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DAILY DISTRIBUTION OF SWEDISH OMX-INDEX RETURNS OVER INTRADAY-TO-INTRADAY TIME INTERVALS*

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This paper examines the intradaily behaviour of the Swedish OMX stock index during the time period January 02 to December 30 1992. Daily 24-hour returns are calculated in 18 different time intervals during the day: open-to-open, intraday-to-intraday and close-to-close. Evidence of different OMX-return generating distributions is found. It is most striking when the distributions from the beginning and the end of the day are compared with the distributions terminating during the middle of the day. The evidence of differences in the variances and autocorrelations is supported by robust significance tests within a simplified setting of the Generalized Method of Moments (GMM) estimation. The variances show a U-shaped pattern when they are plotted against the terminal time of the returns as international studies also have shown, whereas the autocorrelations behave almost in an opposite fashion, which is inconsistent with previous research. Since the series of interval returns are exposed to the same flow of information the differences must be due to microstructure effects. The friction in the market prices seems to be more severe at the beginning and at the end of the trading day than at times in between. This implies that there is comparatively more noise in the pricing process just after the opening and prior to the closing of the exchange. (JEL G10, G12)

1. Introduction

The research in the field of the microstructure of various national stock markets has emphasized the importance of considering exchange-specific features when analyzing the behaviour of stock prices and returns. The reason is that microstructural considerations such as the interplay between the market participants and the trading mechanisms may give rise to different kinds of friction in the market prices. Goldman and Beja (1979) argue that these kinds of frictions make the observed market prices differ from the intrinsic equilibrium values of the stocks. They also suggest a model for explaining the process by which prices adjust towards their equilibrium values.

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Their model results in a number of implications for empirical research concerning the return generating process of the stocks. One of these is that it is possible to derive expressions for the moments of the returns that are depending on how severe the friction is. For instance, the presence of friction in the pricing process causes the variance to be higher and induces a serial dependence among the returns.

Amihud and Mendelson (1987) use a revised version of this model in their empirical investigation. They examine the effects of different trading mechanisms on the behaviour of stock prices at the New York Stock Exchange (NYSE). At the NYSE, the opening procedure resembles a call market procedure whereas the closing transactions are made at prices set continuously by market specialists. To see if there are any effects on prices caused by the trading mechanism per se, they estimate open-to-open and close-to-close returns. Since both return series are affected by the same flow of information any observed differences should be due to microstructure effects such as which trading mechanism is used. The results indicate that the returns seem to be more volatile and serially correlated at the open. In terms of the model there seems to be more friction in the prices resulting from the call market procedure than from the continuous one. This finding is supported by the results of Stoll and Whaley (1990). They use basically the same methodology as Amihud and Mendelson (1987), but they compare open-to-open and close-to-close returns for a considerably larger sample of NYSE stocks.

Amihud et al. (1990) use the same methodology but a different sample of stock prices from the Milan Stock Exchange. Trading at the Italian market is also conducted with two different trading mechanisms: a call and a continuous one. However, the structure is not the same as on the NYSE. The trading in stocks during a typical trading day is first opened at a continuous market, then traded at a call and finally at the continuous again. The prices used by the authors in their investigation are the opening price from the continuous market, the single one resulting from the call and the closing one from the continuous. Their results show that the opening transactions from the continuous market seem to be more volatile. They also suggest that opening the market with the call procedure might reduce the friction in the first transaction price of the trading day.

The methodology is illustrated for a third time by Amihud and Mendelson (1991) with evidence from the Tokyo Stock Exchange. The Japanese trading day is organized in two sessions: the morning and the afternoon. The two sessions are separated by a two-hour nontrading period and they are both opened with a call market procedure. During the rest of the trading day a continuous trading method is used. The results of their investigation, involving the estimation of four 24-hour return series, indicate that the opening prices of the morning trading session contain more friction than the other three prices. This, argue the authors, may be due to the fact that the opening of the morning trading is preceded by an 18-hour nontrading period, whereas the opening of the afternoon trading is only preceded by a two-hour nontrading period.

Alongside with these direct tests of the impact of the microstructure on market prices there exists a slightly different approach which aims to investigate the intradaily behaviour of stock prices and returns without a model based on the microstructure. Harris (1986) and McInish and Wood (1990) both use transaction data from the NYSE in their studies. They conclude that the intradaily stock prices seem to be more volatile at the opening and the closing of the exchange than during the rest of the trading day.

Wood et al. (1985) have also shown that the return generating process for NYSE opening and closing prices seem to be different in comparison with the one for prices during the middle of the trading day. Not only the volatility, i.e. the variance, of stock returns, but also the degree of serial dependence seems to follow a kind of U-shaped pattern. McInish and Wood (1991) study the estimated autocorrelations of the daily NYSE stock index returns measured in 24-hour intraday-to-intraday time intervals. They show that the autocorrelations reveal a U-shaped pattern when they are plotted against the terminal time of the returns.

A comparison between these studies of different national stock markets show the importance of considering microstructure effects in financial analyses. If an investigation of, for example, the stock return generating process in the US comes up with different results compared to a similar investigation carried out in Japan, one should not be too surprised. The differences may be due to dissimilarities in the trading mechanisms used in the two stock markets. To be able to fully understand the functioning of stock markets under different trading mechanisms the analysis must be extended to include other national stock exchanges in the world. In this paper an attempt is made to describe the structural features of the Swedish Stock Exchange and to analyse a set of intradaily data from this market. This has never been done before, probably because of the great amount of work attached to the matter of getting hold of Swedish stock data of such a finetuned character.

The paper is an attempt to combine the two approaches described above. It will contain both a description and implicit testing of a model of the microstructure of the Swedish stock market as well as a purely empirical investigation of the intradaily behaviour of its prices. The trading at the Swedish Stock Exchange is executed with two different procedures. The opening transaction is made at a call market while the rest of the transactions during the day are made at a continuous. The model from Goldman and Beja (1979), with the revisions carried out in Amihud and Mendelson (1987), will be used to theoretically isolate the effects of the friction on stock prices. The methodology from McInish and Wood (1991) will then be used to accomplish the same thing empirically: i.e. 24-hour returns are calculated not only using the opening and closing prices but also intradaily ones terminating every 15th minute.

To be able to compare the series of returns, or rather their moments, a testing procedure is needed. In finding a suitable one a great deal of caution is warranted. The reason is that the series of interval returns, for instance the open-to-open and the close-to-close, are overlapping. Therefore, they can not be regarded as independent and usual tests, relying on for instance the F-distribution, can not be used to compare variances and autocorrelations across intervals. Surprisingly, this problem is not recognized in any of the hitherto cited studies. In this paper, a testing procedure within a simplified setting of the Generalized Method of Moments (GMM) estimation, originally developed by Hansen (1982), is presented. This is constructed in order to take into account the overlapping features of the interval returns.

The results show that the volatility of the 24-hour returns is significantly larger when terminating during the morning and late afternoon trading hours than during the midday. That is to say, when the variances are plotted against the terminal time of the returns they reveal a U-shaped pattern. The first order autocorrelations of the same returns also show significant differences throughout the trading day. But the graphical pattern seems to be the reverse. The autocorrelation coefficients of the returns terminating at the beginning and towards the end of the trading day are not significantly different from zero whereas the ones in between have a tendency to be significantly positive. This kind of behaviour of the returns can not be attributed to a difference in the trading mechanisms. If that were the case, only the open-to-open returns would deviate from the rest and not all of the returns terminating at times before and after noon. Instead, one interpretation of the results is that the pricing process contains comparatively more noise just after the opening and prior to the closing of the exchange. In addition, the adjustment of the prices to information is only partial, i.e. the traders seem to underreact with respect to the flow of information during the whole trading day.

The rest of this paper is organized as follows. Section 2 contains a brief description of the institutional characteristics of the Swedish Stock Exchange. The emphasis is on the process of the trading in the stocks. In section 3 a pricing model isolating the effects of the stock market microstructure, such as the trading mechanisms, is presented. Using the methodology and data from section 4, and the testing procedure from section 5, the empirical analysis of intradaily stock pricing is conducted in section 6. The results, already touched upon, is also presented there in a more elaborate way. Finally, the paper ends with some concluding remarks in section 7.

2. *Institutional characteristics of the Swedish Stock Exchange*

The Stockholm Stock Exchange *(Stockholms fondbörs)* is one of the 15 to 20 largest stock exchanges in the world. However, the most actively traded Swedish stocks are listed on foreign exchanges as well. Especially London (ISE/SEAQ) but also New York (NASDAQ) are important. It is worth noting that approximately half of the market value of the worldwide trading in Swedish stocks is due to trading by foreign investors. For readers interested in historical aspects of the Swedish Stock Exchange the paper of Frennberg and Hansson (1992) is recommended.

The trading at the marketplace is conducted by official stockbrokers *(börsombud)* employed by so called members of the exchange *(börsmedlemmar)*. The latter ones were at the turn of the year 26 in number: 10 banks and 16 stockbroker firms. The marketplace itself is not any longer situated at the traditional trading floor. Since April 1991 the trading in all stocks is computerized. The computer system, called Stockholm Automated eXchange (SAX), is in a way a form of decentralizing the trading in the stocks. Instead of being concentrated to the floor in Stockholm the stock transactions can take place wherever a SAX-terminal is located.

The SAX forms a continuous trading mechanism. When trading starts at 10.00 the computers are switched on and they are switched off at 14.30, the closing of the exchange. During this trading time period all orders, whether they are large, small or in blocks, can be matched either automatically or manually within the mechanism. The trading is carried out with a stockbroker who is obliged to either buy or sell immediately when so is required. To be able to provide this immediacy the broker charges a bid-ask-spread as a compensation. Thus, prices are set continuously during the whole trading day. However, the opening transactions are not executed with this continuous trading mechanism. An opening routine resembling an auction call procedure is present in the SAX. This routine is almost in line with the opening procedure, or clearing as Amihud and Mendelson (1987) prefer to call it, at the New York Stock Exchange (NYSE).

At the open, an opening stock price is set with respect to batched orders, made during the period of nontrading, since the closing of the preceding trading day. The opening transactions are made at this single market clearing price. The opening routine is held sequentially for groups of around ten stocks, with a one-minute break between groups. The opening procedure takes about 15 to 20 minutes to be completely executed, and no orders but the batched ones are submitted to trading. During this period, transactions can be made at other prices than the opening price for the groups of stocks already opened. Hence, the continuous trading commences immediately after the opening, and it is in play until the closing of the exchange at 14.30.

When comparing these procedures to the opening and closing features of the NYSE, some remarks are in order. At the NYSE trading in all stocks is opened at the same time. However, as Stoll and Whaley (1990) note, there is a time delay until the first transaction of the day actually take place. This time delay seems to depend on the trading volumes of the individual stocks. For more (less) actively traded stocks the delay tends to be relatively shorter (longer). Stoll and Whaley conclude that the trading typically stops before the closing at the NYSE. In 1986 an average of 20 minutes elapsed between the last trade and the closing of the NYSE trading day. For the most actively traded stocks the time elapsed is on the average less than one minute. Furthermore, contrary to the Swedish Stock Exchange, the continuous trading at the NYSE does not commence until all of the stocks have gone through the opening procedure. A more detailed description of the actual trading structure at the Swedish Stock Exchange is made in Niemeyer and Sandås (1992).

This amounts to the fact that two different trading mechanisms are operating during a normal trading day. Therefore, the different impacts of these mechanisms on the pricing process can be studied by comparing the opening prices with transaction prices during the rest of the day. This can be done with the assistance of the methodology outlined below.

3. *A pricing model for isolating the microstructure effects*

Changes in stock prices, and stock index prices, are induced by the arrival of new information (see e.g. French and Roll, 1986). The celebrated efficient market paradigm postulates that as soon as a piece of new relevant information reaches the market, the prices immediately change to reflect it. Thus, the stock prices are at all times efficient carriers of the entire set of information. However, to be incorporated in market prices the information flows have first to be interpreted and acted upon by the active traders in the market. This process can give rise to different kinds of friction in the prices.

In his much cited article Black (1986) introduces the concept of noise trading, i.e. by his definition trading on noise as if it was information. According to Black, movements in stock prices can occur although no real new information reaches the market. Furthermore, the traders can react differently to the same set of information. Overreaction of some traders to information may e.g. cause prices to change more than would have been the case if the information had been correctly interpreted. Finally, the trading mechanism, by which prices are set in the market, can in itself have pervasive impacts on the pricing process. Throughout this paper the word friction is used to cover the effects of noise trading, incorrect reactions among traders to information and trading mechanisms on stock prices.

All these microstructure effects imply that the transaction prices differ from what they otherwise would be in a frictionless market (see Cohen et al., 1980). Goldman and Beja (1979) develop a model of the behaviour of stock prices that distinguishes between the observed market price and a theoretical, frictionless, equilibrium value. Their model is dynamic in its nature and rests on the assumption that prices are generated by a continuous time process. Relaxing this assumption, and analysing prices in discrete time intervals, Amihud and Mendelson (1987) use a similar model. The latter one will be described below. In particular, the implications of the model for the moments of the stock returns are examined. The second moment, i.e. the variance and the autocovariance function, is of primary interest to the analysis in the following sections.

Let P_t be the natural logarithm of the stock price observed at time t and V_t the natural logarithm of the intrinsic equilibrium value of the stock. The price discovery process, i.e. the process by which the price of the stock adjust towards its equilibrium value, can be illustrated as:

$$(1) \quad P_t - P_{t-1} = g(V_t - P_{t-1}) + u_t,$$

where g is the adjustment coefficient and the $\{u_t\}$ sequence consists of white noise disturbances each with zero mean and variance σ^2. The natural logaritm of the stock value is assumed to follow a random walk process with drift:

$$(2) \quad V_t = V_{t-1} + m + e_t,$$

where m is the drift-term, i.e. the expected value return, and the $\{e_t\}$ sequence consists of white noise disturbances, independent of $\{u_t\}$ and each with zero mean and variance v^2 .

When new information concerning the stock becomes known to the traders, it affects the value of the stock via the random variable e. If the market is completely free from friction, i.e. if $g = 1$ and $\sigma^2 = 0$, the market price will change accordingly through equation (1) when trading actually take place. If traders have different opinions about the content of the information, the market price will not change in parity with value. This scenario is illustrated in equation (1) when the adjustment coefficient g is not equal to one. An implicit assumtion in this model is that the market is efficient in the sense that all traders react instantly to information. However, their perception of the information may well be incorrect. The traders are allowed both to overreact and underreact. As a consequence, the adjustment process of the price towards its value becomes excessive ($g > 1$) and partial ($g < 1$) respectively. Note that the assumption $0 < g < 2$ is made throughout the analysis.

When informationless trading occurs the picture is quite different. Such noise trading, or liquidity trading as Foster and Viswanathan (1990) prefer to name it, does not give rise to any change in value. However, the observed price is affected through the random variable u in equation (1).

It can be shown that the return of the stock, observed at time t, can be written as:

$$(3) \quad R_t = P_t - P_{t-1} = m + g\sum_{i=0}^{\infty}(1-g)^i(e_{t-i} - u_{t-i-1}) + u_t.$$

The theoretical moments, especially the variance and the first order autocovariance, of the returns can be derived from equation (3). The variance of R_t can be written as:

$$(4) \quad \mathrm{Var}(R_t) = \frac{g}{2-g}v^2 + \frac{2}{2-g}\sigma^2.$$

It is interesting to note that the friction in the prices mentioned above contributes to the observed variance in equation (4). Apart from the value return variance v^2, the expression depends on the adjustment coefficient g and the variance of the noiseterm u_t. When the traders overreact (underreact) to information and $1 < g < 2$ $(0 < g < 1)$, the first part of equation (4) is greater (less) than v^2. Thus, overreaction (underreaction) gives rise to higher (lower) variability in the observed returns. The second part of equation (4) represents the contribution of the effects of noise trading and friction-impeding trading-mechanisms to the observed variance. The more important these effects are the larger the »noisy» variance σ^2 must be.

An expression for the first order autocorrelation coefficient of the stock returns R_t is also derived:

$$(5) \quad \mathrm{Corr}(R_t; R_{t-1}) = \frac{g(1-g)v^2 - g\sigma^2}{gv^2 + 2\sigma^2}.$$

Note that the observed returns are serially uncorrelated when there is no friction whatsoever in the prices, i.e. when $g = 1$ and $\sigma^2 = 0$ simultaneously, or when the two terms in the numerator of equation (5) are equal, i.e. when $g(1-g)v^2 = g\sigma^2$. Otherwise the sign of the first order autocorrelation coefficient depends on the various kinds of friction. It is easily seen that, other things equal, the contribution of the noise to autocorrelation is negative. The larger σ^2 the more negative is the autocorrelation coefficient. It can also be shown that the contribution of the adjustment process is negative for the case when $1 < g < 2$, and positive for $0 < g < 1$.

4. *Methodology and data*

Theoretically, the moments of the stock, and stock index, returns can be separated into one part depending on value and into another part depending on the microstructure. To be able to utilize this separation empirically, the methodology in Amihud and Mendelson (1987) and McInish and Wood (1991) will be used. First, it should be noted that the parameters in the equations presented in section 3 can not be estimated directly. The reason is that the intrinsic value of a stock is not observable. Therefore, the impacts of the friction on the distribution of the returns can only be measured indirectly. It is possible, to a certain extent, to discern between the various kinds of friction mentioned above. For instance, suppose that the estimated first order autocorrelation coefficient of the empirically observed returns turn out to be significantly different from zero. This implies either the presence of noise in the prices or that traders react differently to changes in the available information set. By observing the sign of the estimated coefficient it is possible to get an idea of the real value of the adjustment coefficient g.

To investigate the effects of the market microstructure on intraday price behaviour, the following »trick» is performed. 24-hour returns are calculated in different intervals of time during the day:

$$(6) \quad R_{i,t} = P_{i,t} - P_{i,t-1} \quad i = 1,\ldots,18,$$

where $P_{i,t}$ is the natural logarithm of the observed market price at the end of interval i on day t.

This procedure amounts to calculating 18 daily return series. The first series $R_{i,t}$ is obtained by taking the difference between the natural logarithm of the opening market prices observed on day t and day t–1. Every 15th minute a new return is then obtained until the closing of the exchange. This can be considered as sampling from 18 different, but not independent, distributions. If differences are found in these distributions, i.e. in the moments of the interval returns, they must be due to microstructure effects. Since all 18 intervals contain a 24-hour flow of information the return series reflect equally any new information about the intrinsic market value of the stock or stock index. To see this, assume that a piece of new information reaches the market at some time between the closing on day t–l and the opening on day t. The information is equally reflected in all 18 daily returns computed on day t. All of the 18 intervals during day t contain the same number of trading and nontrading periods.

When information arrives at the market during the trading hours on day t, say for instance between 12.00 and 12.15, it is reflected by movements in prices on day t in intervals 9 to 18 and on day $t + 1$ in intervals 1 to 8. Although the information does not affect all of the interval returns on the same trading day, it does affect all of the series of returns equally except for the first and last day of the sample. The importance of the sample endpoints gets smaller when the number of trading days examined becomes larger. The empirical analysis in the following section was conducted using different sample endpoints. For all practical purposes, no differences in the results emerged.

With this design it is possible to study the impacts of the stock market microstructure per se on return behaviour on the Swedish Stock Exchange. The data used consist of opening, intradaily and closing observations of the Swedish OMX-index for the period of twelve months, January 02 – December 30, 1992. Due to errors in the database, data on the following days are missing: 15/1, 25/2, 28/2, 4/3, 30/3. Also, trading days when the exchange closed earlier than 14.30 or opened later than 10.00 are excluded from the sample. The interval returns are calculated at 220 days during this period. This amounts to a total of 220 times 18, equals 3960, returns as input to the empirical analysis.

The OMX-index was introduced in September 1986 by the Swedish option marketmaking firm *Optionsmäklarna* (OM), to be used as an underlying asset for standardized call and put options as well as forward contracts. It is a portfolio composed of the 30 most actively traded stocks at the *Stockholms fondbörs*. The stocks are weighted according to their respective market values. These weights are changed every six months to keep up with market developments. The OMX-index is of interest as an individual asset although it can not be directly traded at the exchange. But in a well functioning market it can always be replicated by using the standardized options through an arbitrage argument.

A problem when using a stock index in an analysis of this kind is that the transactions in the various stocks do not occur at the same time. This nonsynchronous trading implies that the observed OMX-price, at for instance 12.00, reflects the latest transactions made in all of the 30 individual stocks in the period between 11.45 and 12.00. Obviously, all the 30 stocks are not transacted at the same time. Some of the stocks may even not have been transacted at all in this period of 15 minutes. Luckily, this does not happen so often. The stocks in the OMX-portfolio are most of the time traded at least once within each of the 15 minutes intervals.

The most severe problems are due to the opening procedure of the exchange. The individual stocks in the OMX-index are not opened at the same time. Furthermore, the groups of stocks first opened are allowed to be traded within the continuous procedure although trading in all stocks is not yet opened. This implies that there exists no distinct opening price for the OMX-index. The price that is used in this investigation allows for all OMX-stocks to be opened before it is observed. In practice this takes about ten to fifteen minutes after the official opening time. During this period some of the stocks have been traded with the continuous procedure. But at least no closing prices are lagging from the previous trading day.

5. *Empirical testing*

To evaluate the impact of microstructure effects on pricing at different times of the day the variances and autocorrelations of the 18 return series are estimated. These estimates are then compared to each other and with the theoretical expressions for variance and first order autocorrelation in equation (4) and (5) respectively. It is then possible to get an idea of how serious the friction in the prices is on an intradaily basis.

There is one major problem with comparing and e.g. testing for equality among the variances and the autocorrelations of the 18 interval returns. This problem is due to the fact that the interval returns are not independent of each other. As mentioned above, estimating the returns is like sampling from 18 different distributions each with its particular properties. Since the returns are overlapping they must be distributed in a dependent fashion. The overlapping features are not concentrated within a trading day. The interval returns are also depending on each other within a lag of one day. To see this, consider the return terminating at 12.15, i.e. in interval 9, on day t. This return is overlapping both with the returns in intervals 10 to 18 on day t–1 and the returns in intervals 1 to 8 on day $t + 1$. As a result, all the estimated return series will be contemporaneously correlated at lags 0 and 1.

When comparing the sample moments of the interval returns, this problem must in some way be taken care of. Surprisingly, this problem is not noted in the cited international studies. Amihud and Mendelson (1987) limit themselves to a descriptive analysis, whereas McInish and Wood (1991) completely ignore the fact that the interval returns are contemporaneously correlated. One way to solve the problem is to view the interval return series as a system of 18 equations, assuming a simple model for determining the variances and the autocorrelations. To begin with, the variance of the returns in each interval of time i, as described in equation (6), can be modelled as:

$$(7) \qquad (R_{i,t}-\mu_i)^2 = \sigma_i^2+\varepsilon_{i,t}, \qquad i=1,\ldots,18,$$

where μ_i is the unconditional mean return in interval i, σ_i^2 is the corresponding unconditional variance and $\varepsilon_{i,t}$ is a disturbance term. In fact, the squared deviation of each interval return from its mean is modelled as a constant plus a disturbance term. To allow for contemporaneous correlation in this model is the same as to allow the crosscovariances at lag 0 and 1 between all of the 18 disturbances to be nonzero, i.e. $E(\varepsilon_{i,t}\varepsilon_{j,t-k}) \neq 0$ for all $i,j = 1,\ldots, 18$ and $|k| = 0, 1$. Furthermore, the crosscovariances at lags larger than 1 are all restricted to equal zero, $E(\varepsilon_{i,t}\varepsilon_{j,t-k}) = 0$ for all $i,j = 1,\ldots,18$ and $|k| > 1$. The reason is twofold. First of all the overlapping features of the 24-hour returns are not causing a serial dependence of a higher order than 1. It is also empirically established that autocorrelations at lags larger than one are not even close to be significantly different from zero.

As it stands, this model can be estimated with Hansen's (1982) Generalized Method of Moments (GMM). However, since the mean returns are of limited interest in evaluating the microstructure effects, the model in equation (7) can be approximated by:

$$(8) \qquad (R_{i,t}-\hat{\mu}_i)^2 = \sigma_i^2+\varepsilon_{i,t} \qquad i=1,\ldots,18,$$

where $\hat{\mu}_i = T^{-1}\sum_{t=1}^{T} R_{i,t}$ is the sample mean return in interval i. In the appendix it is shown that the approximation in equation (8) is asymptotically equivalent to equation (7) if the autocorrelation in returns vanishes quickly enough. As noted above this appears to be true.

The model written in equation (8) is even more simple to estimate with GMM. The reason is of course that the system now includes 18 parameters less to be estimated. Furthermore, the system equations are linear in the remaining parameters. This follows from the fact that the GMM-estimates of the interval return variances are identical to the ordinary summary variance statistics, which is not necessarily the case when the means and variances are estimated simultaneously. The important matter is that the GMM-estimates, or rather their standard errors, are robust against the returns being contemporaneously correlated. Therefore, inferences on the variances are now feasible.

To test the null hypothesis of equal variance of return across the 18 intervals, or more formally:

$$(9) \qquad H_0: \sigma_1^2 = \ldots = \sigma_{18}^2 = \sigma^2,$$

the model in equation (8) is estimated without the restriction according to the null hypothesis. A Wald-test is then conducted, resulting in a test-statistic that is χ^2-distributed under H_0, with degrees of freedom equal to 17, i.e. the number of restrictions.

The existence of first order autocorrelation of interval returns can be accounted for within a similar model:

$$(10) \qquad \frac{(R_{i,t}-\hat{\mu}_i)\,(R_{i,t-1}-\hat{\mu}_i)}{\hat{\sigma}_i^2} = \rho_i+\omega_{i,t} \qquad i=1,\ldots,18,$$

where ρ_i is the first order autocorrelation coefficient of return in interval i, $\hat{\sigma}_i^2$ is the estimated variance of return in interval i and $\omega_{i,t}$ is a disturbance term. Treating this model as a system of equations and allowing the disturbance terms to be correlated across equations (i.e. $E(\omega_{i,t}\omega_{j,t-k}) \neq 0$ for all $i,j = 1,\ldots,18$ and $|k| = 0, 1$), the ρ_i-coefficients can be estimated with the GMM-procedure. The presence of $\hat{\mu}_i$ instead of μ_i in equation (10) can be motivated in line with the similar approximation carried out above. In the limit, the expression to the left of the equality sign in equation (10) should not depend of whether $\hat{\mu}_i$ or μ_i is used.

The system of equations is linear in the parameters. Therefore, the ρ_i-coefficients correspond to the usual summary first order autocorrelation statistics. The standard errors of the estimates are, exactly as above, robust against the returns being contemporaneously correlated. Hence, the joint null hypothesis of equality among the 18 different autocorrelation coefficients:

$$H_0: \rho_1 = \dots = \rho_{18} = \rho, \tag{11}$$

can be tested using a similar Wald-test statistic. The GMM-estimations and Wald-tests are executed by using the GMM- and ANALYZ-procedure available in the computer program package TSP, version 4.2.

6. *Results*

The estimated variances of the 18 different interval returns are presented in Table 1. The variance-numbers in the third column are the estimated constants in the system of 18 equations formulated in equation (8). These are by definition equivalent to the ordinary summary variance statistics.

The standard errors of the variance estimates in the third column are computed from the heteroscedastic- and autocorrelation-consistent covariance matrix according to Newey and West (1987). This is an adjustment for the across-equation interdependence of the 18 residual series. Therefore, the standard errors, and any inferences associated with the variances, are robust against the returns being contemporaneously correlated.

No inferences are made concerning the individual variances simply because there exists no a priori value for each variance to be compared with. More important and interesting is to compare the estimated interval variances among themselves. As can be seen in Table 1, the estimates range numerically from the lowest number 1.89 to the highest 2.32. The Wald-test described in the context of equation (9) results in a test-statistic equal to 27.87, with a *p*-value of 0.0465. Under the null hypothesis of equality among all the variances, the test-statistic is χ^2-distributed with 17 degrees of freedom. The null hypothesis can be rejected at the 5 % level of significance. The critical value of the χ^2-distribution with 17 degrees of freedom is 27.59 at the 5 % level. Hence, there seems to be differences among the variances of the interval returns.

Table 1. Estimated variances of the interval returns.

Interval	Time	Estimate	St.error
1	open	2.3151	0.3348
2	10.30	2.3174	0.3482
3	10.45	2.2680	0.3390
4	11.00	2.0891	0.2955
5	11.15	2.0574	0.3251
6	11.30	1.9787	0.3069
7	11.45	1.9389	0.3103
8	12.00	1.8874	0.3058
9	12.15	1.8645	0.2890
10	12.30	1.9325	0.2992
11	12.45	2.0098	0.3148
12	13.00	2.0520	0.3282
13	13.15	1.9950	0.3105
14	13.30	1.9960	0.3192
15	13.45	2.0183	0.2941
16	14.00	2.0814	0.3006
17	14.15	2.1788	0.3131
18	close	2.2598	0.3214

$\chi^2_{17} = 27.87$ (*p*-value = 0.0465)

In Figure 1 the variances are plotted against the time of the trading day. The differences indicated by the Wald-test are most striking when the pattern at the beginning and the end of the trading day is compared with the pattern at times in between. The variance seems to be considerably higher when it is calculated using prices from the morning and the afternoon trading hours than when using prices from the ones during midday. When the trading starts at 10.00, the estimated 24-hour return variance is 2.32, the highest level of the day. Thereafter, the variance is diminishing gradually until it reaches its lowest level of 1.86 approximately during the lunch-hour. Finally, the variance seems to rise again during the last trading hours of the day and reaching a level of 2.26 at the closing of the exchange.

These results do not differ in many aspects compared to the international studies mentioned in the introduction. Wood et al. (1985), and others with them, have reached the conclusion that prices in the US stock markets seem to be more volatile at the beginning as well as the end of the trading day. If visualized as in, Figure 1, this would give rise to a U-shaped pattern with high variance at the beginning of the day, diminishing and reaching the lowest levels during midday and finally rising again towards the end of the day. This is almost exactly the case in this investigation. The pattern of the variances in Figure 1 starts off at a high level at the beginning of the day. Thereafter, it is diminishing precisely as in the cited studies of the US stock market. Furthermore, towards the end of the trading day the variability is increasing again, more or less in parity

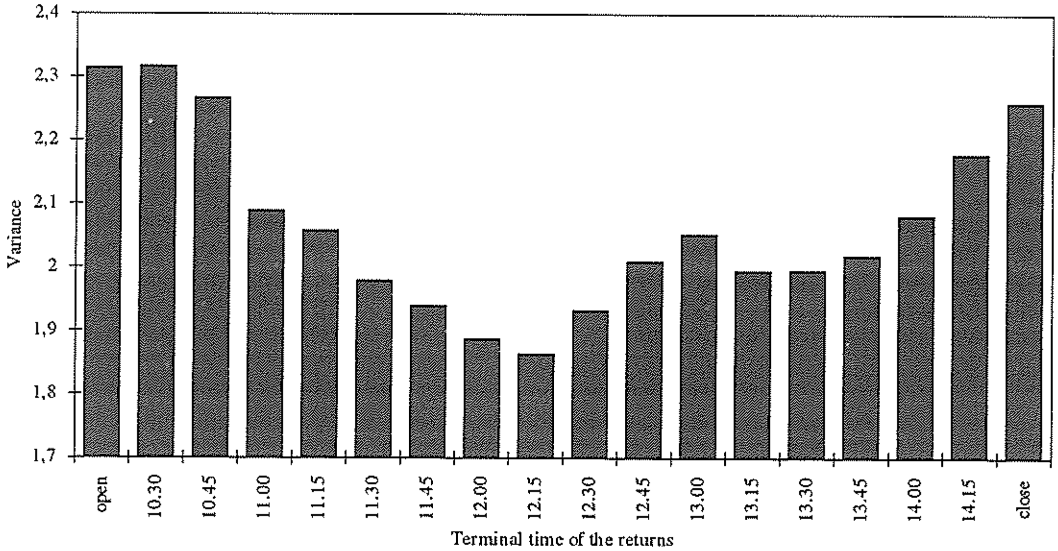

Figure 1. Plot of the variances of the interval returns.

with the results from Wood et al. (1985). Thus, the result is the usual (in an international sence) U-shaped pattern of the variances when they are plotted against the terminal times during the trading day.

If the pattern of the variances in Figure 1 and Table 1 is interpreted in terms of the model developed in section 3, it is clearly an indication that there is comparatively more friction in the prices at the beginning and at the end of the trading day than during the interior. The presence of noise trading and/or the fact that traders overreact to information ($g > 1$ in the model) seem to be more severe during the morning and afternoon trading hours.

The differences in friction do not appear to be due to the trading mechanism with which transactions are made. If that was the case, then the variances of the open-to-open interval returns should differ from the rest in some aspects. The reasoning behind this latter argument is that the opening transactions are executed with a call market procedure, whereas a continuous market procedure is in play during the rest of the trading day. As is evident from Figure 1 and Table 1 not only the opening prices seem to contain more friction, but the ones during the morning trading hours as a whole. Furthermore, the variance of the open-to-open returns is not significantly different from the variance of the close-to-close returns. Hence, the opening and closing procedures seem to give rise to the same amount of friction in the prices at least as far as the variances are concerned. The result is quite interesting since a large amount of research, some of which is cited above, has reached the opposite conclusion. Especially stocks and stock indices at the US markets, the NYSE in particular, seem to exhibit different return behaviour at the open compared to the close. It has to be noted again that the index opening prices used in this investigation do not consist solely of opening prices of the individual stocks. This might explain the divergence from the studies of NYSE stocks.

Further evidence on the subject of differences in the friction during the beginning and the end of the trading day compared to in between appear when the estimated first order autocorrelation coefficients of the interval returns are examined. The estimation procedure is carried out in exactly the same way as with the variances but using the formulation in equation (10) instead. The results are displayed in Table 2. As before, the 18 estimated constants in the third column are identical to the usual summary autocorrelation statistics. And using the arguments from section 5 again, the standard errors in column four

Table 2. Estimated first for autocorrelations of the interval returns.

Interval	Time	Estimate	St. error	t-statistic	p-value
1	open	0.0965	0.0877	1.101	0.2727
2	10.30	0.0903	0.0759	1.189	0.2362
3	10.45	0.1080	0.0811	1.332	0.1849
4	11.00	0.1314	0.0811	1.621	0.1070
5	11.15	0.1405	0.0773	1.818	0.0709
6	11.30	0.1607	0.0790	2.034	0.0436
7	11.45	0.1696	0.0860	1.972	0.0503
8	12.00	0.1769	0.0847	2.090	0.0382
9	12.15	0.1562	0.0837	1.866	0.0638
10	12.30	0.1159	0.0868	1.335	0.1837
11	12.45	0.1010	0.0862	1.171	0.2430
12	13.00	0.0835	0.0892	0.935	0.3510
13	13.15	0.1290	0.0863	1.495	0.1369
14	13.30	0.1506	0.0910	1.672	0.0965
15	13.45	0.1622	0.0892	1.817	0.0710
16	14.00	0.1613	0.0921	1.751	0.0818
17	14.15	0.1320	0.0982	1.343	0.1810
18	close	0.0856	0.0905	0.946	0.3457

χ^2_{17} = 26.05 (p-value = 0.0736)

and the t-statistics in column five are robust against the returns being contemporanously correlated.

The Wald-test of the null hypothesis of equality among the autocorrelation coefficients, described in equation (11) above, results in an estimated χ^2-statistic equal to 26.05 (with a p-value of 0.0736). The null hypothesis of equality can be rejected at this level since the critical value of the χ^2-distribution with 17 degrees of freedom is 24.77 at the 10 % level of significance. As can be seen in Table 2 the autocorrelation coefficients of the returns terminating during the interior of the trading day are larger, and more often significantly different from zero, compared to the corresponding ones at the beginning and at the end of the day. The autocorrelation coefficients are also plotted against the 18 intervals of time in Figure 2. The pattern in this figure is more or less the reverse of the U-shaped pattern in Figure 1.

The combined patterns of the variances and autocorrelations of the interval returns have several implications for the persistence of the friction on an intradaily basis. From the analysis of the variances above it is concluded that the friction appears to be more severe during the morning and late afternoon trading hours. In terms of the model for price adjustment presented in section 2 this implies that traders either (or both) trade more on noise (σ^2 is comparatively large) or (and) tend to overreact to information ($g > 1$) to a larger extent at those times. Using only the variances in the analysis does not make it possible to conclude which kind of friction really is the most severe one.

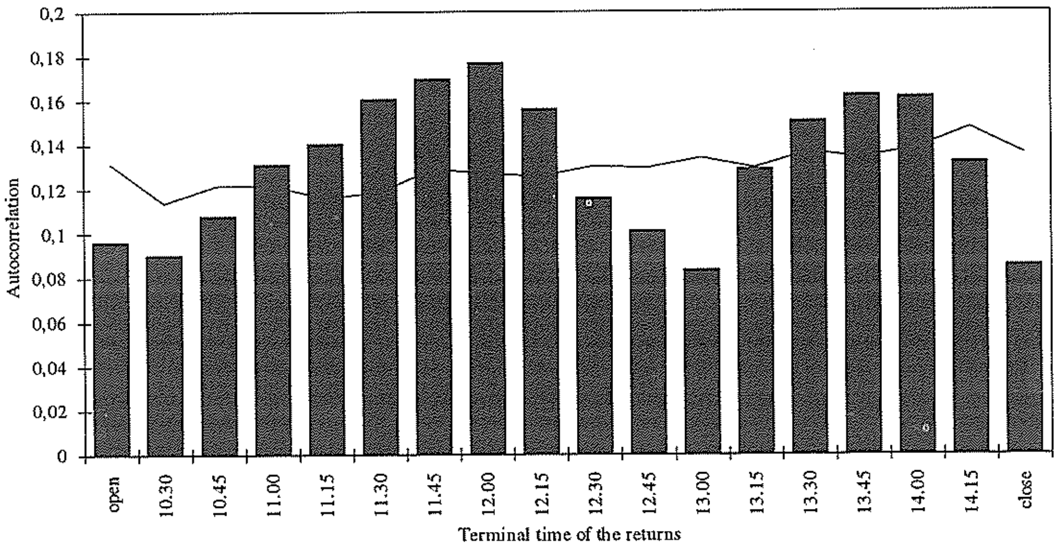

Figure 2. Plot of the first order autocorrelations of the interval returns.

When the pattern of the autocorrelations is combined with the theoretical expression suggested by the model it is possible to be more specific. The fact that each autocorrelation coefficient is positive, or at least not negative, implies that the price adjustment should be only partial. In equation (5) above it is easily seen that the adjustment coefficient g has to be less than 1 for the autocorrelation coefficient to be positive. Furthermore, the »noisy» variance σ^2 can not be too large compared to the value variance v^2. One possible explanation for the U-shaped pattern of the variances and the reverse of the autocorrelations is: there is more noise in the pricing process during early and late trading hours than in between and the price adjustments are partial throughout the whole trading day.

Is it then plausible that the friction in the Swedish stock prices is more apparent at the beginning and the end of the trading day? Could any reasons for the indicated fact that noise trading prevails to a larger extent during the morning trading hours be found? One possible explanation may be the one that Amihud and Mendelson (1991) find important for the case of the Japanese stock market. They present evidence of the fact that the friction in stock prices seems to be more severe at instants preceeded by a long nontrading period. Hence, it is possible that the fact that the Swedish stocks are not traded during the night gives rise to a greater extent of uncertainty concerning the value of the stocks among traders in the morning. But when trading has been going on for a while, this uncertainty is diminishing as perhaps suggested by the plot of the variances in Figure 1.

This nontrading argument cannot explain the tendency for the friction to increase again towards the end of the trading day. Terry (1986) has come up with an explanation of »the day-end return anomaly». He argues that the evident higher returns, and volatility of the returns, towards the end of the trading day can in part be attributed to the fact that liquidity traders seem to increase their purchases at that time. If this is true the friction in the prices should also increase.

7. *Concluding remarks*

This paper examines the intradaily behaviour of the stocks traded at the Swedish Stock Exchange *(Stockholms fondbörs)*. Daily returns of the OMX-index spanning 24-hour intervals are calculated at 18 different terminal times during the trading day. This methodology gives rise to 18 more or less overlapping return series. Since all the series of returns contain the same flow of information, any differences in the moments of the interval returns can be attributed to microstructure effects.

The empirical investigation carried out in this paper suggests that the variances of the interval returns follow a U-shaped pattern when they are plotted against the interval terminal times. In other words, the 24-hour returns appear to be comparatively more volatile when they are calculated using prices from the morning and late afternoon. The first order autocorrelations of the interval returns are likely to follow a pattern more or less the reverse of a U-shape. The autocorrelation coefficients are significantly different from zero during midday whereas they are not at the beginning and towards the end of the trading day.

The empirical evidence of differences among, in particular, variances of the interval returns is supported by robust significance tests using a simplified version of the Generalized Method of Moments estimation procedure. This procedure is formulated to take into account the overlapping features of the interval returns. Hence, the significance tests conducted in this paper are robust against the obvious fact of the returns being contemporaneously correlated.

In terms of the theoretical model outlined in section 3, describing some features of the microstructure of the stock market, this implies that the prices set during the morning and afternoon trading hours contain more friction than those set during the interior of the day. Noise traders seem to be present to a larger extent during the morning and late afternoon trading hours. Black (1986) defines a noise trader as one who is trading on noise as if it is information. This kind of behaviour causes the observed market prices to deviate from the correct values, intrinsic on the flow of relevant information. As a result, there is more uncertainty with respect to the true values of the stocks.

The implied fact that the uncertainty among the traders at the market is greater at the beginning of the trading day may be explained by a nontrading argument. Since the stocks are not openly traded during the 19 and a half hours between the closing of the exchange and the opening on the following day, there may well be uncertainty concerning the correct values of the stocks accumulating during this period. This is clearly an argument for the *Stockholms fondbörs* to consider having the exchange open for trading on a 24-hour basis. Such an arrangement could reduce the friction in the market prices and make the market more efficient. A step in the right direction is taken from the 1st of April 1993 when the trading session is extended with one and a half hour.

More research on this subject has to be done before further statements can be made. An interesting issue may be to try to link this discussion with the one concerning the weekend effect. If the nontrading argument holds, there will be more friction in the prices set on days following weekends than in the ones following ordinary nights. Trading and nontrading effects at the Swedish Stock Exchange are treated in Nordén (1992).

Finally, the results of this study give rise to a practical implication. Since prices seem to contain more noise during the morning and afternoon trading hours they are then less efficient carriers of the prevailing information set. Therefore, it would be advisable for individual investors to undertake any trading during the midday when there seems to be less noise in the prices.

Appendix: Approximation in the GMM estimations

In section 5 it is argued that differences in variances of the interval returns σ_i^2 can be tested for within the system of equations:

$$(A.1) \quad (R_{i,t}-\hat{\mu}_i)^2 = \sigma_i^2 + \varepsilon_{i,t} \qquad i = 1,\dots,18.$$

The reason for using the sample mean returns $\hat{\mu}_i$ in stead of the corresponding population means is twofold. First, the equations in expression (A.1) and (8) become linear in all of their parameters. In fact, the approximation using $\hat{\mu}_i$ involves the estimation of 18 parameters less than the original equations. Second, the estimated variance parameters $\hat{\sigma}_i^2$ from (8) equal the usual variance statistics, that is:

$$(A.2) \quad \hat{\sigma}_i^2 = \frac{1}{T}\sum_{t=1}^{T}(R_{i,t}-\hat{\mu}_i)^2.$$

The approximation is asymptotically valid if the following limiting condition is met:

$$(A.3) \quad \lim_{T\to\infty} \mathrm{E}\,[\,(R_{i,t}-\hat{\mu}_i)^2\,] = \sigma_i^2,$$

where E[.] denotes the expectation with respect to the expression within the brackets. To check if the condition in (A.3) is met the following extensions are made:

$$(A.4) \quad \lim_{T\to\infty} \mathrm{E}\,[\,(R_{i,t}-\hat{\mu}_i)^2\,] = \lim_{T\to\infty} \mathrm{E}\,\{\,[\,(R_{i,t}-\mu_i) - (\hat{\mu}_i-\mu_i)\,]^2\,\} = \lim_{T\to\infty}\{\mathrm{E}\,[\,(R_{i,t}-\mu_i)^2\,] + \frac{1}{T^2}\mathrm{E}\left[\{\sum_{s=1}^{T}(R_{i,s}-\mu_i)\}^2\right] - 2\frac{1}{T}\mathrm{E}\left[(R_{i,t}-\mu_i)\sum_{s=1}^{T}(R_{i,s}-\mu_i)\right]\}$$

$$= \lim_{T\to\infty}\left(\sigma_i^2 + \frac{1}{T^2}\sigma_i^2\sum_{r=1}^{T}\sum_{s=1}^{T}\rho_i(r,s) - 2\frac{1}{T}\sigma_i^2\sum_{s=1}^{T}\rho_i(t,s)\right).$$

The latter expression equals σ_i^2 in the limit if the autocorrelation terms vanish quickly enough, i.e. if $\sum_{r=1}^{T}\sum_{s=1}^{T}\rho_i(r,s)$ is of lower order than T^2 and $\sum_{s=1}^{T}\rho_i(t,s)$ is of lower order than T. Consequently, this means that if the autocorrelations of the returns are of negligible size at large lags, which seems to be a reasonable assumption to make, the approximation is asymptotically valid.

But even for relatively small sample sizes T the approximation may be satisfactory. If the difference:

$$(A.5) \quad \frac{1}{T}\sum_{r=1}^{T}\sum_{s=1}^{T}\rho_i(r,s) - 2\sum_{s=1}^{T}\rho_i(t,s),$$

is of negligible size the small sample bias in (A.1) becomes less important. This is not explicitely checked in the analysis in the text. But nevertheless it might, in addition to the limiting condition, well justify the approximation.

References

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

— (1991). »Volatility, Efficiency and Trading: Evidence from the Japanese Stock Market.» *Journal of Finance,* 46, 1765–1789.

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

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

Cohen, K., G. Hawawini, S. Maier, R. Schwartz, and D. Whitcomb (1980). »Implications of Microstructure Theory for Empirical Research on Stock Price Behavior.» *Journal of Finance,* 35, 249–257.

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

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

Frennberg, P., and B. Hansson (1992). »Swedish Stocks, Bonds, Bills and Inflation (1919–1990).» *Applied Financial Economics,* 2, 79–86.

Goldman, M., and A. Beja (1979). »Market Prices vs. Equilibrium Prices: Returns' Variance, Serial Correlation and the Role of the Specialist.» *Journal of Finance,* 34, 595–607.

Hansen, L. (1982). »Large Sample Properties of Generalized Method of Moments Estimators.» *Econometrica,* 50, 1029–1054.

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

McInish, T., and R. Wood (1990). »A Transaction Data Analysis of the Variability of Common Stocks During 1980–1984.» *Journal of Banking and Finance,* 14, 99–112.

— (1991). »Autocorrelation of Daily Returns: Intraday-to-Intraday Versus Close-to-Close Intervals.» *Journal of Banking and Finance,* 15, 193–206.

Niemeyer, J., and P. Sandås (1992). The Market Micro Structure of the Swedish Stock Exchange: A Descriptive Analysis. Unpublished Manuscript, Department of Finance, Stockholm School of Economics, Sweden.

Newey, W., and K. West (1987). »A Simple Positive Semi-definite Heteroskedasticity and Autocorrelation Consistent Covariance Matrix.» *Econometrica,* 55, 703–708.

Nordén, L. (1992). »Handels- och ickehandelseffekter i OMX-index: är den underliggande processen kontinuerlig?» (Trading and Nontrading Time Effects in the OMX-Index: Is the Underlying Process Continuous?). *Beta,* 6, 36–46.

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

Terry, E. (1986). End of the Day Returns and the Bid-Ask Spread. Unpublished manuscript, Stanford University, Stanford CA, USA.

Wood, R., T. McInish, and K. Ord (1985). »An Investigation of Transactions Data for NYSE Stocks.» *Journal of Finance,* 40, 723–741.