# The Components of the Bid-Ask Spread: The case of the Athens Stock Exchange


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**Abstract**

We analyze the components of the bid-ask spread in the Athens Stock Exchange (ASE), which was recently characterized as a developed market. For 18 large and 13 medium capitalization stocks, we estimate the adverse selection and the order handling component of the spreads as well as the probability of a trade continuation on the same side of the bid or ask, using the Madhavan et al. (1997) model. We extend it by incorporating a variable order size and we find that the adverse selection component exhibits U-shape patterns, while the cost component pattern depends on the stock price. For high priced stocks, the usual U-shape applies, while for low-priced ones, it is an increasing function of time, mainly due to the different magnitude of the order handling spread component. Our analysis shows that the order handling component dominates inventory effects, particularly in the first and last half hour of the trading day and hence we observe economies of scale in trading. Furthermore, the expected price change is higher in the low capitalization stocks, while the most liquid stocks are the high priced ones. Moreover, by estimating the Madhavan et al. (1997) model for two distinct periods we explain why there are differences in the components of the bid-ask spread. Lastly, according to a portfolio model, the information leakage from the general index of ASE does not affect significant the low capitalization stocks, while there are some indications that this is not the case for the other groups.



**Keywords:** Bid-Ask Spread, Asymmetry Information, Transaction Costs, Price Impact.

**JEL Nos: D4, C1**


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# 1 Introduction

In an influential paper, Madhavan et al. (1997) (MRR) showed that security prices change due (a) to new arrival of public information, and (b) the trading process. They pointed out that information asymmetry declines during the day, while transaction costs increase. In an independent work, Huang and Stoll (1997) developed another structural model that incorporated all previous approaches. Their empirical results supported the presence of a large order processing component and smaller adverse selection and inventory ones. Moreover, they argued that spreads are depending on trading volume, a similar conclusion reached by Ahn et al. (2002).

This remark offered the insight for the present paper, which goes on to offer an empirical application to a small electronic order book market. Many researchers have used transaction volume before as an explicit variable to model spread components. Easley and O'Hara (1987), in an influential theoretical paper, predict that informed investors prefer to make large trades. Hausman et al. (1992) conducted a probit analysis to measure the effect of several variables in existing microstructure models. De Jong et al. (1995), showed that, for small trades, the Paris Bourse had lower transaction costs than that of the London Stock Exchange and the cost of trading was a decreasing function of trading volume. A year later, working on the Glosten (1994) model, they estimated (De Jong et al. (1996)) that, in the Paris Bourse, price impact increases with volume and accounts for 25% and 60% of the spread for small and large trades respectively. They also used Hasbrouck's (1991) VAR model for prices and trades to conclude that the permanent price impact effect was between 40% and 115% of the spread and hence the Glosten (1994) model underestimated the transaction costs. Dufour and Engle (2000) also used and expanded Hasbrouck's (1991) model by adding the time between consecutive transaction to the exciting variables and argued that high trading activity is positive associated with spread, volumes and price impacts. Moreover, Chan (2000) studied the price formation process on the Hong Kong Stock Exchange and concluded that the information component was more important than the inventory one. On the contrary, Bollen et al. (2004) developed and tested a model of market makers' bid-ask spread for NASDAQ stocks and concluded that the inventory cost component dominated the adverse selection one.

On the other hand, many researchers have examined the effect of volume on spreads, execution costs and order flows. By studying the volatility-volume relationship, Chan and Fong (2000) demonstrated that, for NYSE and NASDAQ stocks, traded volume was a more significant variable for volatility than the number of trades, but remained rather unclear on the main factors affecting this significant variable. Ahn et al. (2002) and Huang and Stoll (1997) found that the order processing cost decreases with traded volume. Degryse (1999) showed that total trading costs in the Brussels CATS system, as compared to London's, are lower (higher) for small (large) trade sizes and concluded that the relation between the effective spread and trade size depends on the specific characteristics of the exchange. Easley et al. (1997) concluded that large trades have almost twice as much information as small ones, with buys and sells differing only marginally. In contrast to all of these findings, Aitken and Frino (1996) analyzed institutional trades on the Australian Stock Exchange and concluded that buy orders are associated with larger costs than sell orders, probably due to short selling restrictions. For the Helsinki Stock Exchange, Hedvall et al. (1997) reported that asymmetries in the order flow depend on the traded volume and pointed out that "there are more often information reasons behind large buy trades than large sell trades".

Several studies explore the behavior of the bid-ask spread components during the trading day. Ahn et al. (2002) found that both the adverse and the order handling components of the Tokyo Stock Exchange exhibit U-shape intraday patterns. Declerck (2000) studied the trading costs and the spread components for the CAC 40 index stocks and found out that the order processing explains 82% of the spread, while all its components are positively related to the traded volume. Menyah and Paudyal (2000) showed that the inventory cost component is smaller than that of the order processing one for the London Stock Exchange and the asymmetry of information cost accounts for about 47% of the quoted spread, a percentage almost equal to that reported for NYSE/AMEX stocks by Kim and Ogden (1996). The same authors also found that high Normal Market Size (NMS)[1] stocks exhibit higher asymmetric information than low NMS ones: market makers widen the spread in order to limit expected losses from trading with informed investors. Chan (2000) and Brockmanand and Chung (1998) studied intraday price formation of the Hong Kong Stock Exchange and found both price impacts and spreads displaying the familiar U-shape patterns. Silva and Chavez (2002) reported that the higher execution costs of the Mexican Stock Exchange can be attributed to a higher adverse selection cost and not to the specific characteristics of stocks. Kim et al. (2002) analyzed the SIMEX future contract on the Nikkei 225 index and reported an L-shaped intraday pattern for the information cost and an inverse U-shaped one for the inventory holding cost. Gwilym and Thomas (2002) used trades and quotes of the LIFFE FTSE100 futures contract and, examining several measures of spread, concluded that they widen at the open and narrow at the close of day, with transaction spreads being biased estimators of quoted ones. Last but not least, two other studies have examined bid-ask spreads in option markets: Nordén (2003) used data from the Swedish OM market and found that both in- and out-of-the money options are more asymmetric than at-the-money ones, with the theoretical option value closer to the bid than to the ask price. Pinder (2003) used data from the Australian Options Market to examine spread components both before and after a switch from a quote-driven floor-traded system to an order-driven screen-traded one. Among other things, he reported smaller spreads when market makers were providing bid-ask prices continuously.

We try to achieve three objectives in the present paper: first, we incorporate the volume as a variable to the structural model of Madhavan et al. (1997) to examine the idea proposed by Ahn et al. (2002). The Athens Stock Exchange (ASE) lends itself to such an exercise because a lot of listed stocks trade very passively for long periods during the day, making the information asymmetry contained inside the sign traded volume a more important factor than either the trade or the volume individually.[2] At first reading, we reach similar conclusions to those of other researchers, since the adverse selection component exhibits the familiar U-shape pattern. The cost component, however, displays a clear U-shape only for high priced stocks and is *monotonically increasing* for low priced ones. These differences may be explained in the volume-extended model, since the order handling cost effect in low priced stocks is smaller. Furthermore, the adverse selection component explains a significant part of the spread and is increasing with volume, while

[1] The minimum mandatory quote size for which market makers are obligated to post prices.

[2] This is especially true for the period covering the last eleven months of 2002.

the cost component is decreasing in it. Therefore, looking only at the latter component, we observe economies of scale in trading. During a distinct time period, however, from June 1st to August 31, 1999, the cost component was the most significant part of the spread. At that time, it seems that there were mainly uninformed traders participating in the market and, hence, the adverse selection risk was demoted. Second, by studying price impacts caused by different factors, such as order-flow dependence, trade volume and market capitalization, we conclude that high priced - high capitalization stocks are less sensitive to anyone of these factors. Third, we present a price formation model for portfolio trading, like the one of Huang and Stoll (1997), since anecdotal evidence suggests that investors trade shares of a company only because, at the same time period, other shares in the same industrial sector or index trade as well. Based on that model, we find indications that the information component due to market conditions is statistically important *only* in high capitalization stocks.

The remainder of the paper is organized as follows. The next section briefly describes the trading process of the ASE. Section 3 presents the data, while section 4 demonstrates the two structural models, describes the estimation procedure and explains the results. Section 5 presents and estimates the price impact functions, while section 6 demonstrates a portfolio-trading model. The final Section concludes the paper.

# 2 The ASE Trading Process

The Athens Stock Exchange (ASE) is the unique official stock market in Greece. At the end of year 2002, approximately 375 companies were listed in it, with a total capitalization approaching €85.5 billion. ASE members include security brokerage houses, credit institutions and investment service companies that have been granted a license by the Bank of Greece or by the Capital Market Commission. Only ASE Members can execute purchase and sale orders for shares through the Integrated Automatic Electronic Trading System (OASIS) of the market. Members are under the obligation to (a) keep the ASE informed of their realized transactions on a daily basis, (b) keep the Capital Market Commission informed on the use of their own funds, loans and shares on a weekly basis, (c) disclose to the same Commission their larger financial exposure and solvency ratio on a monthly basis, (d) issue transaction slips for all completed transactions and (e) follow the accounting and tax laws.

Five different market segments currently operate inside the ASE: (i) The Main Market, (ii) the Parallel Market, (iii) the New Market (NEHA), (iv) the Greek Market of Emerging Companies (EAGAK), and finally, (v) the Secondary Listings on the ASE from Stock Exchanges outside Greece. The main classification rule for any company to be listed in the first four segments is the amount of their own equity. For example, the minimum amount for the Main Market is €11.7 million, while, for the parallel market, it is only €2.9 million.

Three major stock indices are calculated on a daily basis:

1. The **ASE General**, a market cap-weighted index, represents the general trend of the Greek stock market and its composition criteria include capitalization, transactions value and shares marketability.

2. The **FTSE/ASE - 20** is the large Cap Index, featuring the 20 largest blue chip companies. Companies are included in it on the basis of their capitalization and their free float.

3. The **FTSE/ASE Mid 40** follows the performance of the next 40 larger companies.

The last two indices cover approximately 2/3 of the total market capitalization of the ASE Main Market.

Turning now to the discussion of the trading process, we can safely argue that the ASE is basically an order-driven market, where members may continuously enter bid and offer orders in the system from 11:00 a.m. to 4:00 p.m. (the main trading period of the day). In such a setup, liquidity is provided only through the entry of different types of orders without the intermediation of market makers. Orders are ranked first by price priority and then on time arrival. In this way, interests of buyers and sellers are served in the most efficient way, while only *after* trade execution, the member who entered the order can be informed about his counterparty's identity. The tick size allowed equals 1 cent of a euro for securities with a price up to €2.99, 2 cents for securities up to €59.99 and 5 cents for the rest.

Inside each market segment, there are two different trading mechanisms: the "instantaneous market" includes all securities under regulatory surveillance or having "low liquidity" as classified by the ASE authorities.[3] For these stocks, order execution is serviced through five consecutive call auctions during the trading day. For the rest of the listed stocks in that segment, orders are cleared continuously from 11:00 a.m. to 4:00 p.m. In both mechanisms, all orders in the pre-opening period (10:30 a.m.–11:00 p.m.) are cleared in an opening call auction.

# 3 Data

Transaction data used were drawn from intraday files of the ASE for the period from February 4, to December 30, 2002 and contains the time-stamped prices to the nearest second, volumes, and bid and offer prices with corresponding sizes just before a transaction occurs, for all transactions. Our stock sample was based on the two major equity indexes, the FTASE-20 and FTASE-40, representing the large and medium capitalization companies respectively. For each index, we classified stocks in two independent groups: the first one included those with an average sample price greater than (or equal to) €10 and the second those with an average sample price less than €10.[4] Members of each group and their average price for the chosen time period are presented in Table 1.

For all stocks opening transactions have been eliminated from the dataset, since the opening period of the ASE is cleared as a call market.[5] We also eliminated all trades where the bid was greater than the corresponding ask, as well as those where the time stamp was clearly erroneous.

[3]Since June 2003, all securities that in the last six months had an average percentage spread greater than 2%, were regarded as being rather illiquid. They cannot be a part of any official ASE index.

[4]Though a tick size classification rule would have been more appropriate, this was not possible as there were not enough stocks in each category.

[5]Amihud and Mendelson (1987) pointed out that prices produced by such a call auction are likely to be generated from a different distribution than that of the rest of the trading day.

| FTASE-20 | | | | FTASE-40 | | | |
|---|---|---|---|---|---|---|---|
| Group 1 | | Group 2 | | Group 3 | | Group 4 | |
| Reuter's Code | Price | Reuter's Code | Price | Reuter's Code | Price | Reuter's Code | Price |
| EFGr.AT | 13.03 | ETBr.AT | 3.31 | INLr.AT | 17.44 | VAL.AT | 2.55 |
| DEHr.AT | 13.75 | PANr.AT | 5.77 | FOLr.AT | 18.06 | DOLr.AT | 2.85 |
| HLBr.AT | 15.41 | HEPr.AT | 6.07 | | | EGNr.AT | 3.22 |
| ACBr.AT | 17.02 | HELr.AT | 6.15 | | | SINr.AT | 3.49 |
| OTEr.AT | 17.45 | VIO.AT | 6.41 | | | EPAr | 3.56 |
| NBGr.AT | 22.55 | BOPr.AT | 6.99 | | | OLYr.AT | 3.59 |
| CBGr.AT | 23.2 | INRr.AT | 9.65 | | | MYTr.AT | 3.63 |
| ALGr.AT | 28.43 | OPAr.AT | 9.69 | | | MTKr.AT | 4.31 |
| TTNr.AT | 38.16 | COSr.AT | 9.87 | | | EXCr.AT | 4.43 |
| | | | | | | EYDr.AT | 5.00 |
| | | | | | | AKTr.AT | 6.01 |

Table 1: Stocks studied for the period 02/02 to 12/02. "Price" means the average daily closing price in that time period. Groups 1 and 3 include stocks with average price over €10 that belong to the FTASE-20 and the FTASE-40 indexes respectively. Groups 2 and 4 include stocks, belonging to the same indexes, with average price less than €10.

We also grouped all trades conducted at the same time and price as a single trade (Chan (2000)). Lastly, we classified trades as either buy or sell oriented using a slightly different criterion than the simple "tick" rule: a transaction is considered to be a buy-side (sell-side) trade if its execution price is higher (lower) than the mean of the prevailing bid-ask quotes.[6]

## 3.1 Descriptive Statistics

Table 2 presents summary statistics for the four subgroups. Stocks in Group 1 are the most active, based on trade intensity (180 transactions per day on average) and on average time between trades (99 seconds). Their mean spread is €0.0368 or 0.19% of the bid-ask midpoint. Members of group 2, high cap but low price stocks, are less liquid: there are fewer transactions per day and their average spread (in percentage) is twice that of the first group. On the contrary, for midcap stocks, it is not clear which subgroup is more liquid: trade intensity and time between trades favour the low priced subgroup, while percentage spread favours the high priced subgroup 3. Overall, stocks in the midcap index are less actively traded than the corresponding large cap index, as percentage spread and time between trades are greater, while trade intensity is lower. We further address this important issue in Section 5.

We observe other essential differences between the two share groups. For example, the number of transactions in the FTASE-20 stocks is almost twice as high as that for the FTASE-40 stocks,

[6]Aitken and Frino (1996) also reported that the "tick" rule accuracy was not as high as Lee and Ready (1991) had previously stated.

| | Statistics | | | | | |
|---|---|---|---|---|---|---|
| Group | Aver. Spr. | Spr. SD | Trade Intens. | % Spread | Aver. Size/Trade | Time Bet. Trades |
| FTASE-20 | | | | | | |
| 1 | 0.0368 | 0.0431 | 180 | 0.19 | 379 | 99 |
| 2 | 0.0256 | 0.0159 | 138 | 0.38 | 634 | 130 |
| FTASE-40 | | | | | | |
| 3 | 0.0720 | 0.1289 | 76 | 0.41 | 373 | 236 |
| 4 | 0.0216 | 0.0140 | 98 | 0.63 | 607 | 183 |

Table 2: Descriptive statistics for the 4 stock subgroups for the period February to December 2002.

while the percentage spread is twice as low. These differences were tested using the non-parametric Kruskal-Wallis test, a generalization of the Mann-Whitney test for more than two subgroups.[7] For both the absolute and the percentage spread, the null hypothesis of all subgroups having the same median has clearly been rejected. Table 3 presents results in detail.

Finally, Table 4 shows summary statistics during the trading day: we use a shorter half-hour interval after the opening and before the closing of the market and one-hour intervals in between. This divides the trading day in six intervals: 11:00-11:30, 11:30-12:30, 12:30-13:30, 13:30-14:30, 14:30-15:30, 15:30-16:00.[8] Generally speaking, the mean and the standard deviation of the spread and the mean percentage spread display the familiar U-shape pattern over the day, a result reported by several empirical studies. For group 1 (shown in panel A of the Table), the average absolute spread is almost 5 cents at the opening, drops to 3 cents in the middle of the day and increases back to more than 4 cents towards the closing. The corresponding group of midcap stocks (panel C of the Table) shows similar behavior, but with much larger values. The same occurs for groups 2 and 4 (low priced stocks), though spread differences throughout the day are not as large. Average trade size increases during the day for all subgroups but trade intensity does not follow suit in all time intervals.[9] A possible interpretation may be that more uninformed and private investors participate in the market after having learned about the fundamental asset value through daily trading.

[7]For more details see Sheskin (1997).

[8]We did not use a finer time partitioning since thin trading caused lack of observations for statistically significant estimates of structural models for individual stocks.

[9]For subgroup 3, trade size seems to be decreasing in the last 30 minutes. We must, however, be careful in such a result since there are only two shares in this subgroup.

| Absolute Spread | | | |
|---|---|---|---|
| | Observations | Median | Number above the Overall Median |
| FTASE-20 Group 1 | 275,199 | 0.02 | 127,272 |
| FTASE-20 Group 2 | 211,229 | 0.02 | 97,518 |
| FTASE-40 Group 3 | 25,726 | 0.04 | 18,162 |
| FTASE-40 Group 4 | 232,153 | 0.02 | 66,888 |
| Whole Sample | 744,307 | 0.02 | 309,840 |
| Kruskal-Wallis p_value:0 | | | |

| Percentage Spread | | | |
|---|---|---|---|
| | Size | Median | Number above the Overall Median |
| FTASE-20 Group 1 | 275,199 | 0.14 | 30,340 |
| FTASE-20 Group 2 | 211,229 | 0.32 | 105,118 |
| FTASE-40 Group 3 | 25,726 | 0.25 | 10,592 |
| FTASE-40 Group 4 | 232,153 | 0.53 | 225,706 |
| All | 744,307 | 0.32 | 371,756 |
| Kruskal-Wallis p_value:0 | | | |

Table 3: Non-parametric test for equality of medians (Sample period from February to December 2002.

# 4 Two structural models for intraday price movements

## 4.1 The MRR model

### 4.1.1 Description and estimation procedure

We first introduce the MRR model (Madhavan et al. (1997)) which will serve as a benchmark for our work. According to that seminal paper, the factors moving prices are twofold. First, prices change due to the arrival of new public information, which we assume to be a series of independent and identically distributed random shocks with zero mean and constant variance. Second, the "order of trade" indicator reveals informed traders' beliefs, since a buy (sell) order is associated with an upward (downward) price movement. Hausman et al. (1992) used additional variables for their intraday model, arguing that (a) trade size, a term we will use alongside with the term "volume" to design the number of shares traded, and (b) the time elapsed between trades, are two more factors explaining price movements. Easley et al. (1992) also showed that time affects prices, with time between trades affecting spreads. Following this previous research, we will, in the next subsection, include trade size in the MRR model and estimate it for several time intervals to simultaneously investigate the "time-of-day" effect.

Let $p_t$ denotes the transaction price of the security at time $t$ and $X_t$ be the "trade indicator" variable, equaling +1 if the trade is buy-oriented, and -1 if it is sell-oriented. The coefficient $\phi \geq 0$ represents the cost per share of the market maker in supplying liquidity on demand, $\theta$ measures the degree of information asymmetry and $\mu_t$ is the expected value of the stock. We assume a

| Statistics | Time Intervals | | | | | | |
|---|---|---|---|---|---|---|---|
| | 11-11.30 | 11.30-12.30 | 12.30-13.30 | 13.30-14.30 | 14.30-15.30 | 15.30-16.00 | P-Value of F-stat. |
| **Panel A.** FTASE-20 stocks with average price over €10 | | | | | | | |
| Abs. Spread | 0.0487 | 0.0361 | 0.0324 | 0.0323 | 0.0327 | 0.0438 | 0 |
| Spread SD | 0.0706 | 0.0404 | 0.0313 | 0.0306 | 0.0302 | 0.0535 | |
| Trade Intensity | 18 | 35 | 31 | 30 | 32 | 33 | |
| % Spread | 0.26 | 0.19 | 0.17 | 0.17 | 0.17 | 0.22 | 0 |
| Average Trade Size | 308 | 318 | 354 | 394 | 415 | 486 | |
| Time Between Trades | 70 | 199 | 217 | 234 | 219 | 55 | |
| **Panel B.** FTASE-20 stocks with average price below €10 | | | | | | | |
| Abs. Spread | 0.029 | 0.025 | 0.024 | 0.024 | 0.024 | 0.029 | 0 |
| Spread SD | 0.022 | 0.013 | 0.011 | 0.012 | 0.015 | 0.021 | |
| Trade Intensity | 13 | 28 | 24 | 23 | 25 | 26 | |
| % Spread | 0.42 | 0.36 | 0.35 | 0.36 | 0.36 | 0.43 | 0 |
| Average Trade Size | 496 | 558 | 591 | 681 | 699 | 781 | |
| Time Between Trades | 86 | 249 | 280 | 300 | 280 | 71 | |
| **Panel C.** FTASE-40 stocks with average price over €10 | | | | | | | |
| Abs. Spread | 0.118 | 0.074 | 0.059 | 0.065 | 0.056 | 0.085 | 0 |
| Spread SD | 0.131 | 0.078 | 0.057 | 0.258 | 0.052 | 0.094 | |
| Trade Intensity | 4 | 12 | 12 | 13 | 15 | 21 | |
| % Spread | 0.67 | 0.42 | 0.34 | 0.37 | 0.32 | 0.49 | 0 |
| Average Trade Size | 292 | 358 | 390 | 431 | 430 | 338 | |
| Time Between Trades | 109 | 464 | 547 | 588 | 525 | 112 | |
| **Panel D.** FTASE-40 stocks with average price below €10 | | | | | | | |
| Abs. Spread | 0.024 | 0.021 | 0.020 | 0.020 | 0.021 | 0.024 | 0 |
| Spread SD | 0.018 | 0.013 | 0.011 | 0.012 | 0.012 | 0.018 | |
| Trade Intensity | 8 | 19 | 17 | 16 | 18 | 19 | |
| % Spread | 0.70 | 0.62 | 0.59 | 0.60 | 0.60 | 0.69 | 0 |
| Average Trade Size | 550 | 571 | 584 | 622 | 634 | 681 | |
| Time Between Trades | 109 | 345 | 435 | 446 | 414 | 113 | |

Table 4: Intraday descriptive statistics for the 4 stock subgroups (Sample period from February to December 2002.

standard inventory cost model of market making, $p_t = \mu_t + \phi X_t$, and an information asymmetry model for fundamentals, $\mu_t = \mu_{t-1} + \theta(X_t - \rho X_{t-1})$.Combined, they produce the following intraday price change model:

$$p_t - p_{t-1} = (\phi + \theta)X_t - (\phi + \rho\theta)X_{t-1} + u_t, \tag{1}$$

where $\rho$ is the first-order autocorrelation of $X_t$. The pure random walk is a special case of 1 if $\phi = \theta = 0$.

We estimate 1 by using the generalized method of moments (GMM) methodology, because it does not require as strong distributional assumptions as the maximum likelihood methods. It can also easily accommodate conditional heteroskedasticity of any form. The GMM method is based on a moment condition, $E(f(\chi_t, \vartheta_0)) = 0$, where $f(\chi_t, \vartheta_0)$ is a $q \times 1$ vector function and $\vartheta_0$ is a $p$-dimensional parameter vector. The estimated GMM parameters ($\hat{\vartheta_T} = argmin_\vartheta Q_T(\vartheta)$) are weakly consistent and asymptotically normally distributed and are calculated by minimizing the function $Q_T(\vartheta) = f_T(\chi_t, \vartheta)' A_T f_T(\chi_t, \vartheta)$, where $f_T(\chi_t, \vartheta)$ is the sample mean vector and $A_T$ is the sample symmetric weighting matrix. For our specific equation 1, we set the following moments conditions:

$$E\left\{\begin{array}{c} X_t X_{t-1} - \rho X_{t-1}^2 \\ u_t - \alpha \\ (u_t - \alpha)X_t \\ (u_t - \alpha)X_{t-1} \end{array}\right\} = 0, \tag{2}$$

with $\alpha$ a constant. The first condition defines the autocorrelation of the trade variable and the last three are the normal OLS equations. We use the lagged trade indicator and a constant as instrumental variables.[10]

### 4.1.2 Empirical Results

Table 5 presents the GMM estimates of the MRR model and the corresponding standard errors for each subgroup.[11] We also report the p-value of a Wald within-index subgroup equality test. We also calculate the implied spread, $2(\theta + \phi)$, and the proportion of the it explained by asymmetric information, $\gamma \equiv \theta/(\theta + \phi)$. This ratio is expected to be quite large, due to anonymous trading, until trade execution at least. Anonymity is considered to increase information asymmetry, as Foster and George (1992) showed: if traders are not fully anonymous and make their motivations widely known, the bid-ask spread and the price impact are expected to be lower relative to a fully anonymous market. This conclusion is also supported by the work of Admati and Pfleiderer (1991), where liquidity traders who preannounce the size of their orders enjoy lower transactions costs.

We reach the same conclusion as Easley et al. (1996), who pointed out that, in less frequently traded stocks, it is more common to observe more information-based traded risk. The percentage of the spread attributed to the information component(i.e., parameter $\gamma$) is higher in the smaller cap stocks (subgroups 3 and 4), as lower trading activity and, consequently, lower liquidity increase

[10] Although, Madhavan et al. (1997) introduced one more conditional moment in order to estimate the probability ($\lambda$) of a trade to occur between the bid and the ask price, this is not necessary in our dataset because all trades were executed at either endpoint.

[11] Estimations for individual stocks are available from the authors upon request.

the probability of dealing with an informed investor. Furthermore, as with Ahn et al. (2002), this component is more important in high-priced stocks ($\gamma$ is higher for subgroups 1 and 3). A possible explanation is that, during 2002, only institutional investors were active in the Exchange, dealing with high-priced stocks in a "bear" environment. Given that such investors are rather more informed than private ones, spreads were increasing to take care of such cases. On the contrary, since it is generally assumed that institutional investors are not interested in penny stocks as much, the inventory component received a lower weight for subgroups 2 and 4. The cost component ($\phi$) is higher (in absolute value) for high-priced stocks, as expected. We compute Wald statistics to test for parameter equality in the subgroups of each index: in all cases, they are significantly different at all usual confidence levels, revealing the importance of such partitioning.

Many researchers argued (cf. Ahn et al. (2002), Madhavan et al. (1997), Huang and Stoll (1997)) that spread components and especially the adverse selection one, tend to be underestimated because most trades occur either at the bid or at the ask but not in between. We calculate such bias to be between 21% and 30% of the quoted spread.[12] One explanation of this bias may be the breaking up of large trades into smaller ones. As trading takes place continuously at the one side of the spread, pointing possibly to the fact that this side is more liquid (exhibits larger depth), the spread, as a percentage of the midquote, seems to be smaller, since the midquote converges to the trade price. Given that the implied spread is calculated conditional to actual trades, trade asymmetry will cause the underestimation of the implied spread. This is further supported by the probability of a trade reversal – from a trade at the bid (ask) to a trade at the ask (bid) – being quite low.[13] For example, the reversal probability for stocks in group 1 is 35,34% and for group 3 is only 28,62%, a result reinforcing our belief that investors prefer to execute a series of continuous trades at one side of the quotes.

Table 6 summarizes intraday estimations of spread components, calculates the implied spread and presents the percentage of it explained by the asymmetry information for the six intraday time intervals.[14] We also report the p-value of a Wald test for differences between subgroups for estimated parameters, showing all are significant at all usual levels.

The autocorrelation coefficient does not show any clear pattern during the day. We observe, however, that its maximum value occurs in the last half hour, producing the lowest value for the probability of a trade reversal at that same period. Positive autocorrelation with similar trade size has been reported by several authors (see Madhavan et al. (1997) and Ahn et al. (2002) among others) but this feature of the last half-hour is, to the best of our knowledge, unique to the ASE and probably due to the increase in trading activity. As more investors are coming late into the market and traded volume increases, the breakup procedure increases trade autocorrelation. For example, if an informed investor is attempting to hide a large buy order at that last half-hour, he will choose to split it to smaller bits that particular half-hour in order to better conceal his motivation. Dufour and Engle (2000) have reached a similar conclusion, when they found that higher trading activity is positively associated with trade autocorrelation, volumes and spreads.

The adverse selection component, $\theta$, for all groups, drops sharply after the first 30 minutes, as

[12] The bias is defined to equal $1-$ (implied spread/absolute quoted spread).

[13] This probability, in the MRR structural model, is defined as $\pi = \frac{1-\rho}{2}$.

[14] We have also estimated the model( 1) by using ten time intervals instead, but results were similar.

the trading process adds valuable information to all investors, pushing more uninformed traders into the market. It then remains steady or declines slightly during the rest of the day, and increases sharply again in the last 30 minutes. Informed investors come in to close up their intraday positions just before the close, since by so doing, (a) they minimize risk, and (b) they profit more easily from superior information. Similar to Chan (2000), the increase of traded volume in the last time period, would also lead to a larger adverse selection problem and, hence, widen spreads. Using this argument, Chan (2000) explained the decrease (increase) of the adverse selection component at the NYSE, as average volume decreased (increased). On the other hand, the cost component $\phi$ does not behave uniformly but shows two different time patterns according to stock price. For high priced stocks (groups 1 and 3), it exhibits a clear U-shape, while, for groups 2 and 4, it monotonically increases with time. This is a striking result, since, under the MRR framework, there is no apparent reason behind these differences. We will, however, see shortly that such differences may be explained in our extended model.

In order to further examine the increase of the adverse selection component during the last trading period, we divide it into three smaller 10-minute intervals. Results for each subgroup are presented in Table 7. The increase of $\theta$ occurs mainly during the last 10 minutes of the trading day, with informed investors closing up their daily positions. This pattern is displayed for all subgroups, irrespective of capitalization and absolute price. On the other hand, the cost component gradually increases for high-cap stocks, but decreases for group 3 and remains constant for the fourth one.

#### 4.1.3 The effective spread

In their paper, MRR introduced a new trading cost measure, called *effective bid-ask spread*, which can estimate expected price change between non sequential trades. It approximates the cost that arises from a purchase order at time $t$ and a sale one after $k$ periods. Following our notation, the effective spread can be calculated as:

$$s^E = 2\phi + \theta \tag{3}$$

Madhavan et al. (1997) justified the use of $s^E$ and argued that the bid-ask spread overstates the true cost of trading due to (a) the high probability of midquote execution (which they express as $\lambda$), and (b) the tendency of prices to increase after a buy order. They also pointed out that the percentage of the implied spread that can be traced back to the effective spread, is monotonically increasing over the day and hence the transaction cost affects the effective spread more than the standard adverse selection component $\theta$ does.[15]

In Table 6, we present the effective spread as well as its relation to the implied one, calculated as $r^E = (2\phi + \theta)/2(\phi + \theta)$. For all subgroups, it displays a U-shape pattern similar to that of the implied one, while the ratio an inverse U-shape, contrary to MRR (1997) reported findings. It seems, therefore, that the intraday patterns of both spread components diverge from those observed at the NYSE and, consequently, the effective spread pattern in Athens is not similar to that of NYSE's. The highest trading costs in the ASE occur at the beginning and the end of the

[15]They also reported that $\theta$ decreases over the day, while $\phi$ is expected to increase.

day and, therefore, smaller private investors should focus on trading periods in the middle of the day, as supported by the theoretical model of Admati and Pfleiderer (1988).

Given the above, the U-shape pattern in the implied spread is mainly due to the pattern of the adverse selection component: in most cases, $\gamma$ is greater than 50% for all subgroups. Furthermore, the effective spread pattern is helpful in revealing the time period when trading costs are less and, hence, when it is optimal for uninformed investors to trade.

#### 4.1.4 Do these relations change over time?

The entire preceding analysis was done on the latest available intraday dataset from February 4 to December 30, 2002. We found that the adverse selection component ($\theta$) had greater effect on the spread than the cost component ($\phi$). It is interesting, however, to examine if this relation holds also during a much different historical period for the ASE. The new dataset covers the period from June 1 to August 31, 1999 and contains exactly the same variables: time-stamped prices to the nearest second, volumes, bids and offers with the corresponding sizes just before a transaction occurs. We limited, however, our analysis only to the large capitalization stocks included in FTASE-20 index.[16] The ASE authorities themselves, as do most of the Greek economic press and researchers, consider, that the year 2002 was a very distinct period from the 1999 specific summer months for three main reasons: (a) The level of the FTASE-20 index increased by 13% during this 3-month period, while during the eleven months in 2002, it decreased by 38%; (b) more than 1 million small investors were actively trading in the Athens Stock Exchange at that time, as opposed to a much lower number for the latter period; and (c) the average, reported increase in pre-tax profits of listed companies in 1999 was 43%, compared to a 32% *decline* in 2002.

Table 8 displays GMM estimates (and corresponding standard errors) of the MRR model for the 2 subgroups of FTASE-20 stocks, for the 1999 dataset. As expected, estimated parameters differ between subgroups. The adverse selection component, $\theta$, is close to zero for both subgroups, but statistically insignificant for the second one. The cost component, $\phi$, on the contrary, is significant at all usual confidence levels and is more important than $\theta$ in defining the spread, since $\gamma$ is near zero. We believe these results come into contrast with those of the 2002 dataset, for two reasons: (a) the overconfidence of the uninformed investors about the future positive direction of the market turned out to be unsubstantiated, and (b) the optimistic fundamentals of listed companies in 1999 fostered a bullish movement in prices, as opposed to their serious deterioration that appeared in the following years.

A value of $\theta$ close to zero indicates a possible lack of information-based risk. Given that the majority of investors participating in the stock rally of the summer of 1999 were uninformed, they put much more weight on the cost component of the spread rather than on the adverse selection one. They most probably presumed none had more information than anyone else, a belief grounded on the effortless increase of their wealth during this same period: The price of most stocks at least doubled during that period. Under this point of view, differences in the significance of $\theta$ can be attributed to the large number of uninformed traders with no previous experience in share investments. On the contrary, during 2002, there were mainly institutional investors participating

[16]The mid-cap FTASE-40 index was created at the end of this period and, precisely on December 8, 1999.

| | FTASE-20 | | Chi-square | FTASE-40 | | Chi-square |
|---|---|---|---|---|---|---|
| Components | Group 1 | Group 2 | p-value | Group 3 | Group 4 | p-value |
| $\rho$ | 0.2932 | 0.2818 | 0.0008 | 0.4276 | 0.2580 | 0 |
| SE | 2.33E-03 | 2.53E-03 | | 7.12E-03 | 2.27E-03 | |
| $\theta$ | 0.0075 | 0.0048 | 0 | 0.0176 | 0.0047 | 0 |
| SE | 6.49E-05 | 4.27E-05 | | 5.14E-04 | 3.30E-05 | |
| $\phi$ | 0.0066 | 0.0052 | 0 | 0.0074 | 0.0038 | 0 |
| SE | 6.07E-05 | 4.11E-05 | | 5.22E-04 | 2.99E-05 | |
| Implied Spread | 0.0282 | 0.0200 | | 0.0500 | 0.0169 | |
| $\gamma$ | 53,04% | 48,48% | | 70,54% | 54,92% | |

Table 5: Estimation results of the MRR model for the 4 stock subgroups (sample period from February 4 to December 30, 2002)

in the same market, more naturally considered as informed traders, consequently upgrading the role of the asymmetric information component, $\theta$.

Moreover, the decline of pre-tax profits can decrease uninformed trading, since possible financial distress increases the risk that private investors face, pushing them out of the market. Agrawal et al. (2004) argued that market makers increase the spread of firms that encounter financial problems, in order to protect themselves in case they trade against an informed trader. In such companies, it is common to observe a higher proportion of informed traders, as Hotchkiss and Mooradian (1997) showed, due to the fact they are more able to use sophisticated methods, not available to small investors, in order to value the companies with greater accuracy. Since, during the 2002 fiscal year, reported pre-tax profits declined by 32%, a larger presence of informed traders was expected and, hence, the adverse selection component became more significant than during the 1999 period.

## 4.2 The trade size dependent model

We now turn to an extension of the MRR model, where we explicitly incorporate trade volume as a factor affecting price change. Following the idea of Madhavan et al. (1997), we postulate that:

$$\begin{aligned} p_t &= \mu_t + \phi X_t + \kappa(X_t V_t) \\ \mu_t &= \mu_{t-1} + \theta V_t (X_t - \rho X_{t-1}), \end{aligned}$$

where $V_t$ is the number of traded shares. Given this setup, equation 1 now becomes:

$$p_t - p_{t-1} = \theta V_t (X_t - \rho X_{t-1}) + \phi(X_t - X_{t-1}) + \kappa(X_t V_t - X_{t-1} V_{t-1}) + u_t, \tag{4}$$

where the coefficient $\kappa$ will reveal whether the order handling or the inventory cost is more important. For example, if $\kappa$ turns out to be negative, it will decrease the total cost component for large trades, since it multiplies the signed volume, and will show that the order handling part overcomes the inventory one.

| Intraday parameter estimation | | | | | | | |
|---|---|---|---|---|---|---|---|
| Statistics | Time Intervals | | | | | | |
| | 11-11.30 | 11.30-12.30 | 12.30-13.30 | 13.30-14.30 | 14.30-15.30 | 15.30-16.00 | P-Value |
| **Panel A.** FTASE-20 stocks with price over €10 | | | | | | | |
| $\rho$ | 0.2926 | 0.2772 | 0.2748 | 0.2789 | 0.2856 | 0.3334 | 0.00 |
| SE | 0.0062 | 0.0048 | 0.0049 | 0.0052 | 0.0051 | 0.0050 | |
| $\theta$ | 0.0106 | 0.0074 | 0.0069 | 0.0067 | 0.0068 | 0.0100 | 0.00 |
| SE | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |
| $\phi$ | 0.0073 | 0.0063 | 0.0057 | 0.0063 | 0.0063 | 0.0068 | 0.00 |
| SE | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |
| Implied Spread | 0.0360 | 0.0274 | 0.0253 | 0.0260 | 0.0262 | 0.0335 | |
| $\gamma$ | 59.21% | 54.15% | 54.72% | 51.80% | 52.23% | 59.36% | |
| $s^E$ | 0.0252 | 0.02 | 0.0183 | 0.0193 | 0.0194 | 0.0236 | |
| $r^E$ | 70.39% | 72.99% | 72.62% | 74.23% | 74.05% | 70.24% | |
| **Panel B.** FTASE-20 stocks with price below €10 | | | | | | | |
| $\rho$ | 0.2420 | 0.2637 | 0.2666 | 0.2780 | 0.2796 | 0.3220 | 0.00 |
| SE | 0.0068 | 0.0051 | 0.0054 | 0.0054 | 0.0054 | 0.0053 | |
| $\theta$ | 0.0068 | 0.0050 | 0.0044 | 0.0046 | 0.0045 | 0.0059 | 0.00 |
| SE | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |
| $\phi$ | 0.0044 | 0.0048 | 0.0047 | 0.0048 | 0.0051 | 0.0053 | 0.00 |
| SE | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |
| Implied Spread | 0.0224 | 0.0196 | 0.0183 | 0.0187 | 0.0192 | 0.0224 | |
| $\gamma$ | 60.48% | 51.32% | 48.67% | 48.63% | 47.15% | 52.79% | |
| $s^E$ | 0.0156 | 0.0146 | 0.0138 | 0.0142 | 0.0147 | 0.0165 | |
| $r^E$ | 69.64% | 74.49% | 75.82% | 75.53% | 76.56% | 73.66% | |

| Intraday parameter estimation (cont'd) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Statistics | Time Intervals | | | | | | |
| | 11-11.30 | 11.30-12.30 | 12.30-13.30 | 13.30-14.30 | 14.30-15.30 | 15.30-16.00 | P-Value |
| **Panel C.** FTASE-40 stocks with price over €10 | | | | | | | |
| $\rho$ | 0.4077 | 0.3901 | 0.3801 | 0.3656 | 0.3947 | 0.5299 | 0.00 |
| SE | 0.0245 | 0.0149 | 0.0153 | 0.0141 | 0.0141 | 0.0122 | |
| $\theta$ | 0.0333 | 0.0186 | 0.0158 | 0.0160 | 0.0147 | 0.0233 | 0.00 |
| SE | 0.0030 | 0.0010 | 0.0008 | 0.0009 | 0.0007 | 0.0012 | |
| $\phi$ | 0.0060 | 0.0050 | 0.0048 | 0.0051 | 0.0047 | 0.0053 | 0.86 |
| SE | 0.0026 | 0.0010 | 0.0008 | 0.0009 | 0.0008 | 0.0011 | |
| Implied Spread | 0.0787 | 0.0472 | 0.0411 | 0.0423 | 0.0387 | 0.0571 | |
| $\gamma$ | 84.72% | 78.69% | 76.80% | 75.76% | 75.94% | 81.54% | |
| $s^E$ | 0.0453 | 0.0286 | 0.0254 | 0.0262 | 0.0241 | 0.0339 | |
| $r^E$ | 57.63% | 60.59% | 61.65% | 62.09% | 62.11% | 59.27% | |
| **Panel D.** FTASE-40 stocks with price below €10 | | | | | | | |
| $\rho$ | 0.2063 | 0.2200 | 0.2281 | 0.2375 | 0.2465 | 0.3562 | 0.00 |
| SE | 0.0061 | 0.0048 | 0.0049 | 0.0049 | 0.0047 | 0.0050 | |
| $\theta$ | 0.0063 | 0.0052 | 0.0046 | 0.0045 | 0.0046 | 0.0057 | 0.00 |
| SE | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |
| $\phi$ | 0.0030 | 0.0033 | 0.0035 | 0.0037 | 0.0036 | 0.0038 | 0.00 |
| SE | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |
| Implied Spread | 0.0187 | 0.0170 | 0.0162 | 0.0163 | 0.0164 | 0.0189 | |
| $\gamma$ | 67.59% | 60.75% | 57.04% | 55.23% | 56.36% | 59.88% | |
| $s^E$ | 0.0123 | 0.0118 | 0.0116 | 0.0119 | 0.0118 | 0.0133 | |
| $r^E$ | 66.13% | 69.41% | 71.60% | 72.56% | 71.95% | 70.00% | |

Table 6: Intraday estimation of MRR model for the 4 subgroups of stocks (sample period from February 4 to December 30, 2002).

| Statistics | Time Intervals | | | | | |
|---|---|---|---|---|---|---|
| | 15:30-15:40 | 15:40-15:50 | 15:50-16:00 | 15:30-15:40 | 15:40-15:50 | 15:50-16:00 |
| | FTASE-20 stocks, price >€10 | | | FTASE-20 stocks, price <€10 | | |
| $\rho$ | 0.2851 | 0.2952 | 0.3714 | 0.2728 | 0.2596 | 0.3492 |
| SE | 0.0387 | 0.0340 | 0.0254 | 0.0355 | 0.0302 | 0.0221 |
| $\theta$ | 0.0057 | 0.0054 | 0.0075 | 0.0101 | 0.0101 | 0.0153 |
| SE | 0.0007 | 0.0006 | 0.0006 | 0.0012 | 0.0011 | 0.0013 |
| $\phi$ | 0.0036 | 0.0045 | 0.0051 | 0.0052 | 0.0056 | 0.0064 |
| SE | 0.0007 | 0.0006 | 0.0006 | 0.0012 | 0.0013 | 0.0014 |
| Implied Spread | 0.0186 | 0.0198 | 0.0252 | 0.0306 | 0.0313 | 0.0433 |
| | FTASE-40 stocks, price >€10 | | | FTASE-20 stocks, price <€10 | | |
| $\rho$ | 0.3816 | 0.4579 | 0.5850 | 0.2512 | 0.3127 | 0.4150 |
| SE | 0.0467 | 0.0403 | 0.0245 | 0.0498 | 0.0420 | 0.0303 |
| $\theta$ | 0.0154 | 0.0173 | 0.0340 | 0.0064 | 0.0070 | 0.0092 |
| SE | 0.0021 | 0.0020 | 0.0043 | 0.0010 | 0.0008 | 0.0009 |
| $\phi$ | 0.0015 | 0.0009 | 0.0009 | 0.0025 | 0.0021 | 0.0023 |
| SE | 0.0022 | 0.0020 | 0.0039 | 0.0009 | 0.0008 | 0.0009 |
| Implied Spread | 0.0339 | 0.0365 | 0.0699 | 0.0177 | 0.0183 | 0.0231 |

Table 7: Cross-sectional means of the MRR model and implied spreads for the 4 subgroups. The last half-hour period was divided into three 10-minute trading intervals. Sample period from February 4 to December 30, 2002.

| | FTASE-20 | | Chi-square |
|---|---|---|---|
| Components | Group 1 | Group 2 | p-value |
| $\rho$ | 0.3214 | 0.2155 | 0 |
| SE | 0.0028 | 0.0039 | |
| $\theta$ | 0.00059 | 0.00001 | 0.0133 |
| SE | 0.0002 | 0.00015 | |
| $\phi$ | 0.07165 | 0.04741 | 0 |
| SE | 0.0005 | 0.00040 | |
| Implied Spread | 0.144 | 0.095 | |
| $\gamma$ | 0.82% | 0.01% | |

Table 8: Estimation results of the MRR model for the 2 subgroups of large cap stocks (sample period from June 1st to August 31st, 1999).

Now,let $a_{X_t=1}$ and $b_{X_t=-1}$ be the ask and bid quotes for trade indicator $X_t$. Then the implied spread can be modelled as:

$$\begin{aligned}
a_{X_t=1} &= \mu_{t-1} + \theta V_t[1 - \mathbb{E}(X_t|X_{t-1})] + (\phi + \kappa V_t) \\
b_{X_t=-1} &= \mu_{t-1} - \theta V_t[1 + \mathbb{E}(X_t|X_{t-1})] - (\phi + \kappa V_t) \\
a_{X_t=1} - b_{X_t=-1} &= 2[V_t(\theta + \kappa) + \phi]
\end{aligned}$$

The implied spread is an increasing function of the absolute volume $V_t$, the adverse selection $\theta$ and the cost component $\phi$, while its relation with $\kappa$ depends on the sign of it.[17] If $\kappa$ <0, then the order handling component dominates the inventory cost and produces economies of scale in trading, as cost decreases with increasing volume.

We chose to model transaction prices as functions of the signed traded volume for obvious reasons. The investor in an electronic market, required to implicitly supply liquidity through his orders, will not only consider the direction of the coming trade (a buy or a sell), but also its size. It is normal for him to adjust the spread accordingly, narrowing it for small sizes and widening it for large ones. Although theoretical models suggest expressing the cost component as a linear function of volume, we adopt a concave (square root) function, since several empirical studies have shown its advantages. Barra (1997), in the Market Impact Model™ handbook, argues that, in order to achieve the best fit between midquote returns and volume, they had to use a one-half power law. Almgren (2001) postulated that price impact functions were not linear in volume and chose the power law family, which includes the square root function. Lastly, Hisata and Yamai (2000) also formulated the market impact as a square root function, when they proposed a methodology for Liquidity Adjusted Value-at-Risk.

We estimate model 4 based on the following implied moment conditions:

$$E\left\{\begin{array}{c}
X_t X_{t-1} - \rho X_{t-1}^2 \\
u_t - \alpha \\
(u_t - \alpha) X_t \sqrt{V_t} \\
(u_t - \alpha) X_{t-1} \sqrt{V_{t-1}} \\
(u_t - \alpha) \sqrt{V_t} \\
(u_t - \alpha) \sqrt{V_{t-1}}
\end{array}\right\} = 0. \tag{5}$$

To eliminate outlier effects, we discarded trades with size greater than the 99.5% percentile of their empirical distribution.[18]

We also tested for the well known Glosten and Harris (1988) specification of intraday price changes, which, in our notation, can be set out as follows:

$$\begin{aligned}
p_t &= \mu_t + \phi_t X_t \\
\mu_t &= \mu_{t-1} + \theta_t X_t + U_t \\
\phi_t &= c_0 + c_1 V_t \\
\theta_t &= z_0 + z_1 V_t,
\end{aligned}$$

[17]If $V_t$=1 and $\kappa$=0, this specification simplifies to the MRR model.

[18]See Hausman et al. (1992), De Jong et al. (1995, 1996) among others, for similar transaction filtering.

The $U_t$ variable captures both public information and other factors affecting prices. Using the above equations, the price change can then be estimated as:

$$p_t - p_{t-1} = \alpha + c_0 \Delta X_t + c_1 \Delta X_t V_t + z_0 X_t + z_1 X_t V_t + U_t, \tag{6}$$

where $\alpha$ is a constant. Like the MRR model, the implied spread is equal to $2(c_0 + c_1 V_t + z_0 + z_1 V_t)$, which equals to twice the sum of the order processing and the adverse selection components. Both model (4) and (6) describe in a similar fashion the order processing component, since $c_0$ and $\phi$ measure fixed costs, while $c_1$ and $\kappa$ express the relation between cost and volume. On the other hand, Glosten and Harris's equation writes the asymmetric information component by using two different coefficients: (a) $_0$ measures the part of adverse selection **not** affected by volume, and (b) $z_1$ describes the relation with traded volume. In our specification (4), we assume $z_0 = 0$. Lastly, in 6, Glosten and Harris (1988) have set $\rho = 0$, implying that the order flow does not provide information about the future value of the asset.

### 4.2.1 Estimation results

Table 9 presents the GMM estimates of the extended model, the corresponding standard errors for each stock subgroup, the p-value of the Wald test, calculated implied spreads and the coefficient $\gamma$, which, in this framework, equals:

$$\gamma = \frac{\theta\sqrt{V}}{\theta\sqrt{V} + \kappa\sqrt{V} + \phi}.$$

The last two parameters are calculated for two values of volume: the officially minimum allowed trade size and the average number of shares traded during the sample period.

All parameters are statistically significant and differ between the four subgroups. In most cases, the estimates of model 4 are similar to those of the standard MRR one. Using the average period volume, implied spreads are slightly smaller. We must not forget, however, that we can generate the true implied spread by inputting explicitly the number of shares in the model 4. For subgroups 1, 2 and 3, the average $\gamma$ is lower than 50%, showing that, here, the cost component of the spread $(\phi + \kappa\sqrt{V})$ is more important than the adverse selection one $(\theta\sqrt{V})$. As volume increases, however, $\gamma$ rises and, hence, the importance of the inventory component decreases, similarly to Chan (2000). For a small size trade, the market will most probably believe it has a relatively low information content and, consequently, it will place more weight on the order processing cost. On the other hand, if an investor is willing to trade a large quantity of shares, then the adverse selection risk facing the counterparty will take over, pushing spreads upwards. We calculate the minimum number of shares causing such a switch to be equal to 602, 1081, 274 and 785 for groups 1, 2, 3 and 4, respectively. For these sizes, $\gamma$ is exactly equal to 1/2.

The negative sign of $\kappa$ also has a clear implication: the order processing component decreases with volume, while inventory costs remain unaltered, resulting in economies of scale in trading. This was somehow expected because, in an order-driven market like the ASE, without any explicit market makers, inventory costs cannot be regarded as significant by the large number of anonymous order suppliers, which play the role of liquidity suppliers here. Hausman et al. (1992) reported, on the contrary, diseconomies of scale for their dataset, with an upward sloping price response function, although at a decreasing rate. Ahn et al. (2002) also observed economies of scale in their study, with the order handling part dominating the inventory component. We also find there is a certain amount of shares that makes the cost component disappear. We calculate it to equal 2928, 11216, 2759 and 6112 for each subgroup respectively. For larger sizes, the spread is due solely to asymmetric information, as $\phi + \kappa\sqrt{V}$ becomes negative!

Table 10 displays the OLS estimates of the Glosten and Harris model 6 for all four stock subgroups, as well as the corresponding standard errors, adjusted using the Newey and West (1987) procedure.[19] We also report the Wald test results and calculate the implied spread and the $\gamma$ coefficient, which is here defined by:

$$\gamma = \frac{z_0 + z_1\sqrt{V}}{z_0 + z_1\sqrt{V} + c_0 + c_1\sqrt{V}}.$$

Estimated implied spreads and gammas for both models 4 and 6 are quite similar. As the volume, however, increases, implied spreads become larger in our specification than the Glosten et al. one. Like De Jong (1996), the order processing component is more important than the adverse selection one, for average traded volumes, with $\gamma$ ranging from 33% to 43%. Moreover, the negative sign of $c_1$ – which can be compared to the parameter $\kappa$ of our model – indicates that order handling dominates inventory costs, with total costs falling with the number of traded shares. For subgroups 2, 3 and 4, coefficient $c_1$ is at least four times larger than $\kappa$, resulting in a comparative weakening of the effect of order handling costs.

Table 11 presents the two components of the spread and the proportion of the information effect for all three specifications. While the two models that explicitly incorporate volume as a spread-affecting variable, generate similar estimations, they both differ significantly with the standard MRR model, since they underestimate the adverse selection part and overestimate the cost part (cf. a similar result by Ahn et al. (2002)). In most cases, estimated parameters of model 4 are closer to those of MRR, yielding smaller biases. We should of course remember that MRR results are *treated* as benchmarks, without them *being* necessarily so.

Table 12 presents the estimated parameters of our model 4 using six time intervals. All measures exhibit the familiar U-shape time pattern throughout the day, except for $\kappa$ which seems to follow an inverse U-shape. This may be mean that, as the trading day unfolds, order handling becomes less important than inventory costs. Generally speaking, all time patterns mentioned in our previous analysis, are replicated in Table 12. For example, in most cases, the average implied spread and the adverse selection component are smaller than those of the classical MRR model, while costs are greater. The differences in the pattern of the cost component $(\phi + \kappa\sqrt{V_t})$ between the subgroups of high and low priced stocks is mainly due to the new coefficient $\kappa$. For the two subgroups with low priced shares, the increase in the cost component during the day can be attributed to the smaller effect of order handling, as $\kappa$ is getting closer to zero, although it remains always negative. This dominates the decrease of coefficient $\phi$. This pattern reverses in the last 30 minutes of trading, since the increase in $\phi$, the part of the cost component that does **not** depend

[19]For subgroup 1, we have slightly altered the specification of 6, assuming that $z_0 = 0$, in order to produce statistically significant parameters.

| | FTASE-20 | | Chi-square | FTASE-40 | | Chi-square |
|---|---|---|---|---|---|---|
| Components | Group 1 | Group 2 | p-value | Group 3 | Group 4 | p-value |
| $\rho$ | 0.2906 | 0.2801 | 0.0018 | 0.4279 | 0.2557 | 0 |
| SE | 2.29E-03 | 2.50E-03 | | 7.00E-03 | 2.23E-03 | |
| $\theta$ | 0.0003 | 0.0002 | 0 | 0.0007 | 0.0002 | 0 |
| SE | 2.68E-06 | 1.61E-06 | | 2.37E-05 | 1.25E-06 | |
| $\kappa$ | -0.0002 | -0.0001 | 0 | -0.0003 | -0.0001 | 0 |
| SE | 3.55E-06 | 1.91E-06 | | 2.87E-05 | 1.42E-06 | |
| $\phi$ | 0.0124 | 0.0077 | 0 | 0.0175 | 0.0066 | 0 |
| SE | 9.13E-05 | 5.33E-05 | | 6.14E-04 | 4.27E-05 | |
| Minimum Trade Size | 10 | 10 | | 10 | 10 | |
| Average Trade Size | 379 | 634 | | 373 | 607 | |
| Implied Spread with min size | 0.0252 | 0.0159 | | 0.0376 | 0.0136 | |
| Implied Spread with ave size | 0.0267 | 0.0198 | | 0.0502 | 0.0165 | |
| $\gamma$with min size | 6.96% | 6.40% | | 12.21% | 7.01% | |
| $\gamma$with ave size | 40.36% | 40.92% | | 55.80% | 45.15% | |

Table 9: Estimation results of extended model for the 4 stock subgroups (sample period from February 4 to December 30, 2002).

| | FTASE-20 | | Chi-square | FTASE-40 | | Chi-square |
|---|---|---|---|---|---|---|
| Components | Group 1 | Group 2 | p-value | Group 3 | Group 4 | p-value |
| $c_0$ | 0.0139 | 0.0071 | 0 | 0.01613 | 0.00608 | 0 |
| SE | 6.94E-05 | 8.79E-05 | | 1.98E-04 | 6.46E-05 | |
| $c_1$ | -0.00023 | -0.00002 | 0 | -0.00007 | -0.00004 | 0.0035 |
| SE | 3.87E-06 | 3.41E-06 | | 1.01E-05 | 2.56E-06 | |
| $z_0$ | - | 0.00256 | | 0.00871 | 0.00280 | 0 |
| SE | - | 1.14E-04 | | 2.44E-04 | 8.58E-05 | |
| $z_1$ | 0.00024 | 0.00005 | 0 | 0.00010 | 0.00004 | 0 |
| SE | 3.40E-06 | 4.47E-06 | | 1.30E-05 | 3.41E-06 | |
| Minimum Trade Size | 10 | 10 | | 10 | 10 | |
| Average Trade Size | 379 | 634 | | 373 | 607 | |
| Implied Spread with min size | 0.0279 | 0.0195 | | 0.0499 | 0.0178 | |
| Implied Spread with ave size | 0.0282 | 0.0208 | | 0.0508 | 0.0180 | |
| $\gamma$with min size | 5.45% | 27.86% | | 36.17% | 32.97% | |
| $\gamma$with average size | 33.15% | 36.67% | | 41.67% | 42.68% | |

Table 10: Estimation results for the Glosten and Harris specification for the 4 stock subgroups (sample period from February 4 to December 30, 2002).

| | FTASE-20 | | FTASE-40 | |
|---|---|---|---|---|
| | Group 1 | Group 2 | Group 3 | Group 4 |
| **Information component** | | | | |
| MRR | 0.0075 | 0.0048 | 0.0176 | 0.0047 |
| Trade dependent MRR | 0.0054 | 0.0041 | 0.0140 | 0.0037 |
| Glosten-Harris | 0.0047 | 0.0038 | 0.0106 | 0.0038 |
| **Cost component** | | | | |
| MRR | 0.0066 | 0.0052 | 0.0074 | 0.0038 |
| Trade dependent MRR | 0.0080 | 0.0059 | 0.0111 | 0.0045 |
| Glosten-Harris | 0.0094 | 0.0066 | 0.0148 | 0.0052 |
| **Relative Proportion** | | | | |
| MRR | 53.19% | 48% | 70.40% | 55.29% |
| Trade dependent MRR | 40.36% | 40.92% | 55.80% | 45.15% |
| Glosten-Harris | 33.15% | 36.67% | 41.67% | 42.68% |

Table 11: Comparative results for the three models (sample period from February 4 2002 to December 30, 2002.

on volume, causes the overall cost to increase. This may be associated to the risk of maintaining a position overnight. For high priced stocks (subgroups 1 and 3), this coefficient is more important than $\kappa\sqrt{V}$, because the total cost follows the same pattern as $\phi$. For such expensive stocks, the order handling component is more important than for cheap stocks (subgroups 2 and 4), as the absolute value of $\kappa$ is always greater in the former than in the latter group.

# 5 Price Impact Functions

A perfectly liquid market gives the opportunity to investors to buy or sell any amount of stock without causing any price change. Consequently, in an illiquid market, the main objective of a trader should be to minimize both his/her transaction costs and execution time — the time needed to see his order serviced. Microstructure models help us construct statistics that will proxy the liquidity of the market or each share separately. More specifically, as stated in Aitken and Comerton-Forde (2003), there are two kinds of transaction costs in a stock market: *explicit* ones include general commissions and fees, and *implicit* ones, linked to the trading procedure per se and including bid-ask spreads and price impact. Liquidity is usually measured by trading value, trading volume or the number of daily transactions; the principal advantage of such proxies is their simplicity and ease of calculation. Execution costs, on the other hand, are also called "order-based" costs since they are only approximated by implied bid-ask spreads. In this paper, we will limit our analysis to implicit execution costs and order-based measures of liquidity, since our model can directly estimate them for different traded volumes. Moreover, the price impact of a trade can be related to both *temporary* and *permanent* price effects. The former are linked

Intraday estimated parameters of our extended model.

| Statistics | Time Intervals | | | | | |
|---|---|---|---|---|---|---|
| | 11-11.30 | 11.30-12.30 | 12.30-13.30 | 13.30-14.30 | 14.30-15.30 | 15.30-16.00 |
| **Panel A.** Large cap stocks with price > €10 | | | | | | |
| $\rho$ | 0.2899 | 0.2753 | 0.2718 | 0.2784 | 0.2805 | 0.3316 |
| SE | 0.0056 | 0.0045 | 0.0047 | 0.0048 | 0.0048 | 0.0047 |
| $\theta$ | 0.00040 | 0.00029 | 0.00027 | 0.00023 | 0.00022 | 0.00030 |
| SE | 1.08E-05 | 5.36E-06 | 4.78E-06 | 4.55E-06 | 4.47E-06 | 5.42E-06 |
| $\kappa$ | -0.00043 | -0.00025 | -0.00021 | -0.00017 | -0.00018 | -0.00022 |
| SE | 1.48E-05 | 6.40E-06 | 5.87E-06 | 5.24E-06 | 5.61E-06 | 6.25E-06 |
| $\phi$ | 0.0168 | 0.0122 | 0.0108 | 0.0111 | 0.0114 | 0.0138 |
| SE | 3.25E-04 | 1.44E-04 | 1.48E-04 | 1.29E-04 | 1.39E-04 | 1.76E-04 |
| Size | 307 | 318 | 354 | 394 | 415 | 486 |
| $\theta\sqrt{Size}$ | 0.00707 | 0.00523 | 0.00506 | 0.00454 | 0.00457 | 0.00665 |
| $\phi+\kappa\sqrt{Size}$ | 0.00929 | 0.00768 | 0.00691 | 0.00768 | 0.00778 | 0.00897 |
| Implied Spread | 0.0327 | 0.0258 | 0.0240 | 0.0244 | 0.0247 | 0.0312 |
| $\gamma$ | 43.21% | 40.52% | 42.26% | 37.13% | 37.00% | 42.56% |
| **Panel B.** Large cap stocks with price < €10 | | | | | | |
| $\rho$ | 0.2398 | 0.2639 | 0.2654 | 0.2775 | 0.2775 | 0.3208 |
| SE | 0.0062 | 0.0047 | 0.0051 | 0.0050 | 0.0049 | 0.0048 |
| $\theta$ | 0.00024 | 0.00018 | 0.00015 | 0.00014 | 0.00014 | 0.00018 |
| SE | 5.67E-06 | 3.27E-06 | 2.98E-06 | 2.85E-06 | 2.65E-06 | 3.22E-06 |
| $\kappa$ | -0.00012 | -0.00008 | -0.00006 | -0.00006 | -0.00006 | -0.00010 |
| SE | 7.25E-06 | 3.69E-06 | 3.52E-06 | 3.26E-06 | 3.07E-06 | 3.73E-06 |
| $\phi$ | 0.0081 | 0.0073 | 0.0068 | 0.0072 | 0.0074 | 0.0087 |
| SE | 1.82E-04 | 9.04E-05 | 9.04E-05 | 9.41E-05 | 9.10E-05 | 1.13E-04 |
| Size | 496 | 558 | 591 | 681 | 699 | 781 |
| $\theta\sqrt{Size}$ | 0.00540 | 0.00415 | 0.00374 | 0.00374 | 0.00361 | 0.00502 |
| $\phi+\kappa\sqrt{Size}$ | 0.00549 | 0.00549 | 0.00533 | 0.00558 | 0.00579 | 0.00600 |
| Implied Spread | 0.0218 | 0.0193 | 0.0181 | 0.0187 | 0.0188 | 0.0220 |
| $\gamma$ | 49.57% | 43.06% | 41.19% | 40.14% | 38.41% | 45.56% |

| Intraday estimated parameters of our extended model (continued) | | | | | | |
|---|---|---|---|---|---|---|
| | 11-11.30 | 11.30-12.30 | 12.30-13.30 | 13.30-14.30 | 14.30-15.30 | 15.30-16.00 |
| **Panel C.** Mid cap stocks with price > €10 | | | | | | |
| $\rho$ | 0.3997 | 0.3903 | 0.3766 | 0.3658 | 0.3935 | 0.5262 |
| SE | 0.0207 | 0.0138 | 0.0139 | 0.0127 | 0.0126 | 0.0112 |
| $\theta$ | 0.00128 | 0.00074 | 0.00057 | 0.00057 | 0.00053 | 0.00103 |
| SE | 1.36E-04 | 4.48E-05 | 3.15E-05 | 3.28E-05 | 3.01E-05 | 5.05E-05 |
| $\kappa$ | -0.00082 | -0.00041 | -0.00019 | -0.00021 | -0.00018 | -0.00040 |
| SE | 1.38E-04 | 4.79E-05 | 3.91E-05 | 3.69E-05 | 3.58E-05 | 4.89E-05 |
| $\phi$ | 0.0297 | 0.0164 | 0.0123 | 0.0139 | 0.0118 | 0.0176 |
| SE | 2.53E-03 | 1.03E-03 | 7.91E-04 | 7.95E-04 | 7.46E-04 | 1.03E-03 |
| Size | 292 | 358 | 390 | 431 | 430 | 338 |
| $\theta\sqrt{Size}$ | 0.02182 | 0.01397 | 0.01124 | 0.01176 | 0.01094 | 0.01894 |
| $\phi+\kappa\sqrt{Size}$ | 0.01560 | 0.00857 | 0.00853 | 0.00959 | 0.00820 | 0.01027 |
| Implied Spread | 0.0749 | 0.0451 | 0.0396 | 0.0427 | 0.0383 | 0.0584 |
| $\gamma$ | 58.32% | 62.00% | 56.86% | 55.10% | 57.17% | 64.84% |
| **Panel D.** Mid cap stocks with price < €10 | | | | | | |
| $\rho$ | 0.2033 | 0.2176 | 0.2254 | 0.2343 | 0.2445 | 0.3564 |
| SE | 0.0056 | 0.0045 | 0.0045 | 0.0046 | 0.0043 | 0.0046 |
| $\theta$ | 0.00020 | 0.00017 | 0.00015 | 0.00014 | 0.00014 | 0.00018 |
| SE | 3.93E-06 | 2.40E-06 | 2.25E-06 | 2.32E-06 | 2.10E-06 | 2.69E-06 |
| $\kappa$ | -0.00012 | -0.00010 | -0.00008 | -0.00008 | -0.00008 | -0.00010 |
| SE | 3.97E-06 | 2.85E-06 | 2.71E-06 | 2.67E-06 | 2.54E-06 | 2.96E-06 |
| $\phi$ | 0.0071 | 0.0064 | 0.0061 | 0.0064 | 0.0065 | 0.0072 |
| SE | 1.04E-04 | 7.94E-05 | 7.48E-05 | 7.94E-05 | 7.45E-05 | 8.50E-05 |
| Size | 550 | 571 | 584 | 622 | 634 | 681 |
| $\theta\sqrt{Size}$ | 0.00462 | 0.00402 | 0.00364 | 0.00353 | 0.00361 | 0.00470 |
| $\phi+\kappa\sqrt{Size}$ | 0.00420 | 0.00415 | 0.00424 | 0.00444 | 0.00436 | 0.00457 |
| Implied Spread | 0.0176 | 0.0163 | 0.0158 | 0.0160 | 0.0159 | 0.0185 |
| $\gamma$ | 52.33% | 49.18% | 46.20% | 44.31% | 45.29% | 50.71% |

Table 12: Intraday estimation of our trade size extension model (sample period from February 4 to December 30, 2002).

to inventory behavior and price discreteness, while the latter are associated with the information content of the trade. Because it is difficult to differentiate the two, all price impacts will be treated as permanent in what follows.

We define the price impact function as the percentage of the median price explained by the cost component:

$$\frac{\phi + \kappa\sqrt{\bar{V}}}{MedianPrice}.$$

Such a definition translates the natural interpretation of "effect of volume on price": how much will the transaction price change for larger trade sizes? In Table 13, we present such a price impact function for the four stock subgroups and for chosen trade sizes. While in a perfectly liquid market, we would expect the impact of volume to be nil i.e., such a function to be flat, this is not the case here. It may even show whether there are any economies or diseconomies of scale in trading. In our dataset and for all stock subgroups, the downward-sloping curves reveal the presence of economies of scale, as the percentage of price due to order handling costs decreases with the traded size. Moreover, according to this criterion, high priced stocks (subgroups 1 and 3) are the most liquid, since it is in these groups that we observe the minimum price impact for a fixed trade size. This result is similar to that of Brennan and Subrahmanyam (1995), who observed that transactions costs are negatively related to share price. Hausman et al. (1992) also reported that low priced stocks were less liquid than high priced ones, since the percentage price impact for a given traded value was considerably higher.

In order to measure more accurately the "depth" of each stock subgroup, we calculate the percentage price change for different sequences of traded volumes.[20] In Table 14, we present how the price changes when we switch from a buy transaction at time $t-1$ (row) to a sell transaction at time $t$ (column) for a range from 1 to 3000 shares. Generally speaking, we find that the price effect is bigger if the first trade is small, because the $\kappa(X_t V_t - X_{t-1} V_{t-1})$ part of the impact decreases the total price change (negative $\kappa$). By comparing the stock subgroups according to their capitalization, we observe that, in most of cases, expected price change is higher in mid cap stocks (subgroups 3 and 4), as Hasbrouck (1991a, b) had reported. An interesting point here is that, for small trade volumes, the percentage change in high priced, middle capitalization stocks is smaller than that in low priced, high capitalization stocks. This is not, however, the case for large traded volumes.

# 6 Portfolio Trading

Finally, changes in prices arise not only from order flow innovations, but also from changes in related stocks or indexes. In particular, selling or buying pressures in the market will produce quote changes in specific stocks, as liquidity suppliers attempt to keep their overall portfolios in balance. We further extend the MRR model by postulating that:

[20] A similar measure is the effective spread ($s^E$) which, however, ignores order flow effects.

| | Groups | | | |
|---|---|---|---|---|
| Trade Size | 1 | 2 | 3 | 4 |
| 1 | 0.058% | 0.107% | 0.097% | 0.178% |
| 10 | 0.056% | 0.105% | 0.093% | 0.173% |
| 100 | 0.048% | 0.098% | 0.080% | 0.157% |
| 500 | 0.035% | 0.085% | 0.057% | 0.129% |
| 1000 | 0.025% | 0.076% | 0.039% | 0.107% |

Table 13: Percentage of the median price explained by the cost component (sample period from February 4 to December 30, 2002.

$$
\begin{aligned}
p_t &= \mu_t + \phi X_t \\
\mu_t &= \mu_{t-1} + \theta(X_t - \rho X_{t-1}) + \eta \Upsilon_t,
\end{aligned}
$$

and hence the intraday model of price movements can be described as:

$$p_t - p_{t-1} = \theta(X_t - \rho X_{t-1}) + \phi(X_t - X_{t-1}) + \eta \Upsilon_t + u_t, \tag{7}$$

where $\Upsilon_t$ is the aggregate buy-sell indicator variable based on the General Index of the ASE and $\eta$ is the degree of asymmetry information that is generated by the general conditions of the market. Equation 1 is a special case of 7 when there are no spillover effects from other stocks($\eta = 0$).[21]

This approach will not only distinguish the adverse selection ($\theta$) and the cost component ($\phi$) of the spread, but will also reveal the importance, if any, of buying and selling pressures in the process of the bid/ask adjustment. Specifically, this model (7) assumes that the adverse selection component is not only produced by the order flow for the stock, but also depends on the sign of the trades in the entire market. The implied spread can then be modelled according to the following four cases:

$$\left\{ \begin{aligned} a_t(X_t = 1, \Upsilon_t = 1) &= \mu_{t-1} + \theta + \eta + \phi \\ b_t(X_t = -1, \Upsilon_t = -1) &= \mu_{t-1} - \theta - \eta - \phi \end{aligned} \right\} \Rightarrow \text{Spread} = 2(\theta + \eta + \phi)$$

$$\left\{ \begin{aligned} a_t(X_t = 1, \Upsilon_t = -1) &= \mu_{t-1} + \theta - \eta + \phi \\ b_t(X_t = -1, \Upsilon_t = 1) &= \mu_{t-1} - \theta + \eta - \phi \end{aligned} \right\} \Rightarrow \text{Spread} = 2(\theta - \eta + \phi)$$

$$\left\{ \begin{aligned} a_t(X_t = 1, \Upsilon_t = 1) &= \mu_{t-1} + \theta + \eta + \phi \\ b_t(X_t = -1, \Upsilon_t = 1) &= \mu_{t-1} - \theta + \eta - \phi \end{aligned} \right\} \Rightarrow \text{Spread} = 2(\theta + \phi)$$

[21] We did not use the specification of the trade size dependent model to reduce estimation complexity.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Group 1 | | | | | | | |
| | $V_t$ | | | | | | |
| | | -1 | -10 | -100 | -1000 | -2000 | -3000 |
| $V_{t-1}$ | 1 | -0.1180% | -0.1193% | -0.1235% | -0.1366% | -0.1446% | -0.1507% |
| | 10 | -0.1157% | -0.1170% | -0.1211% | -0.1343% | -0.1422% | -0.1483% |
| | 100 | -0.1082% | -0.1095% | -0.1136% | -0.1268% | -0.1347% | -0.1408% |
| | 1000 | -0.0845% | -0.0858% | -0.0900% | -0.1031% | -0.1110% | -0.1171% |
| | 2000 | -0.0702% | -0.0715% | -0.0756% | -0.0887% | -0.0967% | -0.1028% |
| | 3000 | -0.0591% | -0.0605% | -0.0646% | -0.0777% | -0.0857% | -0.0918% |
| Group 2 | | | | | | | |
| | $V_t$ | | | | | | |
| | | -1 | -10 | -100 | -1000 | -2000 | -3000 |
| $V_{t-1}$ | 1 | -0.2171% | -0.2212% | -0.2341% | -0.2748% | -0.2994% | -0.3183% |
| | 10 | -0.2149% | -0.2190% | -0.2319% | -0.2726% | 0.2972% | -0.3161% |
| | 100 | -0.2080% | -0.2120% | -0.2249% | -0.2656% | -0.2902% | -0.3091% |
| | 1000 | -0.1859% | -0.1899% | -0.2028% | -0.2435% | -0.2681% | -0.2871% |
| | 2000 | -0.1725% | -0.1766% | -0.1894% | -0.2301% | -0.2548% | -0.2737% |
| | 3000 | -0.1622% | -0.1663% | -0.1792% | -0.2199% | -0.2445% | -0.2634% |
| Group 3 | | | | | | | |
| | $V_t$ | | | | | | |
| | | -1 | -10 | -100 | -1000 | -2000 | -3000 |
| $V_{t-1}$ | 1 | -0.1997% | -0.2083% | -0.2353% | -0.3207% | -0.3725% | -0.4122% |
| | 10 | -0.1957% | -0.2042% | -0.2312% | -0.3166% | -0.3684% | -0.4081% |
| | 100 | -0.1828% | -0.1913% | -0.2184% | -0.3038% | -0.3555% | -0.3952% |
| | 1000 | -0.1421% | -0.1507% | -0.1777% | -0.2631% | -0.3148% | -0.3546% |
| | 2000 | -0.1175% | -0.1260% | -0.1530% | -0.2384% | -0.2902% | -0.3299% |
| | 3000 | -0.0986% | -0.1071% | -0.1341% | -0.2195% | -0.2713% | -0.3110% |
| Group 4 | | | | | | | |
| | $V_t$ | | | | | | |
| | | -1 | -10 | -100 | -1000 | -2000 | -3000 |
| $V_{t-1}$ | 1 | -0.3611% | -0.3673% | -0.3870% | -0.4491% | -0.4868% | -0.5157% |
| | 10 | -0.3561% | -0.3623% | -0.3820% | -0.4442% | -0.4818% | -0.5107% |
| | 100 | -0.3404% | -0.3466% | -0.3662% | -0.4284% | -0.4660% | -0.4949% |
| | 1000 | -0.2905% | -0.2967% | -0.3164% | -0.3785% | -0.4162% | -0.4451% |
| | 2000 | -0.2603% | -0.2665% | -0.2862% | -0.3483% | -0.3860% | -0.4149% |
| | 3000 | -0.2371% | -0.2433% | -0.2630% | -0.3251% | -0.3628% | -0.3917% |

Table 14: Percentage price changes from trade reversals of different sizes (sample period from February 4 to December 30, 2002.

$$\left\{ \begin{array}{lcl} a_t(X_t = 1, \Upsilon_t = -1) & = & \mu_{t-1} + \theta - \eta + \phi \\ b_t(X_t = -1, \Upsilon_t = -1) & = & \mu_{t-1} - \theta - \eta - \phi \end{array} \right\} \Rightarrow \text{Spread} = 2(\theta + \phi)$$

An investor who is willing to buy a stock from a "market maker" at the ask price, is expected to execute his trade at $midquote+\theta+\phi$, based on the MRR model. In the case of buying pressures, however, the seller of the stock must adjust his ask price upwards by $\eta$, because of the positive correlation between the general index and the stock. If he does not do so, he loses the opportunity of a higher price sale. On the other hand, if there are selling pressures in the market, he must lower his bid price by $\eta$, as he expects to buy it later at a still lower price due to the general price decline. Based on these relations, the mean value of the implied spread is now defined as $2(\theta + \eta + \phi)$. The other three cases lead to the respective implied spreads shown above.

## 6.1 Empirical Results of model Portfolio Trading

Equation 7 can be estimated by using GMM, with two more instrumental variables: (a)first, the trade indicator of the General ASE Index, and (b) its lag. Our method uses the four stock subgroups and all trades within a 15-minute time interval, in order to align trading time for all stocks.[22] The trade indicator variables $X_t$ and $\Upsilon_t$ were set equal to either +1 or -1, if the transaction price was higher or lower than the previous one, and to zero if the price of the security did not change during the 15-minutes time interval.

Results and corresponding p-values of the Wald test are displayed in Table 15. Recall that for the portfolio trading model (7), price changes were calculated based on a 15-minute interval, while for the MRR model (1), they were calculated for each trade separately. Therefore, estimated parameters are quite different in absolute sizes and cannot be directly compared. Nevertheless, estimated parameters from the portfolio model indicate the following:

1. For all stock subgroups, the probability of a trade reversal is larger than 50%. Hence, investors' practice of breaking up large trades to smaller ones does not seem to last for more than 15 minutes. Alternatively, they prefer not to execute such broken up trades in sequential time intervals. Huang and Stoll (1997) and Kim et al. (2002) similarly report trade reversal probabilities from 58% to 97%, after bunching related data.

2. The significance of the adverse selection parameter ($\theta$) over the cost component one ($\phi$) has increased dramatically. The percentage of implied spread explained from it ($\gamma = \theta/(\theta + \phi)$) is larger than 86% compared to the 50% value, based on estimations of the standard MRR model.[23]

3. The information asymmetry parameter ($\eta$) that describes the general market conditions, is positive and differs between the two high capitalization stock subgroups 1 and 2. It is also statistically significant at all usual confidence levels. Based on the previous discussion, a

[22]We did not use 5 or 10-minute trading intervals due to the thin trading.

[23]For more information, see Table 5

| | FTASE-20 | | Chi-square | FTASE-40 | | Chi-square |
|---|---|---|---|---|---|---|
| Components | Group 1 | Group 2 | p-value | Group 3 | Group 4 | p-value |
| $\rho$ | -0.0893 | -0.1540 | 0 | -0.0659 | -0.1332 | 0 |
| SE | 0.0061 | 0.0058 | | 0.0046 | 0.0129 | |
| $\theta$ | 0.0549 | 0.0310 | 0 | 0.0936 | 0.0306 | 0 |
| SE | 0.0009 | 0.0004 | | 0.0037 | 0.0003 | |
| $\eta$ | 0.0032 | 0.0042 | 0.0086 | 0.0011 | 0.0001 | 0.59 |
| SE | 0.0004 | 0.0002 | | 0.0018 | 0.0001 | |
| $\phi$ | 0.0018 | 0.0008 | 0.0020 | 0.0088 | 0.0046 | 0.14 |
| SE | 0.0003 | 0.0001 | | 0.0028 | 0.0001 | |

Table 15: Estimation results for the portfolio trading model (sample period from February 4 to December 30, 2002.

liquidity supplier must increase (decrease) the ask (bid) price by €0.0032 and €0.0042 for group 1 and 2respectively, if there are buying (selling) pressures in the ASE. On the other hand, for the two subgroups of middle capitalization stocks, ($\eta$) is statistically insignificant and equal between them, and hence no adjustment is necessary: general market conditions seem to have no effect on the spread mechanism.

# 7 Conclusions

This research investigates the bid-ask spread behaviour of the Athens order-driven stock market. For the 11-month period from February to December 2002, we analyze high frequency transaction level data for four independent stock groups, sorted by their average transaction prices and their capitalization. Although information asymmetry is expected to decrease over the day due to "learning by trading", we report a U-shape pattern for all stocks. Furthermore, the cost component exhibits the same U-shape pattern only for high-priced stocks, while, for low-priced ones, it is monotonically increasing during the day. We think this is due to the order handling part of this component, which is more significant in high-priced stocks. This difference is further analyzed in a volume dependent structural model, a natural extension of the MRR specification. Based on it, we have strong indications that the adverse selection increases with trade size while the cost component decreases, a result similar to those of Ahn et al. (2002). For robustness purposes, we also estimate the Glosten and Harris (1988) model, reaching once again similar conclusions.

We also test robustness of such results for another time period from June to August 1999 and provide evidence that the cost component accounted then for more than 98% of the implied spread. At the time, most investors participating in the market had no information of any kind of stocks and trading was generated mostly from a herd behaviour. It is natural that, given such an environment, the importance of adverse selection risk was downgraded by market participants. The differences between the two periods are clearly due to the above mass participation of uninformed traders but also to a rather significantly different fundamental background of listed companies.

Furthermore, we form two different price impact functions in order to investigate the behaviour of each stock subgroup to large orders. We find that, in such an order-driven market, there seem to exist economies of scale in trading, with the inventory component being less important than the order processing cost. High-priced, high-capitalization stocks are the most liquid for both price impact measures. Generally speaking, there are indications that the price changes of high-capitalization stocks are less sensitive to trade sizes and transaction sequence.

Last but not least, we build a portfolio model that tries to explain spread adjustments due to changes in general market conditions. The effect of trading pressures in other stocks is statistically significant only for high-capitalization stocks. This could be explained by the observation that such stocks are more closely related to changes in the ASE General Index. On the other hand, the spread adjustment in low-capitalization stocks is explained mainly from the asymmetric information inherent in the specific share.

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