Laboratory of Economics and Management
Sant'Anna School of Advanced Studies

Via Carducci, 40 - I-56127 PISA (Italy)
Tel. +39-050-883-341 Fax +39-050-883-344
Email: lem@sssup.it Web Page: http://lem.sssup.it

LEM

Working Paper Series

Market Microstructure: Theory and Empirics

*Anna Calamia**

* *University of Rome, La Sapienza and London School of Economics*

1999/19 **September 1999**

Market Microstructure: Theory and Empirics

Anna Calamia

University of Rome, La Sapienza

and London School of Economics

September 1999

Abstract

This paper reviews the literature on market microstructure. Particular emphasis is given to the research dealing with the impact that a specific trading mechanism might have on price behaviour and with the comparison of the performance of alternative market structures. Theoretical models and empirical studies investigating their implications are explored. The major statistical properties and reguliarities of microstructural data are discussed.

1 Introduction. Market Microstructure and High Frequency Data

Market microstructure studies the effects of market structure and individual behaviour on the process of price formation[1]. Most theoretical and empirical research in this area deals with the impact that a specific trading mechanism might have on price behaviour and with the comparison of the performance of alternative market structures.

Over the last years, research on financial markets focuses on institutional and structural influences on market dynamics, accounts for traders' heterogeneity and complex interactions, and gives particular emphasis to microeconomic factors governing markets.

Most literature concerns with the actual behaviour of markets, particularly in the short-run, in order to explain how prices are determined, how price setting rules evolve in markets and why prices exhibit particular time series properties. These issues have important implications for market regulation and for the design of trading mechanisms.

The interaction between the organisational features of a market and the behaviour of heterogeneous traders is a crucial issue in the working of actual markets as it affects important variables such as the volume of trade, the degree of liquidity and transaction costs, price volatility and information processing. Heterogeneity may concern risk aversion, needs for liquidity, asset preferences, beliefs, information as well as learning processes and reaction dynamics.

In particular, the short-run behaviour of trading prices reflects the process of the instantaneous matching of supply and demand from a relatively small number of investors, who are trading the individual asset at a given point in time. Market's equilibrium is determined by investors' trading strategies, which depend on the individual's information, desire for liquidity and perception of the trading environment (e.g., the degree of adverse selection in the marketplace and the extent of liquidity available as well as the uncertainty of the market's valuation of the security).

Several aspects of market structure have been taken into account in the theoretical

[1] In the words of O'Hara (1995): "Market microstructure is the study of the process and outcomes of exchanging assets under explicit trading rules. [...], the microstructure literature analyses how specific trading mechanisms affect the price formation process."

and empirical literature. First of all, the trading arrangements (implicit or explicit rules) and how they are effected by the organisation and by the structure of the market: what can be traded, who can trade, when and how orders are submitted, aggregated and matched, who may see or handle the orders, how prices are set.

Several studies have focused on the role of market makers and brokers in the dissemination and aggregation of information or on the causes and effects, in terms of information flows and prices, of the high volume of inter-dealer trade. A crucial issue concerns the informational content of prices in the presence of market power and collusion among market makers, or in the presence of asymmetric information.

Besides informational efficiency, one of the main issues of microstructure literature concerns market liquidity and transaction costs, usually measured by the size of the bid-ask spread, and their influence on transaction prices and returns. A related puzzle is the observed relationship between volume of trade, price volatility and dispersion of beliefs.

The empirical literature focuses on the existence and determination of predictable patterns and on the impact of the organisation of trade and of institutional rules on market outcomes, price discovery and volatility and time series properties of returns. In standard econometrics, the dynamic properties of financial data are explored without explicit reference to the institutional structures in which prices are determined. For some purposes such aspects of market microstructure can be ignored, particularly when long horizons are involved. Instead, at higher frequencies market microstructure surely matters.

The actual process of trading might have an important impact on the time series properties of asset returns such as non-linearity, non-normality (skewness and kurtosis), volatility clustering and ARCH-GARCH effects. The presence of bid/ask spreads may generate abnormal returns, spurious volatility (due to the bid-ask bounce) and correlation in returns. Market microstructure aims to explain some observed empirical regularities of financial prices.

As the main object is the interpretation of short run dynamics, the micro structural approach involves the use of high-frequency time series and transaction data to test the statistical properties of prices, returns and volume. Therefore, the development of empirical micro-structure analysis goes on in parallel with the use of high frequency data to answer questions concerning market behaviour over short time intervals and with the development of econometric and statistical techniques to deal with this type of data.

2 Market Microstructure Modeling

Most models of price dynamics deal with the traditional distinction between permanent and transitory components of price variations. This dichotomy has been largely used as an empirically testable hypothesis. The permanent component is typically assumed to be information-related and affected by the degree of information asymmetry. The transitory component is thought of as trade-related perturbations due to market frictions i.e., induced by the trade itself that drives the current (and subsequent) transaction prices away from the efficient (permanent component) prices.

Some random walk component is often assumed to reflect the informational structure of the market (permanent component) while the observed price differs from its intrinsic value because there is a noise due in part to the process by which prices are set in the market (Black (1986), Amihud and Mendelson (1987)). This might help to explain some observed empirical regularities and to assess whether they are generic properties of the speculative process (Cutler, Poterba, Summers (1991), or can be interpreted as conditional on the market specific set-up.

The divergence between the efficient price and the actual price may be interpreted as a trading cost or as the effect of price discreteness and inventory control (position management) by dealers. This pricing error may induce systematic patterns in the distribution of prices, given the heterogeneity of agents' characteristics. The dispersion of the pricing error can be thought of as a natural measure of market quality (Hasbrouck (1993)).

The random-walk model has been widely used in the literature on the efficient market hypothesis. It rests on hypotheses -such as the absence of transaction costs- that do not usually hold at the level of microstructure phenomena. At high frequencies or transaction data prices diverge from a random walk, and empirical papers address the question of the size and determinants of this divergence.

However, the decomposition of the price into a random-walk component and a trade-related component may account for the dynamics that reflect microstructure phenomena and the dichotomy between the informational/permanent and the market/transitory effects. Many tests have been proposed and applied to investigate the random walk hypothesis mainly over daily or longer intervals, (e.g., Fama (1970), Lo and MacKinley (1988)). As Hasbrouck (1996) points out, the incorporation of the random walk hypothesis in the microstructure framework requires a plausible specification of the conditioning information set.

2.1 Components of the Bid-Ask Spread

Market microstructure focuses on whether the sources of price variations are trading-related (attributable to one or more transactions). Specifically a trade might influence the two components of the price by the fact and the time of its occurrence, the price and volume (quantity) and whether it is buyer or seller initiated[2]. Inventory models and asymmetric information models account for the distinction between trade-related and unrelated sources of price variation and for some observed stylised facts.

The presence of bid-ask spreads has a non trivial impact on transaction prices and on the time series properties of asset returns, may create spurious volatility due to the bid-ask bounce (movements from the bid to the ask) and serial correlation in returns.

Bid-ask spreads are compensations to market makers (dealers) for providing liquidity. Dealers quote different prices for the bid and the ask to cover three kinds of costs: the order processing costs, the inventory-control costs and the asymmetric information costs. In earlier studies (Demsetz (1968), Tinic (1972)) the spread was viewed as a consequence of the dealer's need to recover fixed transaction costs as well as a normal profit. It arises from traders' desire of immediate executions of orders.

Several papers have estimated the realised spread in the attempt to assess the relative importance of the different components of the bid ask spread. In the simple bid-ask spread model, the error pricing term represents the bid-ask bounce, driven by the current trade (buy or sell) and is a stationary random process whose increments are not trade-

[2]Or active and passive transactor, the former willing to pay for the immediat execution and the latter being the suppliers of immediacy (see Demsetz, 1968).

related. Roll (1984) assumes a simple order processing costs model in which the bid-ask bounce induces negative serial correlation in price changes. The order processing costs are basic operating costs related to the trading mechanism.

In an efficient market, the fundamental value of a security fluctuates randomly. In the absence of trading costs price contains all relevant information. When there are trading costs, the market maker is compensated by the bid-ask spread. Trading costs induce negative serial dependence in successive observed market price changes even if the true prices are uncorrelated. Since recorded transaction occur at the bid or at the ask (not at the average), trades prices continuously bounce between these quotes (Roll (1984))[3].

2.2 Inventory Models

In the inventory models, the trading process is a matching problem in which the market maker, facing an unbalance risk, uses the price to balance supply and demand across time. The key factors are the inventory position and the uncertainty about the order flow. Market makers achieve the inventory control by shifting the quotes (bid and ask) to elicit the imbalance of buy and sell orders. The focus is on dealers' optimisation and on the way in which they deal with price and inventory uncertainty and how market price are set by price setting agents. (Garman (1976), Stoll (1978), Ho and Stoll (1983), Cohen, Maier, Schwarts and Whitcomb (1981), O'Hara and Oldfield (1986)).

The bid-ask spread increases with the market maker's risk aversion, the size of the transaction, the risk of the asset and the time horizon, or it may reflect the dealer's market power (Amihud and Mendelson (1980)).

Despite the different explanations of the spread -market failure, market power, trans-

[3]Given market efficiency, Roll (1984) show that the joint probability of successive price changes, when no new information arrives, depends upon whether the last transaction was at the bid or at the ask. Using daily and weekly data on NYSE, Roll shows that the covariance of transaction returns is an estimate of the realised ("effective") spread in an efficient market and that the latter is less than the quoted spread. The advantage of Roll's model is that the spread is estimated usling only transaction prices. (The quoted bid-ask spread is the difference between the ask and the bid prices quoted by a dealer at a point in time. The realised or effective bid-ask spread is the average difference between the price at which a dealer sells at one point in time and buys at earlier point in time.)

action costs- the general idea focuses on the dealer with a balancing problem who moderates deviations in the order flow. These deviations depend on the behaviour of the market in the short run. The dealer's effect on price is temporary. At the end of the adjustment process, price and inventory have completely reverted, i.e. reversion is not immediate, but there is no permanent price impact in this model because trades are independent of information. In other words, the permanent component of the price change is not trade-related but it is due to public information, while the error term is entirely trade-driven. The market maker changes the quote midpoint (average of the bid and ask quotes) and therefore the price, depending on the trading costs, on the dealer's previous inventory position and on the net demand to the dealer.

2.3 Information-Based Models

As the major concern is with the information-aggregation properties of prices and markets, later works focus on the third component of the bid-ask spread, the adverse selection or asymmetric information costs. These costs arise because some investors are better informed about a security's value and, trading with them, the market maker would, on average, incur into a loss. Since the market maker is unable to distinguish the informed traders from the uninformed ones, a portion of the spreads is the compensation for taking the other side of a potentially information-based trade. Market makers quote a wider spread when there are informed traders, to compensate the losses from trading with them. (Copeland and Galai (1983), Glosten and Milgrom (1985), Easley and O'Hara (1987), Stoll (1989), Glosten (1987, 1989), Glosten and Harris (1988), Kyle (1985), Admati and Pfleiderer (1988, 1989)).

The asymmetric information models allow for heterogeneously informed traders. If a trade might be motivated by superior information, the occurrence of a trade (a public event in most models) will communicate to the market something about this private information. The trading process is viewed as a game involving traders with asymmetric information regarding the asset's true value.

Two main classes of adverse information models are the sequential trade models and the strategic models. The former examine the determinants of bid-ask spreads in a competitive framework with heterogeneously informed agents. These models are characterised by a probability structure where prices act as signals (semi-strong form efficiency) and there is a (Bayesian) learning problem confronting market participants. The bid-ask spread increases with the degree of asymmetric information and decreases as time elapses and the market maker acquires information. (Glosten and Milgrom (1985), Easley and O'Hara (1987), Easley and O'hara (1992)).

The strategic models focus on the idea that private information provides incentives to act strategically to maximise profits and agents choose the time and size of trades. This strategic behaviour might be affected by the trading mechanism (Grossman and Stiglitz (1980), Kyle (1989)). There are several versions of strategic models, which generalise the original Kyle's framework (Kyle 1984). Some of them deal with one informed trader (Kyle (1984, 1985)) or with multiple informed traders (Kyle (1984), Foster and Viswanathan (1993), Holden and Subrahamanyan (1992)). Some other introduce discretionary uninformed traders that take into account the impact and costs of their trade, and choose the size or time of the trade (Foster and Viswanathan (1990), Admati and Pflederer (1988, 1989)). In general, strategic behaviour may induce patterns in trading activity, returns and volatility (e.g., Leach and Madhavan (1992, 1993) examine the effects of strategic quote setting on trade frequency).

The asymmetric information component of the price reflects the public information, the market's estimate of the information contained in the trade, and it is serially uncorrelated if and only if buy and sell orders arrive randomly. The adverse selection component has implications for transaction price dynamics: while the order processing and inventory component exhibit reversal and induce negative serial correlation in returns, the adverse selection component has an additional impact on means and covariances of returns that tends to be permanent and the reversion is not complete (Hasbrouck (1996)).

3 Alternative Trading Mechanisms and Markets

3.1 Institutional Realities

Actual markets exhibit diversity and securities are traded on different market settings and with different procedures. Market performance and the observed statistical regularities are likely to be conditional on specific institutional set-ups and individual characterisations. Alternative trading mechanisms present different institutional features.

A first major feature is the frequency of trading. Markets can be distinguished between periodic call auction (batch markets) or continuous auction. In the former, agents submit orders during certain periods of time to a central system, which establishes aggregate demand and supply schedules. The Clearing House mechanism is an example of periodic market clearing procedure. Buy and sell orders accumulate during some interval and then all trades are executed simultaneously, when the auction is called, at a single market-clearing price. This walrasian auction is used during the opening sessions of several continuous markets (Paris Bourse, Frankfurt Bourse, New York Stock Exchange at the opening, Tokyo Stock Exchange), to restart transactions after a trading halt, in some commodities markets and in some small emerging markets.

In continuous auctions there is a sequence of bilateral transactions that are completed during the opening hours of a market, possibly at different prices. Liquidity is provided by the random arrival of buy and sell orders. Usually continuous markets are dealership markets (NYSE, Foreign Exchange market), in which trading is carried out through market-makers who quote bid and ask prices at which they are willing to buy or sell. Orders are submitted to individual dealers who execute them at current prices. In the NYSE, a designed specialist makes the market and has to provide continuous quotes. On continuous floor or open outcry markets, buy and sell orders arrive in the trading floor and matches are made by and reported to the exchange (TSE, LIFFE, Matif, LSE until 1987).

The second feature is the location of trading: market can be centralised or decentralised. Centralised markets can be either floor (open outcry) markets (NYSE, CBOT, LIFFE, Matif) or computerised markets, where the trade matching mechanism is automated and information is being electronically displayed and transmitted to all market participants (located in physically distinct offices). On electronic continuous auctions, agents submit orders to a centralised system which displays the best limit orders and automatically executes incoming market orders against them and ensures immediate trade publication (Toronto, Paris and Madrid). On centralised markets all transactions are visible to all market participants and explicit trading rules can be imposed and monitored to minimise transaction costs or improve market efficiency.

On decentralised (or over the counter, OTC) markets, multiple dealers or market makers work in distinct locations quoting individual bid and ask prices. They are linked by telephone and/or computer and trade among themselves and with external customers. Many dealership markets are electronic markets where market makers display quotes on an electronic screen (NASDAQ, SEAQ, LSE and most secondary bonds markets).

Other important characteristics of market organisation concern the order flow. First, orders submitted by traders can be market orders or limit orders. Market orders are executed upon arrival in the market according to the priority rules (given by price, time or size) while limit orders are executed contingent on the price level[4]. Both types of orders are used in most continuous markets. Some markets (TSE, Paris Bourse) have introduced an electronic limit order book, where limit and market orders are entered into a central computer system and executed against outstanding limit orders. Second, markets can be quote-driven or order-driven. On quote-driven markets prices are fixed before quantities while on order-driven markets prices and quantities are set altogether. Of paramount importance is also the way in which orders are aggregated and matched, essentially directly or through dealers/market makers[5]. Inter-dealer trading represents a substantial amount of trade on many dealership markets. The role of market makers and brokers is central in determining liquidity and price discovery and much microstructure research focuses on the effect of dealers' behaviour and on the price determination process. Finally, other specific institutional and trading arrangements are to be considered. For instance, market might differ for trading hours, initial margins, trading unit, delivery date, last trading date, publication regime[6]. These features are likely to influence the price formation process.

3.2 Comparison of Alternative Trading Mechanisms

Most theoretical and empirical research on market microstructure deals with the comparison of alternative structures of securities markets and with the impact of the trading

[4] Orders can be contingent on time (e.g. market-at-close orders), on quantity, or on price (e.g. stop orders, limit orders).

[5] A special case is the Foreign Exchange Market. It is a continuous dealership market, characterised by a direct market, where traders deal bilaterally, and an indirect or brokered market. The former is quote-driven and decentralised, while the latter is order-driven and centralised.

[6] Exchange authorities dictate the speed at which publication must take place. Delay can vary from few minutes to 24h or more.

mechanism on market dynamics and on the statistical properties of prices and returns.

Unfortunately, this comparison is conditional of the availability of data, which also is structure-related. Only for certain markets, such as centralised markets, it is easy to find complete data sets, including quotes and transaction prices, volume of trade, identity of trader and other information on trades (e.g., which of the dealer's trades are for customers or personal).

The analysis of the impact of the trading mechanism on market performance focuses on some characteristics of markets. First, pricing efficiency, the fact that prices accurately and instantaneously reflect all available information. The information content of price is probably one of the most investigated aspects of financial markets and it is related to some structural features. The level of information-based trading attracted by a particular market and institutional arrangements is crucial for market design and regulation. Trading arrangements determine traders' anonymity and transparency; hence informed trading and trading costs (e.g. bid-ask spreads) might be related to structural explanations. The speed of price adjustment can be viewed as a measure of market efficiency. How prices adjust to new information and change over time i.e., how the market maker and other informed traders learn from observing market information and how market structure affect price adjustment are major issues of the empirical investigation. Several papers compare different trading mechanisms or examine the role of market makers in price discovery in different market settings.

Second, liquidity, the ability of the market to accommodate, at all time, large orders with minimal price impact, as well as market stability and the speed in absorbing external shocks without incurring into market crashes. Price behaviour and market performance largely depend on the ability of the trading mechanism to match the trading desires of buyers and sellers. The matching process involves the provision of liquidity, which arises from the market maker and from other aspects of the trading mechanism. Liquidity is related to transaction costs and it is one of the most important features of actual markets: it may differ within and across markets, introduce linkages and interactions between markets and may be influenced by these linkages.

Several papers study periodic call markets or compare them with dealership markets (see Garbade and Silber (1979), Mendelson (1982, 1985, 1987), Ho, Schwartz and Whitcomb (1981, 1985)). Periodic call markets involve large numbers and therefore pricing errors should be minimised. Continuous dealership markets have the advantage of the immediate execution. However, it is rare in empirical studies for the two mechanisms to be modelled jointly with fully specified models of both mechanisms.

Amihud and Mendelson (1987) investigate the characteristics of stock returns as reflected by their time series behaviour, under alternative trading mechanisms. Given that "the difficulty with empirical comparison is that different markets trade different assets and these assets are traded in different environments" (Amihud and Mendelson, 1987, page 534), since on NYSE there is a call auction at the opening and after trading halts and a continuous auction thereafter, they compare the behaviour of open-to-open and close-to close returns on NYSE, on the basis of variance ratios of these returns. (See also Amihud and Mendelson (1991), Stoll and Whaley (1990)). Opening returns exhibit greater dispersion and deviations from normality and a more negative and significant autocorrelation pattern than closing returns (deviations from the random-walk form of market efficiency, larger variance of the pricing error). These results are attributed to the particular trading mechanism on NYSE, hence they conclude that the trading mechanism has a significant effect on stock returns. Other studies find that the variance of the morning call is greater than that of the afternoon call (Amihud and Mendelson (1991), Amihud, Mendelson and Murgia (1990), Stoll and Whaley (1990)).

Another possible explanation is that periods of overnight closures are associated with opening transient effects not related to the trading mechanism. As we will see, there is an increasing literature on the effects of market closures and comparison of trading versus non-trading periods. In this view, as opposed to the trading mechanism explanation, call market seem not to be inherently more volatile. (See also Leach and Madhavan (1993), Madhavan (1992)).

Several papers have examined the role of dealers and market makers and their interaction in different market settings, and degrees of competition, and the impact on the determination of bid-ask spreads (Ho and Stoll (1983), Cohen, Maier, Schwarts and Whitcomb (1981)). Madhavan and Panchapagesan (1999) show that the specialist on NYSE can facilitate price discovery in the opening auction mechanism, relative to an automated call auction market. Sofianos and Werner (1998) point out that NYSE floor broker play a very important information role, they provide liquidity and facilitate orders' execution.

Some empirical literature on dealer versus auction markets has found higher spreads in a dealer market. These have been attributed to collusion between dealers to set bid-ask spreads above competitive levels and to differences in market structure (Dutta and Madhavan (1997), Christie and Schultz (1994)). Order forms and the specialist's book where these orders are collected, as well as restrictions of the access to the order flow may influence the level of competition among dealers and the informativeness of the order flow. (Cohen, Maier, Schwarts and Whitcomb (1981), O'Hara and Oldfield (1986), Dutta and Madhavan (1997), Leach and Madhavan (1993), Madhavan (1992))

The comparison between call and continuous markets is related to the debate on computerised markets. Dealers in an anonymous electronic screen-based market are less capable of discerning informed traders from uninformed (liquidity) traders (e.g. Griffiths, Smith, Turnbull and White (1998). Anonymity attracts informed traders. However, informed traders may be reluctant to enter large limit orders as this may reveal their information (Stoll (1992), Domowitz (1990)).

The anonymity on automated markets is sometimes attenuated by the presence of a limit order book, which provides superior information on prices and order flows. Pagano and Roell (1992) suggest that the speed of dissemination of order flow information is greater in centralised markets since prices adjust faster. The extent of public limit order exposure and execution risks are smaller in dealership markets than in electronic continuous auctions or in batch auction, while traders' anonymity is reduced on dealers' floor markets. Bollerslev and Domovitz (1993) in a computer simulation, find that increasing the length of the order book improves price discovery. Bollerslev and Domowitz (1991) argue that volatility in the computerised system should be lower as limit orders remain longer in the book.

The greater speed in trade and information processing allowed by electronic systems should increase market efficiency. Also, since order processing is faster, execution risk should be lower and this should encourage supply of liquidity (Biais, Hillion and Spatt (1995)). Glosten (1994) shows that the electronic system provides as much liquidity as in a situation of adverse selection in a market maker system.

Some evidence on the relative performance of electronic and floor markets, in terms of liquidity, price discovery and volatility does not seem to indicate the intrinsic superiority of one trading mechanism. Fremault-Vila and Sandmann (1997) compare market liquidity and informational efficiency in computerised and traditional open outcry markets (NIKKEY stock index futures, traded simultaneously on open outcry and computerised) and conclude that the existence of two competing trading mechanisms is due to transaction costs and other exogenous trading restriction rather than to inherent inefficiency of one of the trading mechanisms.

A related issue concerns the desirability of market transparency. Greater transparency should be related to a greater and faster diffusion of information, and prices should more efficient (Madhavan (1995), Pagano and Roell (1996)). Madhavan (1992) finds that price efficiency is greater in quote-driven markets (more transparent) than in order-driven markets. Greater transparency (reduced anonymity) should reduce adverse selection thereby reducing spreads. Indeed, it is possible that less transparency induces competition among dealers for the order flow and therefore smaller spreads (Madhavan (1995)). There is little consensus on the overall effect of market transparency and empirical evidence is mixed (Board and Sutcliffe (1995), (1996), Gemmil (1996)).

Bloomfield and O'Hara (1999), conduct a laboratory experiment and find that transparency involves higher spreads and more "efficient" prices. They show that trade disclosure increases the informational efficiency of transaction prices but also the opening bid-ask spreads, by reducing market makers' incentives to compete for order flow. They also find that quote disclosure has no significant effect on market performance. Flood, Huisman, Koedijk and Mahieu (1999) examine the effects of price disclosure on market performance in a continuous experimental multiple-dealer market with actual securities dealers and find that transparency involves narrower spreads and higher trading volume and liquidity. However, price discovery is faster in less transparent markets where dealers adopt more aggressive pricing strategies. They attribute these results to the behaviour of speculating dealers exploiting the lower search costs in more transparent markets.

3.3 Related and Parallel Markets

We have seen the puzzling evidence of the co-existence of different competing trading mechanisms and the theoretical and empirical attempts to assess whether some of them perform better for at least specific assets and economic environments. Furthermore, trading is often fragmented among more or less inter-related markets and, on the other side, different securities are traded within the same trading mechanism. Opening calls and specific block trades mechanisms are often used as alternative trading mechanisms that parallel regular trading in a single market. Equities are listed on different competing markets, and although there might be electronic links among the exchanges, trading and quote setting may vary considerably.

Several theoretical studies are concerned with market fragmentation, and cross-listing securities as well as linkages between markets where identical or closely related securities are traded. (E.g., Madhavan (1995) De Jong et al. (1995), Pagano and Roell (1991), Kleidon and Werner (1996)). This fragmentation of trading across markets might affect market stability and performance. Liquidity and information efficiency appear to be related to multimarket activity. The inter-relations among markets affect trading behaviour, liquidity and information flows. Hasbrouck (1995) examines homogeneous or closely linked securities traded in multiple markets. To determine where price discovery occurs, he uses an econometric approach based on the implicit unobservable efficient price common to all markets. The information associated with a market is defined as the proportional contribution of that market's innovation to the innovation in the common efficient price.

Much empirical research on inter-market linkages uses intraday (or daily) changes in prices, volumes and spreads to investigate volatility spillovers and price discovery effects. The focus is on the linkages between geographically separated but related markets and on the international transmission of returns and volatility (e.g., Hamao et al. (1990), Lin et al. (1994)). Lin et al. (1994) report the following stylised facts on the international transmission of returns and volatility: volatility of stock prices is time-varying; when volatility is high, the price changes in major markets tend to be highly correlated; correlation in volatility and price appears to be asymmetric in causality between the US and other countries.

Engle et al. (1990) investigate volatility patterns in the Foreign Exchange market and volatility correlations across trading centres and time. Examining the volatility in the yen/dollar exchange rate (daily data), they distinguish between volatility clustering that are country-specific ("heat weave") and those that travel between financial centres ("meteor shower"). They find evidence of the meteor shower and against the heat wave hypothesis, possibly due to private information or heterogeneous beliefs or to stochastic international policy co-ordination (similar results are found by Ito et al. (1992), Lin et al. (1994), Baillie and Bollerslev (1991), Dacorogna et al. (1993), Hogan and Melvin (1994)). Baillie and Bollerslev (1989), using hourly data, find evidence of both the heat wave and meteor shower effects.

A related question is whether and how the ability to trade derivative instruments affect market behaviour and liquidity. Gennotte and Leland (1990) examine the effect of hedging strategies on market liquidity and the stock market crash of October 1987. Harris et al. (1994) find that program trading and intraday volatility of the S&P500 Index are correlated, and particularly that futures prices lead program trading. Gerety and Mulherin (1991) suggest that there is no evidence of systematic increase in volatility following the introduction of new financial instruments, such as index futures (data on intraday stock market volatility). There is a strong evidence in favour of a lead-lag relationship in returns and volatility between stock index futures and the underlying cash market (e.g., S&P500), particularly indicating that the futures leads the index. Evidence on futures leading cash is even stronger when looking at market wide information flows, i.e., when all stocks move together. (Kawaller, Koch and Koch (1987, 1990), Chan (1992), Harris (1989), Stoll and Whaley (1990), Chan et al. (1991); Huang and Stoll (1994)).

4 Statistical Properties of Microstructural Data

4.1 Time and Discreteness

Most traditional studies of price behaviour refer to calendar time and therefore use observations drawn at fixed time interval. Timing considerations in actual markets are much more complicated. Trades are not equally spaced points in real time but they take place at random times during the day. The frequency of price changes is also related to the frequency of order arrival and transaction occurrence.

Market microstructure studies how prices are derived from an explicit modelling of the trading process and from the interactions of agents decision rules. Therefore it naturally refers to transaction data which are real time data sampled at irregularly spaced random intervals (whenever trades occur) and observations that are unlikely to be identically distributed. The timing of trades is not regular and there are time intervals in which no transactions occur. Besides the information contained in actual prices, the time interval between quotations is of paramount importance and can be viewed as a signal conveying information (Easley and O'Hara (1992), Engle and Russel (1997)).

This issue is related to the structure of the market. Some institutional features give rise to alternating periods of quiescence and extreme volatility. For example, Diamond and Verrecchia (1987) suggest that no-trade intervals are bad signals because they can be due to short-sales constraints that preclude desired trades.

Models in which trading plays a central role cannot rely on the assumption of time homogeneity. Prices do not behave in the same way during trading and non-trading periods and even during trading sessions markets exhibit concentration of activity. This time-varying and irregular frequency generates intra-daily seasonals in trading volume, price volatility and spreads.

As shown in Andersen and Bollerslev (1997) and Guillaume et al. (1994), the presence of these seasonal patterns introduces strong biases in the computation of simple statistics and in the estimation of statistical properties of intra-daily data, and can lead to spurious results. There are several ways to deal with this seasonality. Baillie and Bollerslev (1989, 1990, 1990) introduces seasonal dummies. Andersen and Bollerslev (1997), Andersen, Bollerslev and Das (1999) use a flexible Fourier framework to model the frequencies corresponding to the different seasonal peaks. Dacorogna et al. (1993) use a different time-scale, the J-time, that expands daytimes having high mean volatility and contracts daytimes having low volatility (and weekends). Seasonal patterns almost vanish with this time scale.

Empirical investigation using transaction data may turn out to be biased because it ignores the informational content of non-trading intervals. This sampling bias is reduced when using bid-ask quote series, continuously updated by the market maker. Furthermore, transactions can be more likely to occur when there is more information and the variance of transaction price series turns out to be time varying. This is consistent with ARCH-GARCH effects as resulting from time dependence in the arrival of information[7].

[7]Usually ARCH in speculative price is interpreted in terms of the nature of information flow reching the market. If it is non-uniform (clustered) then this may generate heteroskedasticity in price change measured in calendar time. Even if the price follows geometric Brownian Motion between subsequent transactions the distribution of price changes over fixed calendar time interval will not be normal as the number of transaction is not drawn from a uniform distribution. The number of transactions has

This issue is central to many empirical studies dealing with the idea that price variance is related to trading activity (Clark (1973), Tautchen and Pitts (1992)). This time effect might also be a consequence of the market maker widening the spread to reduce the frequency of incoming order arrival. In this case, using the trade frequency as a proxy for informational intensity could lead to wrong inferences (Easley and O'Hara (1992), Easley, Kiefer and O'Hara (1997a).

Beside the clock time and the transaction time, an alternative approach is the time scaling. It allows to calibrate market activity in a relative sense, for example trading activity is measured expanding daytime periods with a high mean volatility and reducing period with a low volatility. Muller et al. (1990) and Muller and Sgier (1992) propose this time scale to investigate the time patterns in the forex and to account for the time dimension of global market activity, resulting from the combination of regional time patterns. This scaling law relates the volatility over a time interval to the size of the interval. Guillaume et al. (1994) suggest that one possible interpretation is that it "represents a mix of risk profiles of agents trading at different time horizons".

A related issue is that of discreteness and price clustering. Prices and quantities are often assumed to be continuous random variables, while in fact they are discrete. Transaction sizes are discrete and prices are quoted in discrete units (e.g., ticks) and this discreteness can induce dynamic patterns, generate price clustering and approximation errors when using continuous time models[8]. The term price clustering refers to the tendency of prices to fall more frequently on certain values than on others, especially with transaction data. Harris (1991) notes that stock prices cluster on round fractions (integers more common than halves, halves more than odd quarters, etc.). Similar effects are found in NYSE limit order prices and NYSE quotes (Harris 1994). Cohen, Maier, Schwarts and Whitcomb (1981) discussing the role of limit orders and market orders, the bid-ask spread and the need for the market maker, observe that the existence of transaction costs limits the trading activity and induces discreteness in the price process. Discreteness is also found in the distribution of quoted spread (Bollerslev and Melvin (1994)) and these conventional spreads have evolved over the years (Muller and Sgier

the effect of deforming the distribution away from the normal.

[8]Statistically, it can generate intractable problems for the general VAR microstructure models. Hausman, Lo and MacKinley (1992) present an ordered probit model of price changes (trades and other explanatory variables drive a latent continuous price variable, mapped onto the set of dicrete prices). Other models of price discreteness are rounding and barrier models.

(1992)).

4.2 Evidence on Returns, Quotes and Trades

The empirical literature has found evidence of negative autocorrelation in quotes and returns, particularly strong at very high frequency. Negative first order aucorrelation is consistent with models of price adjustment based on transaction costs and inventory control. Transaction costs introduces a short-run bounce (bid-ask bounce) in price movements as buy and sell orders arrive randomly (Roll (1984), Stoll (1989)). If market makers care about inventories, price changes exhibit negative serial correlation since they skew the spread in one particular direction to rebalance inventory (Bollerslev and Domowitz (1993)). Prices reversals compensate providers of immediacy for inventory and order processing costs. If data do not distinguish between buy orders at the ask and sell orders at the bid, the first order negative autocorrelation is accentuated buy the bid-ask bounce and is stronger the higher the frequency of the data. Many results on NYSE are therefore biased due to the bid ask bounce (see Porter (1992), Harris (1986)). Indeed, after taking account of the bid-ask bounce, there is some weak evidence of positive autocorrelation in returns (Hasbrouck and Ho (1987), Lo and MacKinley (1988)). In some cases, for instance when limit orders are allowed, the presence of positive serial correlation in returns (as well as in quotes and trades) can be explained by the clearing of incoming (large) orders against the existing ones.

Other studies find evidence of higher order serial correlation and lagged price adjustment arising from lagged adjustment of quotes by market makers to new information or from lagged dissemination of information (Beja and Goldman (1979, 1980), Amihud and Mendelson (1987), Hasbrouck and Ho (1987), Damodaran (1993)). This has been interpreted as evidence of an information effect. A characteristic of information-based models is that price adjustment is not immediate and tends to be more permanent. That is why, since the short-run implications of inventory and information models are similar[9], some tests of inventory versus information-related effects are based on the short-run versus long-run dynamics (Hasbrouck (1996, 1988, 1991, 1991).

[9]Both predict that prices move in the direction of order flow: prices rise (fall) in response to a buy (sell) order either to rebalance inventory or in response to the information revealed.

There is strong evidence of negative serial correlation in quotes at very high frequency. On the foreign exchange markets, several studies on Reuters FXFX indicative quotes find strong sign of a first order moving average negative auto-correlation, disappearing as the information process is over. (Goodhart (1989), Goodhart and Figliuoli (1991), Goodhart and Giugale (1993), Baillie and Bollerslev (1990, 1990), Goodhart et al. (1996)). This evidence can be attributed to the fact that these quotes are indicative quotes from banks with different order imbalances or persistent tendency to quote high or low (Bollerslev and Domowitz (1993), Bollerslev and Melvin (1994)), or with different information sets (Goodhart and Figliuoli (1992)). It could also be due to the existence of thin markets (Goodhart and Payne (1996)). Goodhart et al. (1996) do not find a corresponding auto-correlation in real transaction prices on Foreign Exchange Market, possibly due to the small data sample. The quoted spread does not exactly reflect the transaction spread, which is usually smaller except in periods of high volatility (Goodhart et al. (1996))[10].

There is also evidence of strong positive autocorrelation in trades i.e., a trade at the ask (bid) is more likely to be followed by a trade at the ask (bid). (Huang and Stoll (1994), Madhavan et al. (1997), Easley et al. (1997b), Hasbrouck (1991, 1991, 1988), Hasbrouck and Ho (1987), Goodhart et al. (1996)). The positive auto-correlation in trades is stronger for stocks with a high volume, or when they are traded with a limit order procedure, while if the stock has a low volume, there might be negative autocorrelation in trades as a consequence of inventory control by dealers. While dealer pricing induces a negative autocorrelation in order arrival[11], other factors such as limitations of transaction size at posted orders, or asymmetric information tend to generate a positive correlation (e.g. Easley and O'Hara (1987)).

The empirical literature has also found a relation between trades and quotes (and spreads) and some evidence that trades cause price to move. Volume of trade leads to changes in the bid and ask prices quoted by the individual market makers through three

[10] The fact that the realised spread is less than the quoted spreads may be an implication of both the inventory cost model and of the adverse selection model. In the former case because the dealer changes both bid and ask prices after a trade to induce transactions that equilibrate inventory, while in the latter case prices are changed to reflect the information conveyed by the transaction.

[11] The dealer attempts to revert to a mean or preferred level of inventory, should imply stationarity in the inventory series. Indeed the hypothesis of unit root cannot be rejected probably due to the low power of the tests or to other factors such as a time-varying preferred inventory levels (Hasbrouck and Sofianos 1993, Madhavan and Smidt 1993).

channels: the inventory management control by market makers, the information content of the order flow (asymmetric information) and the quantity traded (Lyons (1995, 1996)).

It is however not very clear which trades drive prices. A larger trade should be associated to larger price effects both because of inventory positions of the market maker and because large trades should reveal more information. Market prices should vary with trade size, with large trades occurring at worse prices (as in Easley and O'hara (1987)), even though some theoretical models suggest that informed trades might prefer smaller trades to disguise their identity. (Admati and Pfleiderer (1988, 1989), Foster and Viswanathan (1990, 1993)). Madhavan and Smidt (1991) find that, on NYSE, price response is different for large trades and for buyer-initiated versus seller-initiated trades. The first result might be in part due to the particular trading mechanism. On the NYSE the large (block) trades are negotiated in the 'upstairs' market and then formally transacted ('crossed') on the exchange and reported to the transaction tape. These large orders are important for their size and for their specific trading mechanism and different price behaviour that they induce. (Holthausen, Leftwich and Mayers (1987), Barclay and Warner (1993), Burdett and O'Hara (1987), Grossman (1992), Seppi (1990, 1992), Madhavan and Cheng (1997), Keim and Madhavan (1996) and Seppi (1992)). Hasbrouck (1991, 1991) using data on NYSE, finds that prices adjust to trades with a lag and that the change in quotes is increasing in trade size. Spread size is positively related to trade size and the trade impact on prices is greater when spreads are wider. The price impact and the extent of information asymmetry are more significant for firms with smaller market values. In contrast, Goodhart et al. (1996), using FX data find that the direction of the trade has a significant effect while the quantity traded add little explanatory power. Similar results were found by Easley et al. (1997b) and Jones et al. (1994): it seems to be transactions, rather than volume, that move market prices[12]. While in Hasbrouck (1991, 1991) the size of quote revision has a significant effect on the order flow, Goodhart et al. (1996) find that the order flow is affected by the frequency of quote revisions, rather than by the size.

[12] Lyons (1994) using data on trades find that interdealers trading accounts for a large part of deals on forex, as a consequence of inventory rebalancing among dealers ("hot potato" hypothesis). Hence, the quantity traded is significant only when transaction intensity is low.

4.3 Empirical Tests of Spread Determination

Microstructure theory states that price adjust to past prices and trades to incorporate private information, to manage inventory and to cover operating costs. In general, the empirical literature on market microstructure finds some evidence of systematic behaviour in the short-run pattern of stock prices and supports both the inventory and adverse selection theories of the spread. The empirical studies suggest that the quoted spread is related to characteristics of securities such as the volume of trading, the stock price, the number of market makers, the risk of the security.

Dealers, facing inventory costs and adverse information risk, adjust quotes in response to the observed transactions and to reflect the information it conveys. (Hasbrouck (1988, 1991), Hasbrouck and Ho (1987), Madhavan and Smidt (1991), Stoll (1976, 1989), Roll (1984), Glosten and Harris (1988)). Ho and Macris (1984), based on Ho and Stoll (1983) model of inventory, find significant spread and inventory effects in the American Stock Exchange.

Since testing the pure inventory models is complicated by the lack of inventory data, there are only a few tests of pure inventory control models (Smidt (1971), Ho and Macris (1984)). Usually tests are conducted on the NYSE or by direct access to books of quotes and inventory positions of individual market makers (Lyons (1996b), Madhavan and Smidt (1991, 1993)).

Other studies include the possibility of asymmetric information, beside inventory control. Inventory and information models predict that prices move in the same direction as the order flow; hence it is difficult to distinguish the two effects. Some papers test the short-run mean reversion in securities prices and the short-run autocorrelation in trades implied by the inventory models. Hasbrouck (1988, 1991), Habrouck and Sofianos (1993) find relative weak intraday inventory effect in equity markets. Lyons (1995) finds strong evidence on the Foreign Exchange Market.

Madhavan and Smidt (1991) regress the price change over the direction of trade, its size and the inventory, thus capturing the three components of the cost of trading i.e., the information content of the order flow, the transaction and inventory carrying costs. Using data on NYSE, they find evidence of cost effects and asymmetric information as perceived by the specialist, and weak evidence of inventory effect. Other papers on

NYSE suggest that information asymmetries have a significant impact on prices (e.g., Glosten and Harris (1988), Easley et al. (1997a)).

The estimates of the relative importance of the different components vary across studies. This might be due to different specifications for the dynamics of the bid-ask spread and to the use of different datasets. As Goodhart and O'hara (1997) point out, these empirical results might be affected by the structure of the market. If, instead of one single market maker there are multiple dealers, the spread is not a choice variable and it is endogenously determined by the decisions of more market makers whose inventory positions are unknown.

Huang and Stoll (1994) model incorporates the various theories of market microstructure and lagged stock index futures returns. Empirical results support both the adverse selection theory of the bid-ask spread and the inventory theory. Results indicate that short-run quote and price changes are predictable on the basis of the information available when the predictions are made, including lagged futures returns. However, profitable arbitrage opportunities are not necessarily implied, given the presence of transaction costs.

Finally, there is a positive association between volatility and spreads, since greater volatility is related to the revelation of information and to price uncertainty. This relation can be accentuated if price volatility reflects the bid-ask bounce.

Easley et al (1996) show that infrequently traded stocks have a higher probability of information-based trades, hence they suggest that higher spreads are necessary to compensate the market makers for the greater risk. Market makers will cover themselves by conventionally larger spreads in period of higher risk such as the release of important news (Goodhart 1989), the closing or opening of the market (Bollerslev and Domowitz 1993) and lunch breaks (Muller et al. 1990). Volatility and spreads are high when market is thin but they are also positively correlated when market is very active. Spreads are found to depend positively on the variance and negatively on volume (see, Bollerslev and Domovitz (1993) and Bollerslev and Melvin (1994)). Bollerslev and Melvin (1994) regress the spread on a variety of explanatory variables (using indicative quotes on Foreign Exchange Market) and find that spreads rise as volatility increases. Foster and Viswanathan (1990) use intraday data on NYSE and find that trading costs and adverse selection component present a U-shape during the day. They also find patterns in interdaily data, such as a greater information effect on Monday. Madhavan et al. (1997) find that the inventory effect is greater at the end of the day. Foster and Viswanathan (1993) find that, on NYSE, return volatility is higher in the first half-hour of the day and that, for actively traded firms, trading volume is low and adverse selection costs are high on Monday.

4.4 The Volume-Volatility Relationship

Beside the serial correlation mentioned above, a number of studies, based on intraday and interday data, have reported evidence of other patterns in the behaviour of prices or returns, such as heteroskedasticity, kurtosis and skewness in daily price changes. Volume and volatility exhibit serial correlation and cross-correlation. Price volatility seems to be irregular, and to exhibit persistence, long memory and clusters, in line with the predictions of ARCH GARCH models. Market intraday patterns are also found in measures of trading activity such as transaction frequency, trading volume rates and bid-ask spreads. These patterns are found in different securities and markets.

Although the FX market is virtually a global market, strong (deterministic) seasonal patterns corresponding to the hour of the day, the day of the week and the presence of traders in the three major geographical trading zones, can be observed. These patterns are found for volatility, relative spread, tick frequency, volatility ratio and directional change frequency.

There is evidence of high autocorrelation (both short and long term) in volatility and clustering in period of high volatility and periods of low volatility on the line of ARCH-GARCH type models (Mandelbrot (1963), Engle (1982), Bollerslev (1986), Bollerslev et al. (1992)). Intra-daily studies confirm short and long term memory for the volatility (Dacorogna et al. (1993)) and other variables such as the spread (Muller and Sgier 1992), the tick frequency (Goodhart and Demos (1990), Muller et al. (1990)) and give some insights on the origin of these clusters. One possible interpretation is that it is due to the clustering of news as the market adjusts perfectly and immediately to it. Another possibility lies in the learning process of traders with different priors who may take some hours of trading to resolve their expectational differences after the arrival of important news. This would result in volatility spillovers (Engle et al. (1990), Lin et al. (1994), Baillie and Bollerslev (1989)).

Lamoureux and Lastrapes (1990) findings suggest empirical support for the notion that ARCH in daily stock return data reflects time dependence in the process generating the information flow reaching the market. ARCH-GARCH effects account for the persistence over time of volatility shocks, and for observed phenomena such as clustering, non-normality and non-stability of empirical asset return distributions. Daily trading volume (as a proxy for the arrival of information) has a significant explanatory power regarding the variance of daily returns, which is an implication of the assumption that daily returns are subordinated to intraday equilibrium returns. ARCH effects tend to disappear when volume is included in the variance equation. Lamoureux and Lastrapes (1990) use volume as a proxy for information arrival. Laux and Ng (1993) use the number of price changes.

Pesaran and Robinson (1993) suggest that the presence of ARCH in speculative price, instead of being generated by the information flow, might be the effect of a change in the significance attached to news items by market participants. The explanation relates to the activity of different types of speculators (fundamentalists and chartists) and to the resulting distribution of transactions through time.

Perhaps one of the most striking patterns is that both volume and volatility are persistent and they are highly correlated contemporaneously. The empirical research has identified a strong link between volume and the absolute value of price changes. The positive correlation between volume and volatility has a possible interpretation in terms of news arrivals. (Goodhart, Ito and Payne (1996), Goodhart and Giugale (1993), Goodhart and Demos (1990) Gallant, Rossi, Tauchen (1992))[13].

Information-based models imply that uninformed (liquidity) traders prefer to trade when markets are liquid and deep, so that trading costs are expected to be lower. This increases market depth and liquidity leading to concentration of trade. Informed traders will also trade to disguise their identity and information. Thus, more information is revealed and prices become more volatile. This can explain the observed positive relation

[13]Using the news pages from Ruters, Goodhart (1989) find no significant impact of general economic and political news, while major economic news announcements are significant (see also Godhart et al. (1993), Almeida, Goodhart and Payne (1996). However this effect is transitory and unpredictable, possibly due to the effect of nonlinearity (Guillaume et al. 1996).

between volume and volatility.

In Tauchen and Pitts (1983), the relationship arises because volume and volatility are both positively related to an unobserved mixing variable, the number of new pieces of information. This mixture of distributions approach is based on the idea that the information arrival induces traders to adjust their reservation prices. The resulting trade induces a change in market price[14]. The variance of the daily price change and the mean daily trading volume depend upon three factors: the average daily rate at which new information flows arrive to the market; the extent to which traders disagree when they respond to new information; the number of active traders in the market. In particular, given the number of traders, an increase in volume, due to diversion of beliefs, is associated with an increase in volatility. If the number of traders is growing, mean trading volume increases linearly with the number of traders and the variance of price change (average of traders' reservation prices) decreases with more traders (Jorion (1994), Tauchen and Pitts (1983)).

4.5 Intraday Seasonalities and Market Closures

As said above, there is evidence of a strong relationship between volume and volatility. In particular, trading activity and price volatility exhibit a U-shaped pattern during the trading period i.e., they tend to be concentrated at the opening and at the closing. U-shaped patterns in volume and volatility, as well as bid-ask spreads, are particularly evident on the NYSE, also due to the particular structure of this market. However, similar patterns in volume and volatility, though rarely for spreads, have been found also in other markets, such as LSE, NASDAQ, and Forex (e.g., Easley et al. (1997a), Goodhart and Demos (1992)). In general, markets with a well-defined daily opening and closure, produce these intraday patterns in volatility (and spreads), while markets with round-the-clock trading in partially overlapping regional segments, such as the Forex interbank market, produce more complex patterns (Wood et al. (1985), Harris (1986), Dacorogna et al. (1993), Andersen and Bollerslev (1998)). These patterns appear to be quite robust with respect to different market microstructures and to arise from time-of-

[14]Tauchen and Pitts assume price changes to be normally distributed. The Central Limit Theorem implies that daily price changes and volume can be described by mixtures of independent normals, where the mixing variable depends on the rate of information arrival. See also, Clark (1973).

day phenomena such as opening and closing, lunchtime, gap between close and opening in different areas.

In actual markets, trading takes place usually during organised trading sessions, separated by periods of non-trading or market closures (lunch break, overnight, weekend or holiday). The empirical literature on market closures has found several patterns in stock returns and trading activity associated with market closures. Intraday trading volume is U-shaped (Jain and Joh 1988). Week-end returns are lower than week-day returns (French (1980), Gibbons and Hess (1981), Keim and Stambaugh (1984)). Intraday mean return and volatility are U-shaped (Harris (1986, 1988, 1989), Gerety and Mulherin (1994), Andersen and Bollerslev (1994, 1987), Kleidon and Werner (1996), Foster and Viswanathan (1993)). Open-to-open returns are more volatile than close-to-close returns (Amihud and Mendelson (1987, 1988), Stoll and Whaley (1990), Gerety and Mulherin (1994)). Returns over trading periods are more volatile than returns over non-trading periods (Fama (1965), French and Roll (1986), Amihud and Mendelson (1991), Barclay, Litzemberher and Warner (1990)).

Several theoretical models attempt to understand these empirical findings (e.g., Admati and Pfeiderer (1988, 1989), Foster and Viswanathan (1990), Spiegel and Subrahmanyan (1995), Brock and Kleidon (1992)). Market closures may impact the economy in two ways: they preclude from trading in the market and they prevent investors from learning about the economy by observing market prices and trading activity. Trading increases volatility through the arrival of public information (more likely during trading hours) or through the revelation of the private information that motivates trades. Furthermore, errors in pricing are more likely to occur during trading hours.

Brock and Kleidon (1992) show that transactions demand at the open and close is greater and less elastic than at other times of the day. This greater desire to trade is motivated by the arrival of information during market's closure and, when closure approaches, by the fear of not being able to readjust before the closure. As market orders reveal private and public (or interpretation of public) information, volume and volatility as well as spreads rise. Gerety and Mulherin (1992) model the desire of trading at the beginning and at the end as a function of overnight volatility, and interpret this symmetric response of trading as being due to investors heterogeneity in the ability to bear risk when the market is closed and to the desire of investors to trade prior to market closings.

Stoll and Whaley (1990) suggest that the monopoly power of the specialist in setting the opening price could explain the evidence that open-to-open volatility is larger than close-to-close on NYSE. Biais, Hillion and Spatt (1998) find that orders in the pre-opening can convey information, particularly in the last few minutes before the opening, and contribute greatly to price discovery.

French and Roll (1986) examine stock market closures for which the flow of public information does not change. They find that return volatility decreases during these closures. They find only a small role for pricing errors and they conclude that private information is the main source of the high trading-time volatility on NYSE.

Ito, Lyons, Melvin, (1998) find that lunch-return variance doubles with the introduction of trading on the TSE[15] even though the flow of public information did not change and mispricing contribution to lunch-hour variance falls after the opening (while variance increases). They also find a flattening of the U-shaped patterns after the introduction of lunchtime trading, suggesting a reallocation of informative trades during lunch hours. They interpret these results as evidence of private information in the foreign exchange market. Andersen, Bollerslev and Das (1999) point out that these findings are affected by the technique used, sensitive to serial correlation and outliers in high frequency data. They develop a new robust approach[16] for inference with high frequency data and find that, apart from an increase in volatility over lunch (consistent with Ito, Lyons and Melvin), volatility patterns is unaffected by the deregulation.

5 Complexity, Predictability and Trading Rules

Standard theories based on hypothesis such as efficient markets and identical agents imply that prices reflect information, and rule out the possibility of abnormal returns and the usefulness of technical trading. The existence of nonlinearities and potentially predictable patterns together with the traders' view and the fact that technical rules are

[15]The Tokyo FX market was restricted from trading over the lunch break and this restriction has been abolished in December 1994.

[16]After having converted the FXFX quotes (indicative quotes) into a series of linearly interpolated continuously compounded five-minute returns, to eliminate the bias in these quotes, they use a Fourier flexible form regression and develop a inference procedure for hypothesis regarding the shape of the intraday pattern.

widely used have stimulated research in other directions. The objective is to account for systematic observable patterns, such as the correlation between trading volume and price volatility, or the autocorrelation in stock returns.

Recent studies suggest that asset returns exhibit nonlinear complex dynamics. Being characterised by large and unstable correlation dimension, returns are hard to predict out of sample (Brock (1998) Guillaume et al. (1997)). More sophisticated bootstrapping[17] type tests have found evidence of some conditional predictability of returns out of sample, provided the conditioning information set is chosen carefully. There seems to be empirical support for technical strategies in predicting stock price changes and that trading rules have predictive power in Forex (Brock, Lakonishok and LeBaron (1992, JF); Brock (1998); Le Baron (1992)). Goodhart and Curcio (1992) use data by Reuters instead of constructing artificial trading rules. Guillaume et al. (1997) report evidence of predictability in volatility. This evidence of predictability suggests the presence of more complex and time varying regularities and the possibility of abnormal returns using technical trading rules.

There is a vast amount of empirical literature reporting apparent anomalies in stock returns, i.e. abnormal returns related to different data frequencies. Some papers find evidence of day of the week effects, such as low mean returns on Monday (e.g. French (1980), Keim and Stambaugh (1984)), or week of the month effects (e.g. Lakonishok and Smidt (1988)). Other find evidence of month of the year effects (Keim (1983), Roll (1983)), such as high returns in January, or turn of the month effects (e.g. Lakonishok and Smidt 1988) and turn of the year effect (Lakonishok and Smidt (1984), Roll (1983)). Other evidence suggests the existence of a holiday effect (Lakonishok and Smidt (1988)).

Some of these calendar effects have been justified by theories relating to institutional arrangements in the markets. The January effect has been linked to year-end tax-loss selling pressure that could suppress stock prices in December. Thaler (1987) suggests that institutional and behavioural reasons, such as investors' pessimism or optimism and overreaction, might explain some of the calendar effects, such as the January effect. Explanation for the Monday effect include delays between trading and settlement in stocks (Lakonishok and Levi 1982), measurement error (Keim and Stambaugh 1984), institutional factors (Flannery and Protopapadakis 1988) and trading patterns (Lakonishok

[17]Bootstrapping is a technique of resampling from i.i.d. driven null models to approximate the null distribution of complicated statistics under such models.

and Maberly 1990).

Sullivan, Timmermann, White (1998) argue that the strong evidence of seasonal regularities in stock returns that seems to contradict the standard economic theory, might be simply a result of data snooping. They find that although many different calendar rules produce abnormal returns that are highly statistically significant when considered in isolation, once the effects of data-snooping and the dependencies operating across rules are accounted for, then the best calendar rule is not significant in the sense of its mean returns or Sharpe ratio performance. However, as they point out, they do not consider small or foreign firms' equities, which are more likely to exhibit calendar effects (e.g. Kamara 1998). It is also to be noted that many of these calendar effects do not necessarily imply inefficiency, as they often cannot be exploited to generate profits because of the presence of high transaction costs.

The co-existence of different types of traders might explain the fact that conditional forecasts are possible although price changes are globally unpredictable. Harris and Raviv (1993) present a model of trading based on differences of opinion to explain the empirical regularities in the time series properties of prices and volume and in the price-volume relationship. They find that the absolute price change and volume are positively correlated, consecutive price changes are negatively serially correlated, and volume is positively autocorrelated.

Dynamic learning or adaptive belief model, based on the heterogeneity of agent and social interactions in belief formation, attempt to understand the economic mechanisms that give rise to these facts (see Guillaume et al.(1997), Goodhart and O'Hara (1997), Brock and Le Baron (1996)). Guillaume et al. (1997) suggest that the nonlinearity, unpredictability and endogeneity (arising from information flows among agents) of the exchange rates dynamics, might be evidence of a complex chaotic system. It is the complex linear interaction and learning process that is responsible for the large and unpredictable movements of exchange rates movements.

Marengo and Torjman (1998) propose a model based on micro-heterogeneity and imperfect adaptive rationality in which market prices are determined by the interaction of agents with different and evolving beliefs. This can explain the persistence of predictable profit opportunities and the statistical anomalies of price series, such as leptokurtosis and volatility clustering. Arthur, Holland, LeBaron, Palmer, Tayler (1998) implement an artificial stock market to model asset pricing with heterogeneous agents, continuously adapting their expectations. They find statistical features characteristic of actual markets data: trading volume is high and autocorrelated, volatility is autocorrelated, there is a significant cross-correlation in volume and volatility and periods of quiescence alternate with periods of intense activity. Market exhibit complex patterns, with evidence of bubbles and crashes, heterogeneity of beliefs persist and technical rules are profitable. They give an evolutionary explanation to these empirical regularities, based on agents constantly exploring and testing new expectations. When more successful expectations are discovered, these change the market and trigger further changes in expectations, leading to increased volatility and volume (periods of turbulence followed by periods of quiescence). Beside these existing computer-simulated artificial markets, Chiaromonte and Dosi (1999) set up a micro-founded computer simulated model for decentralised trade. This environment allows experimenting with alternative hypothesis on individual behaviour and learning processes, and institutional characteristics of the markets.

Blume et al. (1994) show that technical analysis of volume data may be useful due to the multi-faceted nature of new information. While the information contained in prices is a major issue, other informative variables have been included in several models. Some of these include volume (Harris and Raviv (1993); Blume, Easley and O'Hara (1994)) and time (Hausman, Lo, MacKinley (1992)). There is some evidence that lagged volume has predictive power for near-future returns and price reversals tend to follow abnormally high volume (Brock (1998)). Similarly, some structural models that allow for nonlinearity in the trade/price impact (Hasbrouck (1991, 1991, 1993)).

Behavioural finance attempts to show how psychological factors can contribute to market prices under- or over-reacting to new information (e.g. Lee et al. (1991)). Thaler (1991) suggests that individuals have different beliefs and tend to overweight recent information and underweight prior data and to overreact to unexpected and dramatic news events. Such behaviours are likely to have an impact on price dynamics. This overreaction hypotheses can explain some empirical regularity, such as reversals and clustering in price movements. Also Guillaume et al. (1997) suggest that mean reversal in stock prices can be viewed as evidence of overreaction and of divergent opinions among traders.

Similarly, Daniel, Hirshleifer and Subrahmanyan (1998) propose a theory of securities markets under/overreactions based on investor overconfidence about the precision of private information and on variations in confidence arising from biased self-attribution of investment outcomes. The theory implies that investors tend to overreact to private information signals and to underreact to public information signals. These psychological factors account for some observed anomalies, such as the event-based return predictability, the short-term positive autocorrelation in stock returns, the long-term negative autocorrelation in returns and the high volatility of asset prices.

6 Conclusion

Over the last years the theoretical and empirical research on financial markets has seen an increasing interest in the short-run behaviour of markets arising from the interaction of heterogeneous traders in different market settings. Most of this research focuses on the information flows (both public and private), on the structural and organisational characteristics of competing markets, on alternative hypothesis on investors' behaviour and on the learning problems and interactions among heterogeneous traders.

This interest in the short-run dynamics has been followed by an increasing use of high frequency data and by the implementation of specific techniques to deal with them. Given the complexity of the empirical investigations and the limitations in the availability of data, the empirical research has been paralleled by a number of laboratory experiments, and in the last few years, by computer simulated markets. Computer experiments can be used to test alternative hypothesis on market structure and individuals' decision processes. The advantage of computer simulations is that they allow the study of complex interactions among heterogeneous agents and of the aggregate dynamics that emerge.

References

References

Admati A., Pfleiderer P. (1988), A Theory of Intraday Patterns: Volume and Price Variability. Review of Financial Studies, 1, 3-40

Admati A., Pfleiderer P. (1989), Divide and Conquer: A Theory of Intraday and Day-of-the-Week Mean Effects. Review of Financial Studies, 2, 189-223

Almeida A., Goodhart C., Payne R. (1998) The Effect of Macroeconomic 'News' on High Frequency Exchange Rate Behaviour. Journal of Financial and Quantitative Analysis, 33, 383-408

Amihud Y., Mendelson H. (1980) Dealership Market: Market-Making with Inventory. Journal of Financial Economics, 8, 31-53

Amihud Y., Mendelson H. (1987), Trading Mechanisms and Stock Returns: an Empirical Investigation. Journal of Finance, 42, 535-553

Amihud Y., Mendelson H. (1988) Liquidity and Asset Prices: Financial Management Implications. Financial Management, 17, 5-15

Amihud Y., Mendelson H (1991) Volatility, Efficiency and Trading: Evidence from the Japanese Stock Market, Journal of Finance, 46, 1765-1789

Amihud Y., Mendelson H., Murgia M. (1990) Stock Market Microstructure and Return Volatility: Evidence from Italy. Journal of Banking and Finance, 14, 423-440

Andersen T.G., Bollerslev T. (1997) Intraday Periodicity and Volatility Persistence in Financial Markets. Journal of Empirical Finance, 4, 115-158

Andersen T.G., Bollerslev T. (1998) Deutsche Mark- Dollar Volatility: Intraday Activity Patterns, Macroeconomic Announcements, and Longer-Run Dependencies. Journal of Finance, 53, 219-265

Andersen T.G., Bollerslev T., Das A. (1999) Testing for Microstructure Effects in Volatility: Revisiting the Tokyo Experiment. mimeo

Arthur W.B., Holland J.H., LeBaron B., Palmer R., Tayler P. (1998) Asset Pricing under Exogenous Expectations in an Artificial Stock Market. In The Economy as an Evolving System. Arthur et al. (eds.), Addison-Welsey

Baillie R.T., Bollerslev T. (1989) The Message in Daily Exchange Rates: A Conditional Variance Tale. Journal of Business and Economics Statistics, 7, 297-305

Baillie R.T., Bollerslev T. (1990) A Multivariate Generalized ARCH Approach to Modeling Risk Premia in Forward Foreign Exchange Rate Markets. Journal of International Money and Finance, 9, 309-324

Baillie R., Bollerslev T. (1991) Intra-Day and Inter-Market Volatility in Foreign Exchange Rates, Review of Economic Studies, 58, 565-585

Barclay M.J., Litzenberger R.H., Warner J.B. (1990) Private Information, Trading Volume and Stock-Return Variances. Review of Financial Studies, 3, 233-253

Barclay M.J., Warner J.B. (1993) Stealth Trading and Volatility: Which Trades Move Prices? Journal of Financial Economics, 34, 281-306

Beja A., Goldman M. (1979) Market Prices vs. Equilibrium Prices: Return Variances, Serial Correlation, and the Role of the Specialist, Journal of Finance, 34, 595-607

Beja A., Goldman M. (1980) On the Dynamic of Behavior of Prices in Disequilibrium. Journal of Finance, 35, 235-248

Biais B., Hillion P., Spatt C. (1995) An Empirical Analysis of the Limit Order Book and the Order Flow in the Paris Bourse. Journal of Finance, 50, 1655-1689.

Biais B., Hillion P., Spatt C. (1998) Price Discovery and Learning During the Preopening Period in the Paris Bourse. mimeo

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

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

Blume L.E., Easley D., O'Hara M. (1994) Market Statistics and Technical Analysis: The Role of Volume. Journal of Finance, 49, 153-181

Board J.L.G., Sutcliffe C.M.S. (1995) The Effects of Trade Transparency in the London

Stock Exchange: A Summary. London School of Economics, Financial Market Group, Discussion Paper.

Bollerslev T. (1986) Generalized Autoregressive Conditional Heteroskedasticity. Journal of Econometrics, 31, 307-327

Bollerslev T. Chou R.Y., Kroner K.F. (1992) ARCH Modeling in Finance: A Review of the Theory and Empirical Evidence. Journal of Econometrics, 52, 5-59

Bollerslev T., Domowitz I. (1991) Price Volatility, Spread Variability and the Role of Alternative Markets Mechanisms. Review of Futures Markets, 10, 78-102

Bollerslev T., Domowitz I. (1993) Trading Patterns and Prices in the Interbank Foreign Exchange Market. Journal of Finance, 48, 1421-1443

Bollerslev T., Melvin M. (1994) Bid-Ask Spreads and Volatility in the Foreign Exchange Market: An Empirical Analysis. Journal of International Economics, 36, 355-372

Brock W.A. (1998) Asset Price Behaviour in Complex Environments. In The Economy as an Evolving System. Arthur et al. (eds.), Addison-Welsey

Brock W.A., Kleidon A. (1992) Periodic Market Closure and Trading Volume. A Model of Intraday Bids and Asks. Journal of Economic Dynamics and Control, 16, 451-489

Brock W.A., Lakonishok J., LeBaron B. (1992) Simple Technical Trading Rules and the Stochastic Properties of Stock Returns. Journal of Finance, 47, 1731-1764

Brock W.A., LeBaron B. (1996) A Dynamic Structural Model for Stock Return Volatility and Trading Volume. Review of Economic and Statistics, 78, 94-110

Burdett K., O'Hara M. (1987) Building Blocks: An Introduction to Block Trading. Journal of Banking and Finance, 11, 193-212

Chan K. (1992) A Further Analysis of the Lead-Lag Relationship Between the Cash Market and Stock Index Futures Market. Review of Financial Studies, 5, 123-152

Chan K., Chan K.C., Karolyi G.A. (1991) Intraday Volatility in the Stock Index and Stock Index Futures Markets. Review of Financial Studies, 4, 657-684

Chiaromonte F., Dosi G. (1999) Modeling a Decentralized Asset Market: Financial "Toy Room", IIASA Interim Report

Christie W.G., Schultz P.H. (1994) Why do NASDAQ Market Makers Avoid Odd-Eighth Quotes? Journal of Finance, 49, 1813-1840

Christie W.G., Harris J.H., Schultz P.H. (1994) Why did NASDAQ Market Makers Stop Avoiding Odd-Eighth Quotes? Journal of Finance, 49, 1841-1860

Clark P.K. (1973) A Subordinated Stochastic Process Model with Finite Variance for Speculative Prices, Econometrica, 41, 135-155

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

Copeland T., Galai D. (1983) Information Effects and the Bid-Ask Spread, Journal of Finance, 38, 1457-1469

Cutler D.M., Poterba J.M., Summers L.H (1991), Speculative Dynamics. Review of Economic Studies, 58, 529-546.

Dacorogna M.M., Muller U.A., Nagler R.J., Olsen R., Pictet O. (1993). A Geographical Model for the Daily and Weekly Seasonal Volatility in the Foreign Exchange Market. Journal of International Money and Finance, 12, 413-438

Damodaran A. (1993) A Simple Measure of Price Adjustment Coefficients, Journal of Finance, 48, 387-400.

Daniel K., Hirshleifer D., Subrahmanyan A. (1998) Investor Psychology and Security Market Under- and Overreactions, Journal of Finance, 53, 1839-1885

De Jong F., Nijman T., Roell A. (1995) A Comparison of the Cost of Trading French Shares on the Paris Bourse and on SEAQ International. European Economic Review, 39, 1277-1301

Demos A., Goodhart C.A.E. (1990) Reuters Screen Images of the Foreign Exchange Market: the Deutschemark/Dollar Spot Rate. Journal of International Securities Markets, 4, 333-348

Demos A., Goodhart C.A.E. (1992) The Interaction between the Frequency of Market Quotations, Spread, and Volatility in the Foreign Exchange Market. London School of Economics, Financial Markets Group Discussion Paper, no. 152

Demsetz H. (1968), The Cost of Transacting, Quarterly Journal of Economics, 82, 33-53

Diamond D.W., Verrecchia R.E. (1987) Constraints on Short-Selling and Asset Price Adjustment to Private Information. Journal of Financial Economics, 18, 277-311

Domowitz I. (1990) The mechanics of Automated Trade Execution Systems. Journal of Financial Intermediation, 1, 167-194

Dutta P.K., Madhavan A. (1997) Competition and Collusion in Dealer Markets, Journal of Finance, 52, 245-276

Easley D., O'Hara M. (1987) Price, Trade Size, and Information in Securities Markets. Journal of Financial Economics, 19, 69-90

Easley D., O'Hara M. (1992) Time and Process of Security Price Adjustment. Journal of Finance, 47, 577-605

Easley D., Kiefer N.M., O'Hara M. (1997a) One Day in the Life of a Very Common Stock. Review of Financial Studies, 10, 805-835

Easley D., Kiefer N.M., O'Hara M. (1997b) The Information Content of the Trading Process. Journal of Empirical Finance, 4, 159-186

Easley D., Kiefer N.M., O'Hara M., Paperman J. (1996) Liquidity, Information, and Infrequently Traded Stocks, Journal of Finance, 51, 1405-1436

Engle R. (1982) Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. Econometrica, 50, 987-1007

Engle R.F., Ito T., Lin W.L. (1990) Meteor Showers or Heat Waves? Heteroskedastic Intra-Daily Volatility in the Foreign Exchange Market. Econometrica, 58, 525-542

Engle R.F, Russel J.R. (1997) Forecasting the Frequency of Changes in Quoted Foreign Exchange Prices with the Autoregressive Conditional Duration Model, Journal of Empirical Finance, 4, 187-212

Fama E.F. (1965) The Behavior of Stock Market Prices, Journal of Business, 38, 34-105

Fama E.F. (1970) Efficient Capital Markets: A Review of Theory and Empirical work, Journal of Finance, 25, 383-417

Flannery M.J., Protopapadakis A.A. (1988) From T-Bills to Common Stocks: Investigating the Generality of Intra-Week Return Seasonality. Journal of Finance, 33, 431-450.

Flood M.D., Huisman R., Koedijk K.G., Mahieu R.J (1999) Quote Disclosure and Price Discovery in Multiple-Dealer Financial Markets, Review of Financial Studies, 12, 37-59

Foster F.D., Viswanathan S. (1990), A Theory of the Interday Variations in Volume, Variance and Trading Costs in Securities Markets, Review of Financial Studies, 3, 593-624

Foster F.D., Viswanathan S. (1993) Variations in Trading Volume, Return Volatility, and Trading Costs: Evidence on Recent Price Formation Models. Journal of Finance, 48, 187-211

Fremault Vila A., Sandmann G. (1997), Floor Trading versus Electronic Screen Trading: an Empirical Analysis of Market Liquidity in the NIKKEI Stock Index Futures Markets. mimeo

French K.R. (1980) Stock Returns and the Weekend Effect. Journal of Financial Economics, 8, 55-70.

French K.R., Roll R. (1986) Stock Return Variances: The arrival of Information and the Reaction of Traders. Journal of Financial Economics, 17, 5-26.

Gallant A.R., Rossi P.E., Tauchen G. (1992) Stock Prices and Volume, Review of Financial Studies, 5, 199-242

Garbade K.D., Silber W. (1979), Structural Organization of Secondary Markets: Clearing Frequency, Dealer Activity and Liquidity Risk, Journal of Finance, 34, 577-593

Garman M. (1976) Market Microstructure, Journal of Financial Economics, 3, 257-275

Gemmil G. (1996) Transparency and Liquidity: A Study of Block Trades on the London Stock Exchange under Different Publication Rules. Journal of Finance, 1765-1790

Gennotte G., Leland H. (1990), Market Liquidity, Hedging and Crashes, American Economic Review, 80, 999-1021

Gerety M.S. and Mulherin J.H. (1991), Patterns in Intraday Stock Market Volatility, Past and Present. Financial Analysts Journal, 71-79

Gerety M.S. and Mulherin J.H. (1992) Trading Halts and Market Activity: An Analysis of Volume at the Open and the Close. Journal of Finance, 47

Gerety M.S. and Mulherin J.H. (1994) Price Formation on Stock Exchanges: the Evolution of Trading within the Day. Review of Financial Studies, 7, 609-629

Gibbons M.R., Hess P. (1981) Day of the Week Effects and Asset Returns. Journal of Business, 54, 579-596

Glosten L. (1987) Components of the Bid-Ask Spread and the Statistical Properties of Transaction Prices, Journal of Finance, 42, 1293-1307

Glosten L.R. (1989) Insider Trading, Liquidity and the Role of the Monopolist Specialist. Journal of Business, 54, 211-235

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

Glosten L.R., Harris L.E. (1988) Estimating the Components of the Bid-Ask Spread, Journal of Financial Economics, 21, 123-142

Glosten L.R., Milgrom P.R. (1985) Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders, Journal of Financial Economics, 14, 71-100

Goodhart C.A.E. (1989) News and the Foreign Exchange Market. Manchester Statistical Society, pamphlet.

Goodhart C.A.E., Curcio R.J. (1992) When Support/Resistance Levels are Broken, can Profits be Made? Evidence from the Foreign Exchange Market. London School of Economics, Financial Markets Group, Discussion Paper no. 142

Goodhart C.A.E., Figliuoli L. (1991) Every Minute Counts in Financial Markets, Journal of International Money and Finance, 10, 23-52.

Goodhart C.A.E., Figliuoli L. (1992) The Geographical Location of the Foreign Exchange Market: a Test of Island Hypothesis. Journal of International and Comparative Economics, 1, 13-28.

Goodhart C.A.E., Giugale M. (1993) From Hour to Hour in the Foreign Exchange Market. The Manchester School, 61, 1-34

Goodhart C.A.E., Hall S., Henry S., Pesaran B. (1993) News Effects in a High-Frequency Model of the Sterling-Dollar Exchange Rate. Journal of Applied Econometrics, 8, 1-13.

Goodhart C.A.E., Ito T., Payne R. (1996), One Day in June 1993: A Study of the Working of the Reuters 2000-2 Electronic Foreign Exchange Trading System. In Frankel J., Galli G. and Giovannini A. (eds.), The Microstructure of Foreign Exchange Markets, University of Chicago Press.

Goodhart C.A.E., O'Hara M. (1997) High Frequency Data in Financial Markets. Issues and Applications. Journal of Empirical Finance, 4, 73-114

Goodhart C.A.E., Payne R. (1996) Microstructural Dynamics in a Foreign Exchange Electronic Broking System. Journal of International Money and Finance, 15, 829-852

Griffiths M., Smith B., Turnbull D., White R. (1998) Information Flows and Open Outcry: Evidence of Imitation Trading. mimeo

Grossman S.J. (1992) The Informational Role of Upstairs and Downstairs Trading, Journal of Business, 65, 509-528.

Grossman S.J., Stiglitz J.E. (1980), On the Impossibility of Informationally Efficient Markets, American Economic Review, 70, 393-408

Guillaume D., Dacorogna M.M., Dave R., Muller U.A., Olsen R.B., Pictet O. (1997) From the Bird's Eye to the Microscope: A Survey of New Stylized Facts of the Intra-Daily Foreign Exchange Market. Finance and Stochastic, 1, 95-129

Hamao Y., Masulis R.W., Ng V. (1990) Correlations on Price Changes and Volatility across International Stock Markets. Review of Financial Studies, 3, 281-308

Harris L. (1986) A Transaction Data Study of Weekly and Intradaily Patterns in Stock Returns. Journal of Financial Economics, 16, 99-117

Harris L. (1988) Intraday Stock Return Patterns. In Dimson E. (eds), Stock Market Anomalies, Cambridge University Press.

Harris L. (1989) The October 1987 S&P 500 Stock-Futures Basis. Journal of Finance, 44, 77-99.

Harris L. (1991) Stock Price Clustering and Discreteness, Review of Financial Studies, 4, 389-415

Harris L. (1994) Minimum Price Variations, Discrete Bid-Ask Spreads and Quotation Sizes, Review of Financial Studies, 7, 149-178.

Harris M., Raviv A. (1993) Differences of Opinion Make a Horse Race. Review of Financial Studies, 6, 473-506.

Harris L., Sofianos G., Shapiro J.E. (1994), Program Trading and Intraday Volatility. Review of Financial Studies, 7, 653-685

Hasbrouck J. (1988) Trades, Quotes, Inventories and Information. Journal of Financial Economics, 22, 229-252

Hasbrouck J. (1991) Measuring the Information Content of Stock Trades. Journal of Finance, 46, 179-207

Hasbrouck J. (1991) The Summary Informativeness of Stock Trades: An Econometric Analysis. Review of Financial Studies, 4, 571-595

Hasbrouck J. (1993) Assessing the Quality of a Security Market: a New Approach to Transaction-Cost Measurement, Review of Financial Studies, 6, 191-212

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

Hasbrouck J. (1996) Modeling Market Microstructure Time Series. In Maddala G.S., Rao C.R. (eds.), Statistical Methods of Finance, Handbook of Statistics Series, vol. 14, 647-692

Hasbrouck J., Ho T.S.Y. (1987) Order Arrival, Quote Behavior and the Return-Generating Process. Journal of Finance, 42, 1035-1048

Hasbrouck J., Sofianos G. (1993) The Trades of Market Makers: An Empirical Analysis of NYSE Specialists. Journal of Finance, 48, 1565-1593

Hausman J., Lo A., Mackinley A.C. (1992) An Ordered Probit Analysis of Transaction Stock Prices, Journal of Financial Economics, 31, 319-379.

Ho T., Macris R. (1984) Dealer Bid-Ask Quotes and Transaction Prices: An Empirical Study of Some AMEX Options. Journal of Finance, 39, 23-45

Ho T., Schwartz R.A., Whitcomb D.K. (1981) A Comparative Analysis of Alternative

Security Market Trading Arrangements, New York Stock Exchange

Ho T., Schwartz R.A., Whitcomb D.K. (1985), The Trading Decision and Market Clearing Under Transaction Price Uncertainty, Journal of Finance, 21-42

Ho, T.S.Y., Stoll H.R. (1983) The Dynamics of Dealer Markets under competition. Journal of Finance, 38, 1053-1075

Hogan K., Melvin M. (1994) Sources of Meteor Showers and Heat Waves in the Foreign Exchange Market. Journal of International Economics, 37, 239-247

Holden C., Subrahamanyan A. (1992) Long-Lived Private Information and Imperfect Competition. Journal of Finance, 47, 247-270

Holthausen R.W., Leftwich R.W., Mayers D. (1987) The Effect of Large Block Transactions on Security Prices: A Cross-Sectional Analysis. Journal of Financial Economics, 19, 237-267

Huang R.D., Stoll H.R. (1994) Market Microstructure and Stock Returns Predictions. Review of Financial Studies, 7, 179-213

Ito T., Engle R.F., Lin W.L. (1992) Where Does the Meteor Shower Come from? Journal of International Economics, 32, 221-240

Ito T., Lyons R.K., Melvin M.T. (1998) Is There Private Information in the FX Market? The Tokyo Experiment. Journal of Finance, 53, 1111-1130.

Jain P.C., Joh G.H. (1988) The Dependence between Hourly Prices and Trading Volume. Journal of Financial and Quantitative Analysis, 23, 269-283

Jones C.M., Kaul G., Lipson M.L. (1994) Transactions, Volume, and Volatility. Review of Financial Studies, 7, 631-651

Jorion P. (1996) Risk and Turnover in the Foreign Exchange Market. In Frankel J.A., Galli G. and Giovannini A. (eds.), The Microstructure of Foreign Exchange Markets, University of Chicago Press.

Kamara A. (1998) Time Variation in the Turn-of-the-Year Seasonal. University of Washington and University of California, Los Angeles, Mimeo

Kawaller I., Koch P., Koch T. (1987) The Temporal Price Relationship Between S&P

500 Futures and the S&P 500 Index. Journal of Finance, 42, 1309-1329

Kawaller I., Koch P., Koch T. (1990) Intraday Relationships between Volatility in S&P 500 Futures Prices and Volatility in the S&P 500 Index. Journal of Banking and Finance, 14, 373-397

Keim D. (1983) Size-Related Anomalies and Stock Return Seasonality: Further Statistical Evidence. Journal of Financial Economics, 12, 13-32

Keim D., Madhavan A. (1996) The Upstairs Market for Large-Block Transactions: Analysis and Measurement of Price Effects. Review of Financial Studies, 9, 1-36

Keim D.B., Stambaugh R.F. (1984) A Further Investigation of the Weekend Effect in Stock Returns. Journal of Finance, 39, 819-835.

Kleidon A., Werner I. (1996) U.K. and U.S. Trading of British Cross-Listed Stocks: an Intraday Analysis of Market Integration. Review of Financial Studies, 9, 619-664.

Kyle A.S. (1984) Market Structure, Information, Futures markets, and Price Formation. In International Agricultural Trade: Advances Readings in Price Formation, Market Structure and Price Stability, Story G., Schmitz A., Sarris A. (eds.), Westview Press, London

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

Kyle A.S. (1989), Informed Speculation with Imperfect Competition, Review of Economic Studies, 56, 317-356

Lakonishok J, Levi M. (1982) Weekend Effects on Stock Returns: A Note. Journal of Finance, 37, 883-889

Lakonishok J., Maberly E. (1990) The Weekend Effect: Trading Patterns of Individual and Institutional Investors. Journal of Finance, 40, 231-243

Lakonishok J., Smidt S. (1984) Volume and Turn-of-the-Year Behaviour. Journal of Financial Economics, 13, 435-456

Lakonishok J., Smidt S. (1988) Are Seasonal Anomalies Real? A Ninety-Year Perspective., Review of Financial Studies, 1, 403-425.

Lamoureux C.G., Lastrapes W.D. (1990) Heteroskedasticity in Stock Return Data: Volume versus GARCH Effects. Journal of Finance, 45, 221-229

Laux P.A., Ng L.K. (1993) The Sources of GARCH: Empirical Evidence from an Intraday Returns Model Incorporating Systematic and Unique Risk. Journal of International Money and Finance, 12, 543-560

Leach J.V., Madhavan A. (1992) Intertemporal Price Discovery by Market Makers: Active versus Passive Learning, Journal of Financial Intermediation, 2, 207-235

Leach J.C., Madhavan A. (1993), Price Experimentation and Security Market Structure, Review of Financial Studies, 6, 375-404

LeBaron B. (1992) Do Moving Average Trading Rule Results Imply Nonlinearities in Foreign Exchange Markets? University of Wisconsin, technical report.

Lee C.M.C., Shleifer A., Thaler R.H. (1991) Investor Sentiment and the Closed-End Fund Puzzle. Journal of Finance, 46, 75-110

Lin W.L., Engle R.F., Ito T. (1994) Do Bulls and Bears Move Across Borders? International Transmission of Stock Returns and Volatility. Review of Financial Studies, 7, 507-538

Lo A.W., Mackinley A.C. (1988) Stock Market Prices Do Not Follow Random Walks: Evidence from a Simple Specification Test. Review of Financial Studies, 1, 41-66

Lyons R.K. (1995) Test of Microstructural Hypothesis in the Foreign Exchange Market. Journal of Financial Economics, 39, 321-351

Lyons R.K. (1996), Foreign Exchange Volume: Sound and Fury Signifying Nothing?, In Frankel J.A., Galli G. and Giovannini A. (eds.), The Microstructure of Foreign Exchange Markets, University of Chicago Press.

Lyons R.K. (1996) Optimal Transparency in a Dealer Market with an Application to Foreign Exchange. Journal of Financial Intermediation, 5, 225-254

Madhavan A. (1992) Trading Mechanisms in Securities Markets, Journal of Finance, 47, 607-642

Madhavan A. (1995) Consolidation, Fragmentation, and the Disclosureof Trading Information. Review of Financial Studies, 8, 579-603

Madhavan A., Cheng M. (1997) In Search of Liquidity: Block Trades in the Upstairs and Downstairs Markets. Review of Financial Studies, 10, 175-203

Madhavan A., Panchapagesan V. (1999) Price Discovery in Auction Markets: A Look Inside the Black Box, University of Southern California, mimeo

Madhavan A., Richardson M., Roomans M. (1997) Why Do Security Prices Change? A Transactions-Level Analysis of NYSE Stocks. Review of Financial Studies, 10, 1035-1064

Madhavan A., Smidt S. (1991) A Bayesian Model of Intraday Specialist Pricing. Journal of Financial Economics, 30, 99-134

Madhavan A., Smidt S. (1993) An Analysis of Changes in Specialist Inventories and Quotations. Journal of Finance, 48, 1595-1628

Mandelbrot B.B. (1963) The Variation of Certain Speculative Prices. Journal of Business, 36, 394-419.

Marengo L., Tordjman H. (1996) Speculation, Heterogeneity and Learning: A Simulation Model of Exchange Rates Dynamics. Kiklos, 49, 407-438

Mendelson H. (1982), Market Behavior in a Clearing House, Econometrica, 50, 1505-1524

Mendelson H. (1985), Random Competitive Exchange: Price Distributions and Gains from Trade, Journal of Economic Theory, 254-280

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

Muller U.A., Dacorogna M.M., Olsen R., Pictet O., Schwarz M., Morgenegg C. (1990) A Statistical Study of Foreign Exchange Rates, Empirical Evidence of a Price Change Scaling Law, and Intraday Analysis. Journal of Banking and Finance, 14, 1189-1208.

Muller U.A., Sgier R. (1992) Statistical Analysis of Intra-Day Bid-Ask Spreads in the Foreign Exchange Market. Internal Document UAM 04-10, Olsen and Associates, Zurich

O'Hara M. (1995), Market Microstructure Theory, Blackwell Publishers, Cambridge, MA

O'Hara M., Oldfield G.S. (1986) The Microeconomics of Market Making. Journal of Financial and Quantitative Analysis, 21, 361-376

Pagano M, Roell A. (1991) Dually-Traded Italian Equities. Lonmdon School of Economics, Financial Markets Group, discussion paper no. 116.

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

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

Pesaran B., Robinson G. (1993), The European Exchange Rate Mechanism and the Volatility of the Sterling-Deutschemark Exchange Rate, Economic Journal, 103, 1418-1431

Porter D.C. (1992) The Probability of a Trade at the Ask: An Examination of Interday and Intraday Behavior. Journal of Financial and Quantitative Analysis, 27, 209-227

Roll R. (1983) Vas ist Das? The Turn-of-the-Year Effects and the Return Premia of Small Firms, Journal of Portfolio Management, 18-28

Roll R. (1984), A Simple Implicit Measure of the Effective Bid-Ask Spread in an Efficient Market, Journal of Finance, 39, 1127-1159

Seppi D.J. (1990) Equilibrium Block Trading and Asymmetric Information, Journal of Finance, 45, 73-94.

Seppi D.J. (1992) Block Trading and Information Revelation Around Quarterly Earnings Announcements, Review of Financial Studies, 5, 281-305.

Sofianos G., Werner I. (1998) The Traders of NYSE Floor Brokers, mimeo

Spiegel M., Subrahmanyan A. (1995) On Intraday Risk Premia. Journal of Finance, 50, 319-339.

Stoll H.R. (1978) The Supply of Dealers Services in Securities Markets, Journal of Finance, 33, 1133-1151.

Stoll H.R. (1989) Inferring the Components of the Bid-Ask Spreads: Theory and Empirical Tests. Journal of Finance, 44, 115-134

Stoll H.R. (1992) Principles of Trading Market Structure. Journal of Financial Services and Research, 6, 75-107;

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

Sullivan R., Timmermann A., White H. (1998) Dangers of Data-Driven Inference: The Case of Calendar Effects in Stock Returns. London School of Economics, Financial Markets Group Discussion Paper no. 304.

Tauchen G.E., Pitts M. (1983) The Price Variability-Volume Relationship on Speculative Markets. Econometrica, 51, 485-505.

Thaler R.H. (1987) Anomalies: The January Effect. Journal of Economic Perspectives, 1, 197-201

Thaler R.H. (1987) Anomalies: Weekend, Holiday, Turn of the Month, and Intraday Effects. Journal of Economic Perspectives, 1, 169-178

Thaler R.H. (1991) Quasi Rational Economics, Russel Sage Foundation, New York

Tinic S.M. (1972), The Economics of Liquidity Services, Quarterly Journal of Economics, 86, 79-94