSE. The DAX index, a value weighted index of the most actively traded stocks in the German market, is calculated and reported by the FSE every minute. In computing the DAX, dividends are treated as if they were reinvested in the stock that paid the dividends and the index is rebalanced annually to adjust for dividends.

The futures price database, obtained from the DTB, consists of over 1.5 million transaction prices which are time stamped to the nearest second. The sample includes all DAX futures transactions from the introduction of the contract in November 1990 to the expiration of the September 1991 contract. The DAX index futures contract is based on quarterly expiration cycle. A new contract is introduced as soon as the nearby contract expires. Consequently, there are always three contracts available for trading. The last trading day of the DAX futures contract is the Thursday before the third Friday of the expiration month. The contract is cash settled on the basis of the average opening price of the DAX stocks on the expiration day, which is the third Friday of the expiration month. The contract denomination of the DAX futures is 100 times the futures price. Since the DAX futures contract trades for a longer period each day than the underlying DAX index, we restrict our sample to the 10:30 AM to 1:30 PM period each day during which both the spot and futures markets are open.

Following Stoll and Whaley (1990a) and Chan (1992), the time series of transaction prices is converted to 5-min returns. The nearest transaction price available after the 5-min interval is used to calculate the futures

TABLE II
AUTOCORRELATIONS OF 5-MIN DAX INDEX AND DAX FUTURES RETURNS

	DAX index		DAX futures	
Lag	Autocorrelation	*t*-Statistic	Autocorrelation	*t*-Statistic
1	0.152	12.67	0.034	2.83
2	0.026	2.17	−0.028	−2.33
3	−0.034	−2.83	−0.032	−2.67
4	−0.008	−0.67	−0.012	−0.92
5	−0.005	−0.42	−0.003	−0.33
6	0.006	0.50	0.012	0.92

Note. The autocorrelations are based on intraday 5-min returns, where the first six 5-min returns for each day are excluded in order to avoid computing autocorrelations using returns from different days. The sample period is November 1990 to September 1991.

return. Because the DAX index is reported every minute, 5-min returns for the DAX index are calculated directly. Since the trading day lasts from 10:30 AM to 1:30 PM, there are thirty-six 5-min intervals during each trading day. Note that overnight returns are excluded from the sample by this procedure. To control for the possibility of stale opening prices, we also exclude that first 5-min interval of each trading day.

As in both MacKinlay and Ramaswamy (1988) and Stoll and Whaley (1990a), each contract is followed during the period in which it is the nearby contract, where this period begins on the expiration date of the previous contract and ends on the day prior to the expiration date of the contract. The reason for following the nearby contract is that the majority of the trading volume is for the nearby contract. The prices of August 19th and 20th, 1991 are excluded from the sample. This is because prices in many European stock markets dropped more than 10% on August 19th because of the Gorbachev crash in the former Soviet Union.[12]

Table II presents summary statistics for the time series properties of the 5-min spot and futures returns. The first-order serial correlation of the index returns is 0.152. This first-order serial correlation, however, is significantly less than the first-order serial correlation for five-minute S & P 500 index returns of 0.448 reported by Stoll and Whaley (1990a). As discussed by Roll (1984), MacKinlay and Ramaswamy (1988), and Stoll and Whaley (1990a), returns for individual stocks can display negative serial correlation because of the bid–ask spread. This effect, however, is mitigated for stock indexes because of the averaging of stock prices. In contrast, stock index prices can display positive serial correlation if individual stocks trade infrequently. Thus, the positive serial correlation in

[12] Excluding these 2 days from the sample had little effect on the results.

stock indexes can serve as a measure of the liquidity of the component stocks in the index.

The DAX index futures returns display less serial correlation than other stock index futures such as the S & P 500 or the Major Market Index. For example, Chan (1992) reports that the first three serial correlation coefficients for five-minutes S & P 500 index futures returns during 1987 are −0.068, 0.032, and −0.021, respectively. Similarly, the first three serial correlation coefficients for the Major Market Index futures returns are 0.042, −0.016, and −0.030.

V. THE LEAD–LAG RELATION

In this section, we focus on the lead–lag relation between DAX index and DAX index futures returns. As in Stoll and Whaley (1990a), we use a multiple regression framework to identify the lead–lag relation. Following their approach, we control for the effects of infrequent trading and bid–ask spreads by estimating the regression using an infrequent-trading and bid–ask-spread-adjusted value for the index return. First, we estimate an ARMA model for the time series of index returns using all 5-min returns in the sample. The results indicate that the DAX stock index returns are well described by an AR(3) process. We then use the return innovation from the AR(3) estimation as the infrequent-trading and bid–ask-spread adjusted index return since it is orthogonal to the previous index returns. We denote the return innovation as $\hat{R}_t$. We regress $\hat{R}_t$ on the contemporaneous futures return, the first five lagged futures returns, and the first five leading futures returns,

$$\hat{R}_t = \alpha + \sum_{i=-5}^{5} \beta_i F_{t+i} + u_t,$$

where F_t is the futures return. In estimating this regression, we use only futures returns from the same day as the index return to avoid comparing returns from different days. The t-statistics reported are based on the White (1980) heteroskedasticity-consistent estimate of the covariance matrix.[13] Table III reports the results of estimating the lead-lag regression in (1). As shown, there is clear evidence that the futures market leads the spot market. In Table III, the first three leading 5-min futures returns have significant explanatory power for the index returns. In addition, the fourth

[13] Since the return innovations $\hat{R}$ are essentially serially uncorrelated, the White (1980) estimate of the covariance matrix is virtually the same as the Hansen (1982) heteroskedasticity and autocorrelation consistent estimate of the covariance matrix.

leading futures return appears to have weak explanatory power.[14] The regression coefficients for the leading futures returns are large in economic terms as well, ranging from 0.0418 for the second leading futures return to 0.0080 for the fourth leading futures return. Simple F tests for the hypotheses that the first five leading futures returns are equal to zero and that the sum of the slope coefficients for the first five leading futures returns equals zero provides strong evidence that DAX index futures returns lead DAX index returns.[15]

These results are consistent with the hypothesis that screen-trading markets incorporate information into prices more rapidly than floor-trading markets. It is important, however, to consider alternative explanations for our results. One possibility is the illiquidity of the spot market, rather than the informational efficiency of the screen-trading futures market. Table I shows that the average time between trades for the firms in the DAX index is 4.94 minutes, while the average time between trades for the nearby DAX index futures contract is 2.98 minutes. This implies that some portion of the lead–lag relation could be due to the relative liquidity of the futures and spot markets. Given the length of the lead–lag relation, however, relative liquidity is unlikely to account for more than a small portion of the lead–lag relation.

Stoll and Whaley (1990a) also find significant evidence that futures prices lead cash prices in U.S. markets. The length of the lead relation, however, is considerably less than for the DAX index. Using data for the 1982–1987 period, they show that S & P 500 index futures returns lead S & P 500 index returns by approximately five minutes.[16] Chan (1992) shows that the average time between trades for S & P 500 futures is about 15 s, while the same measure for the largest 20 firms in the index is about 1.7 min. Thus, the relative liquidity of S & P 500 spot and futures prices is roughly equal to the relative liquidity of DAX index spot and futures prices. This suggests that differences in relative liquidity do not account for the longer lead–lag relation for DAX index futures and spot prices.

Table III also shows that DAX index futures returns lag DAX index

[14] We also estimated the regressions using the futures return innovation from a time series model similar to that for the stock index returns. Since the futures returns display very little serial correlation, the results from these were virtually the same as those reported in Table III.

[15] Similar results are obtained using the actual DAX index return as the dependent variable rather than the return innovation $\hat{R}_t$.

[16] Stoll and Whaley (1990a) and Chan (1992) also examine the lead–lag relation for the Major Market Index. Stoll and Whaley find that the futures prices lead the index by about 5 min while Chan finds that the futures prices leads the index by 10–15 min. Other papers that consider the lead–lag relation between futures and spot prices include Stoll and Whaley (1986) and Kawaller *et al.* (1987).

TABLE III
PARAMETER ESTIMATES FROM REGRESSION OF DAX INDEX RETURN INNOVATIONS FROM AR(3) MODEL ON LAGGED, CONTEMPORANEOUS, AND LEADING NEARBY DAX FUTURES RETURNS

Parameters	Estimates	Std. errors	t-Statistics
α	−0.000004	0.000010	−0.41
β_{-5}	0.005463	0.007275	0.75
β_{-4}	0.008030	0.005311	1.51
β_{-3}	0.027545	0.005126	5.37
β_{-2}	0.041805	0.013100	3.19
β_{-1}	0.020467	0.010620	1.93
β_0	0.710180	0.038700	18.35
β_1	0.012625	0.006884	1.83
β_2	−0.006955	0.004961	−1.40
β_3	−0.004197	0.004546	−0.92
β_4	0.000982	0.005056	0.19
β_5	−0.000549	0.004217	−0.13
R^2	0.788		

Hypothesis	F-statistic	p-value
$\beta_{-1} + \beta_{-2} + \beta_{-3} + \beta_{-4} + \beta_{-5} = 0$	9.559	0.002
$\beta_{-1} = \beta_{-2} = \beta_{-3} = \beta_{-4} = \beta_{-5} = 0$	8.478	0.000
$\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 = 0$	0.805	0.370
$\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$	1.988	0.077

Note. Parameter estimates are obtained from time series regressions using 5-min returns for all days of the sample period. Only DAX futures returns from the same day as the DAX index returns are used in the regression. $\hat{R}_t$ is the 5-min DAX index return innovation and F_t is the 5-min DAX futures return. Standard errors are based on the White (1980) estimate of the covariance matrix. Five thousand, one hundred observations in the sample. The regression equation is

$$\hat{R}_t = \alpha_t + \sum_{i=-5}^{5} \beta_i F_t + u_t.$$

returns by 5 min. Recall from Section II that this result is consistent with Stoll and Whaley (1990a), Subrahmanyam (1991), and Chan (1992), who show that informed traders with firm-specific information may choose to trade in the spot market rather than in the index futures market. The magnitude of the lag relation, however, is much smaller and is less significant than that of the lead relation. In fact, the F tests reject the hypotheses that the first five lagged futures returns and the sum of the slope coefficients for the first five lagged futures returns are significantly different from zero.

Stoll and Whaley (1990a) also find evidence of a lag relation between S

& P 500 index futures and spot prices. In particular, they show that the first three lagged 5-min futures returns are significantly related to the stock index return.[17] Thus, the lead–lag relation between DAX index futures and index returns is much more unidirectional than the lead–lag relation between S & P 500 index futures and index returns.

VI. THE LEAD–LAG RELATION FOR SQUARED RETURNS

The previous section focused on the lead–lag relation between DAX index futures and spot returns. In this section, we use the same methodology to examine the lead–lag relation between squared futures and spot returns. By regressing squared DAX index returns on squared futures returns, we can examine whether the lead–lag relation differs when larger returns are given more weight in the regression.

To test this, we repeat the regression in Table III using squared futures and spot return innovations:

$$\hat{R}_t^2 = \alpha + \sum_{i=-5}^{5} \beta_i F_{t+i}^2 + u_t. \tag{2}$$

Table IV reports the results. Surprisingly, the results are very similar to those in Table III. The first three leading squared futures returns have significant explanatory power for squared index returns. The fourth leading squared futures return again has weak explanatory power. The F tests again confirm the significance of the lead–lag relation between squared futures and spot returns.

As before, there is little evidence that the lead–lag relation is bidirectional. In fact, none of the lagging squared futures returns are significant and the F tests reject the joint significance of the lagging coefficients. These results provide evidence that the lead–lag relation does not change when larger returns are given more weight.

Since we only examine the lead–lag relation between squared futures and spot returns, our results cannot be interpreted as providing evidence about the lead–lag relation between the volatility of futures and spot returns. Nevertheless, it is interesting to observe that using S & P 500 index and index futures data for the 1984 to 1986 period, Kawaller *et al.* (1990) apply Ganger causality tests and find no evidence of a systematic pattern of futures volatility leading index volatility or index volatility leading futures volatility. Similarly, Chan *et al.* (1991) report the cross

[17] Stoll and Whaley (1990a) and Chan (1992) find similar results for the relation between Major Market Index spot and futures returns.

TABLE IV
PARAMETER ESTIMATES FROM REGRESSION OF SQUARED DAX INDEX RETURN INNOVATIONS FROM AR(3) MODEL ON LAGGED, CONTEMPORANEOUS, AND LEADING NEARBY SQUARED DAX FUTURES RETURNS

Parameters	Estimates	Std. errors	t-statistics
α	−0.000001	0.000001	−2.01
β_{-5}	−0.000459	0.000608	−0.75
β_{-4}	0.000949	0.000592	1.60
β_{-3}	0.002326	0.000289	8.03
β_{-2}	0.003059	0.000989	3.09
β_{-1}	0.017555	0.010990	1.60
β_0	0.793450	0.117700	6.74
β_1	−0.001906	0.002476	−0.77
β_2	0.000084	0.000548	0.15
β_3	0.000111	0.000174	0.64
β_4	0.000466	0.000517	0.90
β_5	0.000302	0.000282	1.07
R^2	0.928		

Hypothesis	F-statistic	p-value
$\beta_{-1} + \beta_{-2} + \beta_{-3} + \beta_{-4} + \beta_{-5} = 0$	4.532	0.033
$\beta_{-1} = \beta_{-2} = \beta_{-3} = \beta_{-4} = \beta_{-5} = 0$	15.998	0.000
$\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 = 0$	0.138	0.710
$\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$	0.468	0.800

Note. Parameter estimates are obtained from time series regressions using 5-min returns for all days of the sample period. Only DAX futures returns from the same day as the DAX index returns are used in the regression. $\hat{R}_t$ is the 5-min DAX index return innovation and F_t is the 5-min DAX futures return. Standard errors are based on the White (1980) estimate of the covariance matrix. Five thousand, one hundred observations in the sample. The regression equation is

$$\hat{R}_t^2 = \alpha_t + \sum_{i=-5}^{5} \beta_i F_t^2 + u_t.$$

correlations of squared S & P 500 index and futures returns and show that there is no clear lead–lag relation between the two series during the 1984 to 1989 period.[18]

VII. VOLATILITY RATIO TESTS

The lead–lag regressions reported in previous sections address the issue of whether information is incorporated into prices more rapidly in an

[18] Chan *et al.* (1991) also report similar results for the lead–lag relation between S & P 500 spot and futures volatility using a bivariate GARCH framework.

TABLE V
FRENCH–ROLL VOLATILITY RATIOS FOR DAX FUTURES AND DAX INDEX RETURNS FOR THE INDICATED HORIZONS.

	2-day horizon	5-day horizon
DAX index		
Mean variance ratio	0.798	0.575
Std. error of mean	0.052	0.127
t-statistic	−3.9	−3.3
DAX index futures		
Mean variance ratio	0.975	0.779
Std. error of mean	0.015	0.101
t-statistic	−1.7	−2.2

Note. The 2-day ratio is the ratio of the variance of 2-day returns divided by twice the daily return variance. Similarly with the 5-day ratio. The mean variance ratio and its standard error are based on the distribution of the variance ratios obtained by dividing the sample into 10 subperiods and computing the variance ratio for each subperiod. The *t*-statistic tests the hypothesis that the mean variance ratio equals 1. The ratios are based on 204 daily close-to-close observations.

electronic screen-trading market than in a floor-trading market. In this section, we examine whether prices in screen-trading markets are less noisy than prices in floor-trading markets.

French and Roll (1986) propose a simple variance ratio test that examines whether the variance of returns grows linearly with time. If prices move only in response to the arrival of new information, return innovations should be uncorrelated. Thus, the variance of a 2-day return will be twice the variance of a 1-day return. In contrast, if prices are affected by noise in the trading process, a portion of the price change in a period may be reversed in the subsequent period. Thus, if markets are noisy, the variance of returns need not grow linearly with time.

Table V summarizes the variance ratios for the DAX index and index futures returns. The 2-day variance ratio is computed as the variance of 2-day close-to-close returns divided by twice the variance of the 1-day close-to-close returns. Similarly for the 5-day variance ratios. A variance ratio of less than 1 indicates that short-horizon returns are relatively more volatile than long-horizon returns and is consistent with the presence of noise in the returns. It should be noted, however, that variance ratios different from 1 could arise for other reasons. For example, variance ratios could differ from 1 if prices were mean reverting or if expected returns were time varying. Thus, the results of this test should be interpreted with care.

As shown, the 2-day variance ratio for the DAX index returns is 0.798.

In contrast, the 2-day variance ratio for the DAX index futures is 0.975. Similarly, the 5-day variance ratio for the spot market is much lower than the corresponding measure for the futures market. These results are consistent with prices in the screen-traded DAX index futures market being less noisy signals of actual values than prices in the floor-traded DAX index spot market. Again, it is important to stress that these results provide only indirect evidence.

VIII. CONCLUSION

We have examined the relation between screen-traded DAX index futures returns and the corresponding floor-traded DAX index returns. We find that DAX index futures returns lead DAX index returns by about 15–20 min. This lead–lag relation is unlikely to be due to differences in the liquidity of the DAX index futures and spot markets alone. In addition, this lead–lag relation is longer and more unidirectional than in markets where both the stock index and the index futures are floor traded. The results for the lead–lag relation between squared DAX index and index futures returns are similar.

Our results are consistent with the hypothesis that electronic screen trading accelerates the price discovery process. Although our analysis leaves open the question of exactly how screen trading accomplishes this, factors such as lower transaction costs, the visibility of the limit order book, mechanical and reporting efficiencies, or reduced transparency could play a role.

Finally, we have focused only on the price discovery issue. Another equally important issue is whether screen trading reduces the overall liquidity of the market. As more data becomes available for screen-trading markets, future research should focus on the tradeoff between liquidity and price efficiency in screen-trading markets.

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