

Market Transparency and Traders' Behavior: An Analysis on Euronext with Full Order Book Data

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Abstract

More and more order-driven markets now allow traders to submit hidden orders. This widespread practice results in the presence of quantities which are available in the limit order book but not disclosed to market participants. The main contribution of this paper is to show how this unobservable information affects traders' behavior. Extending previous empirical analyzes on order aggressiveness, we evidence that traders account not only for information displayed on the market screens but also for information they can infer from limit order book movements. The other contribution of this paper is to report large reductions in implicit transaction costs due to hidden depth available in the order book. Results are provided for 82 Euronext blue chips over a three-month period.

JEL Classifications : G14, G10

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1 Introduction

The current proliferation of limit order book systems leads to a growing interest on liquidity dynamics in such a market design. Since traders can choose to supply or consume liquidity, understanding how they behave in an order-driven environment is increasingly relevant. Empirical research has evidenced that traders' behavior is significantly affected by market conditions: traders tend to provide liquidity when the bid-ask spread is large and the order book is thin. Indeed, to determine their order placement strategy at a given time, traders rely on information available on the market screens.

Nowadays, most order-driven trading systems as well as hybrid markets diffuse their limit order book in real time, or at least, the 5 best limits. So, market participants are now used to observe a large set of information such as price and disclosed depth available at the different bid-ask quotes. Moreover, they often have access to price and size of last trades. However, orders and trades often remain anonymous.

While most trading systems have moved towards greater transparency, there is today a patent trend to give market participants the opportunity to limit their exposure. Indeed, the use of undisclosed quantities has become a widespread practice over the world, whatever the market design. Even if hidden order processing differs slightly from a trading system to another, liquidity providers can reduce their exposure when trading on Euronext, the Toronto Stock Exchange, the Australian Stock Exchange, the Frankfurt Stock Exchange or Inet ATS.¹ Similarly, Nasdaq market makers as well as MTS² market makers have the ability to post additional depth in their quotes that is not visible to the market place.

Numerous papers [Biais, Hillion & Spatt (1995), Griffiths, Smith, Turnbull & White (2000), Ranaldo (2004), Beber & Caglio (2003), Pascual & Veredas (2003)...] assume and demonstrate that traders base their order placement upon information observable in the limit order book. However, as information is a key element when making a trading decision, a reasonable hypothesis is that, even if market participants cannot infer the magnitude of hidden depth in the order book, they are able to detect whether hidden orders are present at the best quotes or not. Indeed, it is well-known that traders monitor the limit order book and that they can infer from changes in observable information whether undisclosed depth is likely to be present or not at the best bid or ask. Actually, when hidden depth at the best quote is hit, a new quantity is automatically disclosed to the market place. So, traders are expected to guess the presence of undisclosed orders by monitoring limit order book movements.

In this paper, we check whether traders account for the presence of hidden quantities at the best limit of the order book when submitting their orders on Euronext. Thanks to

¹The broker dealer name "The Island ECN" is now "Inet ATS".

²MTS is the leading market in Europe for the electronic trading of fixed income securities.

very detailed order book data, we are able to know whether hidden depth is available at the best bid or ask at any time during the continuous session. Assuming that market participants can detect this undisclosed depth, we analyze how this new piece of information can affect traders' behavior. In the same time, we also show how implicit transaction costs can be overestimated when ignoring the presence of hidden orders in the order book.

This empirical paper and its main results contribute to the existing literature in several ways. First of all, we report accurate findings about undisclosed liquidity for a large sample of stocks. To date, hidden depth has been rarely investigated, often for lack of complete order book data. We show how the presence of hidden orders can substantially reduce implicit transaction costs on Euronext. Next, we propose a new order aggressiveness classification which depends on how the order arrival affects the prevailing spread or depth available at the best limit of the order book. Using an ordered probit model, we highlight how the presence of hidden depth at the best quotes can significantly influence traders' behavior on Euronext. Such findings are of great interest to market authorities, microstructure researchers and, of course, to traders who deal with best execution.

The paper is organized as follows. In Section 2, empirical and institutional background is presented. Section 3 describes the data and the stock sample. Methodologies and empirical findings are reported in Section 4. The first subsection is devoted to implicit transaction costs. Order aggressiveness is analyzed in the second subsection while the impact of hidden order presence on traders' behavior is reported in the third subsection. Section 5 concludes the paper.

2 Background

2.1 Empirical Background

With the increasing availability of detailed information such as time-stamped data about trades and orders, market microstructure researchers are now allowed to empirically investigate at a level of detail never before possible. However, research is always seeking for new possible extensions and more and more sophisticated data are often required to improve our knowledge about market dynamics and traders' behavior.

Although market data were often limited to transaction prices and best quotes during the eighties (see Harris (1986), Admati & Pfleiderer (1988) and Stoll (1989)), intraday data about orders became necessary in the nineties for analyzing order placement strategies (e.g. Harris (1996) and McInish & Wood (1995)), price discovery (Biais, Hillion & Spatt (1999)), and other issues focusing on order flow. Recently, the needs for more complete and detailed databases arose again in order to better understand traders' behavior (Kavajecz (1999)) or liquidity dynamics (Chordia, Roll &

Subrahmanyam (2002) and Domowitz & Xiaoxin (2002)). Facing these requirements, some researchers try to combine very detailed data about orders and trades to obtain the state of the order book. As mentioned by Kavajecz & Odders-White (2004), the principle behind the order book estimation is that, at any time, the order book should reflect orders remaining after netting all prior execution and cancellation records. These methodologies often result in an approximation of the actual order book because of the incompleteness of the databases or the complexity of programming the numerous rules organizing the market trading session. In this paper, we use very detailed information about trades and orders recorded on Euronext and we account for the different market rules in our algorithm. The output is a complete limit order book available at any time and including all the features defining order price and time priorities.

Defined by Black (1971), market liquidity has been widely analyzed in the literature. Since two liquidity dimensions - tightness and depth - are closely related to implicit costs incurred by traders, we mainly focus on these dimensions. Tightness implies that the bid-ask spread is narrow while depth refers to quantities available in the limit order book. While most databases now allow for analyzing spreads in a suitable way, assessing depth involves several difficulties. For example, on the NYSE, the order data used by Kavajecz (1999) allow for the construction of an estimate of the limit order book but this estimate is incomplete since orders brought to the floor via a floor broker are not included. Another example is the investigation of Degryse, de Jong, van Ravenswaaij & Wuyts (2005) about market resiliency. Since hidden depth was not available in their database, these authors had to comment their results carefully. In this paper, we assess implicit transaction costs with the Cost of Round Trip Trade. This ex-ante measure of immediate liquidity for a given trade size was proposed by Irvine, Benston & Kandel (2000) and makes it possible to account for both the spread and the volume (displayed and hidden) available at the different limit prices in the order book.

In the literature, several empirical studies dealing with order aggressiveness used databases that were already quite detailed. Indeed, the famous classification scheme proposed by Biais et al. (1995) relates order price and size to the prevailing bid and ask quotes. This methodology was later applied by Bisière & Kamionka (2000) on the Paris bourse and by Griffiths et al. (2000) on the Toronto Stock Exchange. All these studies focus on traders' behavior and more specifically on their order placement strategies. These strategies rely on information available to traders when placing their orders. On a market where hidden orders are allowed, it is quite natural to base the order aggressiveness analysis on displayed depth associated with the best limit. However, two elements are worth noticing.

First, aggressiveness is closely linked to liquidity in an order-driven market since aggressive orders take liquidity from the market while passive orders provide liquidity.

In the paper, a slightly different aggressiveness classification from the one designed by Biais et al. (1995) will be proposed in order to better link the two concepts. It focuses more on how the order arrival affects market liquidity (prevailing spread or depth) than on how the order is executed (totally or partially filled) at its arrival on the market.

Second, the questions of what a trader can know from the observation of sequential order book states and which set of information she uses before submitting an order are very relevant. It is well-known among practitioners that, even if traders do not observe hidden depth, they can infer the presence of hidden orders at the best quotes from changes in the displayed limit order book. These questions will be addressed in this paper using ordered probit models.

2.2 Institutional Background

Euronext is now one of the most important markets in Europe³ and relies on a homogeneous order-driven structure.⁴ Its platform is very transparent since market participants have access to the whole order book (pre-trade transparency) and can immediately observe the last trades recorded by the system (post-trade transparency). However, two features reduce market transparency. First, orders and trades are anonymous since April 2001, so that pre-trade transparency and post-trade transparency are affected. Second, the so-called hidden or iceberg orders make it possible to disclose only a part of the order size to the market place.

The Euronext continuous trading system enforces a price-time order precedence rule to arrange trades. Though the market opens at 9:00 a.m. with a call auction, traders can place, modify or cancel orders from 7:15 a.m. without any trade taking place before 9:00 a.m. The market closes at 17:30 p.m. with a second call auction following a short pre-closing period of 5 minutes. Both opening and closing prices are set by crossing the supply and demand curves and selecting the price that maximizes the trading volume.

During the continuous session, orders are partially or totally executed if they hit a quote on the opposite side of the order book. If no suitable counterpart exists, orders are registered in the book according to their price and time priorities. Traders can submit *limit orders* at any price on a pricing grid defined by a tick size. They can also submit *market-to-limit orders* which are executed at the best opposite quote. If the liquidity available at this best quote is insufficient to totally fill the order, the excess is converted into a limit order at that price. *Market orders* are orders that will be

³Euronext was created in September 2000 by the merger of the exchanges in Amsterdam, Brussels and Paris. It becomes the first fully integrated, cross-border, European market for equities, bonds, derivatives and commodities. At present, Euronext includes the former exchanges of Amsterdam, Brussels, Lisbon, Porto, Paris and also the LIFFE.

⁴Over the sample period (last three months of 2002), some small disparities among the market systems in operation in Amsterdam, Brussels and Paris still existed but have since disappeared.

immediately executed in full at any price. The order book is instantaneously updated on traders' screens when an order is placed, modified or canceled.

At any time during the pre-opening/closing period, an indicative market-clearing price that would result from the order book is displayed on the market place, together with the indicative trading volume at that price, and the other disclosed bid and ask quotes at that price.

Euronext trading system offers traders to submit limit orders that are not fully disclosed to other market participants. These orders are called hidden orders or iceberg orders.⁵ The disclosed quantity is the number of shares the trader wishes to be displayed on the market screens. When a hidden order is filled for its disclosed quantity, this quantity is automatically renewed and the order is positioned behind other orders at the same limit price. **This disclosure of hidden quantities makes the limit order book different from what one could expect after a given trade. So, traders monitoring the limit order book are expected to infer the presence of hidden depth.**

Undisclosed quantities are not exposed to the market place but are available to market authorities. It is worth noticing that, before December 2003, only Euronext members had access to the whole limit order book, except hidden quantities and members' identification codes (ID codes) while other traders could observe the aggregate 5 best limits of the order book. Today, the access to all quotes making the order book has been extended to the market place.

Dual-trading is allowed on Euronext. Hence, market members are *brokers-dealers*. They can submit orders either for their own account (own account orders) or for the account of their customers (client orders). Besides, for small and mid caps, market members may act as *liquidity providers*.⁶ As market specialists for their stocks, liquidity providers have a commercial agreement with Euronext whereby they undertake to quote two-way bid and ask prices in the limit order book, with a minimum volume and within a maximum spread. According to Euronext, the role of liquidity providers is to protect against variations in volatility, to guarantee trades at all times and to boost trading volumes.

3 Data and Sample

3.1 Data description

Each month, Euronext publishes very detailed data about orders, trades and best quotes of the order book. These intraday data allow for a large variety of empirical work. For our investigations, we used public data about orders and trades for a sample

⁵See D'Hondt, De Winne & Francois-Heude (2004) for a detailed presentation of these orders.

⁶Liquidity provider agreements do not exist for the stocks included in the Euronext 100 index.

of 82 common stocks belonging to AEX, Bel20 or CAC40 indexes⁷ over the three-month period from October 1 to December 31, 2002. The public trade data include the identification code of the stock, the date and time of the trade (with a precision to the second), the trade price and the number of shares traded. The public order data contain the following information: the identification code of the stock, the date and time of order submission, the order direction (buy/sell), both total order size and disclosed quantity ("peak") for iceberg orders, the order type (limit order, market-to-limit order, market order), the limit price (if any), the date of order validity and the state of the order at a particular date (totally executed, modified, cancelled, ...). Two codes referenced both by day and by market member are also mentioned in this public order data set. They allow for linking records describing different states of a single order that has been modified.

In addition to publicly available information, Euronext provided us with other private information that are necessary for rebuilding the limit order book.⁸ Hence, we received market members' ID codes⁹ for both orders and trades. For orders, we got information about the time when an order disappears from the system (cancellation or total execution for example) and the date of the order modification if any. As for trades, we obtained the date when both buy and sell orders triggering a given trade have been introduced (or last modified) and the sequence number of both orders included in the order file. This additional information allows us to identify which orders initiated a particular trade.

Another important piece of information we got for each order referred in the database is under which status the market member submitted the order. As explained before, a market member on Euronext can act as a broker when he submits orders on his customers' behalf (client orders), as a dealer when he submits orders for his own account (own account orders) or as a liquidity provider when he submits orders within the context of his commercial agreement with Euronext (LP orders). In the paper, we will consider that client orders, own account orders and LP orders are three different *order status*.

Thanks to both public and private data, we have developed a program allowing us to rebuild the limit order book second by second. Within this program,¹⁰ the state of

⁷These indexes contain the blue chips of the former stock exchanges of Amsterdam, Brussels and Paris that merged in order to create Euronext. During November 2002, GIB was replaced by Mobistar in the Belgian Bel20 index. We decided to exclude both stocks from our sample. The exit of the CMG stock from the AEX index led to its exclusion from our sample as well.

⁸Given the organization of the different databases, rebuilding the order book is impossible with public data only. Several operations, such as order modifications, actually have to be related to the original order within the set of orders submitted by the same member.

⁹Actually, these ID codes are not sufficient to know the market members' identities but allow us to isolate the whole set of orders or trades associated with a given member from the other orders and trades in the sample.

¹⁰A note describing the methodology applied to build the limit order book from Euronext order and trade files is available on request.

the order book is updated whenever a new order is submitted, a standing limit order is modified or cancelled. The output is accurate order book data including aggregate displayed and hidden quantities associated with each limit price. This new information set is very valuable because we can know, at any moment, what Euronext members observe in real time on their computer screens but also hidden quantities available at every quote on both bid and ask sides. Furthermore, ID codes allow us to know how many market members supply depth at a particular price as well as under which status they do this.

3.2 Sample presentation

The market value of our stock sample is about 1000 billion euros and the daily average traded volume is above 4.6 billion euros for our three-month period. Tables 2 and 3 give more information about activity and market capitalization. For the 82 stocks, we have 19 670 023 states of the limit order book during the continuous session.¹¹ Different usual liquidity measures for each stock are reported in Tables 4 and 5. For the purpose of comparison across stocks, time-weighted depth measures are expressed in EUR by multiplying the number of shares by the mid-quote. We can observe that Belgian stocks have spreads that are twice as large as AEX or CAC stocks. Depth measures are also much worse for Belgian stocks which are undoubtedly the least liquid in our sample. During our three-month period, three out of them are even subject to liquidity provider agreements (UMICORE, ALMANIJ, BEKAERT). The fourth stock (BUHRMANN) in our sample for which liquidity providers are present is a Dutch one.

On average, displayed depth at the best quotes only accounts for half of the total depth available at these prices while about 40% of depth at the five best quotes is hidden. This confirms the relevance of our investigations since ignoring hidden depth may lead to strong empirical biases. Depth at the best quotes represents slightly less than 20% of the aggregate volumes available at the five best quotes.

Looking at individual depth measures, we can observe that a greater proportion of depth is displayed on the Dutch segment. Since the microstructure is similar across the three indexes, this difference is difficult to explain. The French and Dutch subsamples are very similar in terms of market capitalization and activity. So, the only explanation that we propose is that Dutch traders have less experience in the Euronext trading system¹² than French and Belgian traders. This could affect their inclination to use hidden orders. Based on the assumption that market members whose activity is mainly devoted to Dutch stocks are Dutch members, we examined their order placement in order to corroborate this explanation. We observed that several of those Dutch

¹¹Due to their specific trading process, pre-auction periods have been dropped from our analysis.

¹²The Euronext market model has been used in Amsterdam for about 1 year (October 29, 2001) while this model has been used for a much longer time in Brussels and Paris.

members did not use any hidden order. Among these market members, several ones still belong to the 10 most active members for the Dutch segment.

Contrary to Irvine et al. (2000), who assess that the proportion of displayed depth is high on the Toronto Stock Exchange, our results show that quite a substantial proportion of the available liquidity on Euronext is hidden. So, these undisclosed quantities are likely to significantly affect the level of any liquidity measure based on depth, such as Kyle's (1985) lambda or Irvine et al.'s (2000) Cost of Round Trip Trade (CRT).¹³

4 Empirical Work

4.1 Implicit Transaction Costs

As mentioned by Irvine et al. (2000), an *ex ante* liquidity measure is useful to indicate the upper bound of transaction cost at which an order can be immediately executed. However, on a market where hidden orders are allowed, undisclosed quantities are likely to significantly lower this cost compared with what one may expect from the displayed quantities in the limit order book. This should be especially true for large trades.

4.1.1 Methodology

At a given point in time, the Cost of Round Trip Trade for a trade size T corresponds to the difference between the cost of buying T shares of a stock and the amount received from selling these T shares. Due to the spread, this difference is always positive in continuous trading. For the purpose of comparison across stocks or trade sizes, this difference is divided by the value of these T shares at the mid-point. So, given the limit order book described in Table 1, the Cost of Round Trip Trade for a trade size of 750 shares of stock i at time t will be computed as follows, according to either the displayed depth ($CRT_{i,t}^d(750)$) or the real depth ($CRT_{i,t}^r(750)$):

$$\begin{aligned} CRT_{i,t}^d(750) &= \frac{(300 * 52 + 450 * 52.20) - (400 * 50 + 100 * 49,60 + 250 * 49,50)}{750 * 51} \\ &= 4,59\% \\ CRT_{i,t}^r(750) &= \frac{(500 * 52 + 250 * 52.20) - (700 * 50 + 50 * 49,60)}{750 * 51} \\ &= 4,10\% \end{aligned}$$

We compute both measures every time an order is placed for each stock in our sample. Since required market depth is more important for large trades, computing

¹³Because Kyle's (1985) lambda focuses exclusively on the best quotes, we prefer to illustrate the relevance of our approach using the CRT, which potentially exploits different limits in the order book.

these costs for large trade sizes should lead to even more striking differences. To show evidence of this phenomenon, we decided to compute the CRT for 3 different trade sizes. The first one is equal to the median order size computed over the three-month period for the given stock. Both other trade sizes correspond respectively to the upper quartile and the upper percentile computed across order sizes for the given stock. To give an idea about the numbers of shares in question, these different trade sizes are presented for each stock in Tables 6 and 7.

4.1.2 Results

Implicit transaction cost indicators for each stock in our sample are provided in Tables 8 and 9.¹⁴ For Dutch stocks, hidden depth contributes on average to a CRT reduction of about respectively 3%, 6% and 18% when the trade size is equal to the median, upper quartile or upper percentile order size. As for Belgian stocks, the presence of hidden orders leads on average to a decrease in implicit transaction costs of about respectively 4%, 7% and 29% while the average reduction ranges from 5% to 32% for French stocks. As expected, we can conclude that accounting for hidden depth leads to a substantial decrease in the CRT, especially for large trades. So, all these figures show how much liquidity assessment can be improved when we take hidden quantities into account. By ignoring them, we tend to substantially underestimate the available liquidity on Euronext. This kind of bias can be quite annoying when making comparisons across competitive market venues or trading systems.

Concerning differences across stocks, we can see in Tables 8 and 9 that the CRT for a given trade size is quite similar for stocks belonging to AEX and CAC indexes but almost twice higher for Belgian stocks. This finding is totally consistent with other usual liquidity measures described earlier. Moreover, the impact of hidden quantities on implicit transaction costs appears the lowest for Dutch stocks. This result is due to the highest proportion of displayed depth for these stocks.

4.2 Order Aggressiveness

4.2.1 Methodology

While order aggressiveness has been usually studied as a feature of traders' behavior, it can also be viewed as a measure of the extent to which orders take liquidity from the market or supply liquidity to the market. The order aggressiveness classification we propose differs from the Biais et al.'s (1995) one for the most aggressive orders. Our proposal includes five categories that will be exposed with regards to the "liquidity effect", i.e. how the order arrival affects the prevailing liquidity. The first two categories

¹⁴In some cases, the total depth available in the limit order book was not sufficient to cover the given trade size. So, we report in Tables 8 and 9 the number of order book states for which the CRT was successfully computed. This number logically decreases with the trade size.

contain orders taking liquidity and are the most aggressive ones. They affect either the best opposite quote (category 1) or the depth associated with that best quote (category 2). Categories 3 and 4 contain less aggressive orders which improve liquidity in terms of best quote on the same side (category 3) or in terms of depth available at that best quote (category 4). All other orders fall into the fifth category and increase the overall depth in the order book without affecting the best limit in terms of either price or quantities. So, the aggressiveness classification of orders resulting in immediate execution (categories 1 and 2) is based on the opposite quote as well as on the depth available at that quote. For other orders, the aggressiveness classification will rely on the best quote on the same side as the incoming order and its associated depth. Let us notice that order cancellations and modifications are not classified. So, only new order submissions lead to a classification. A numerical example illustrating this new aggressiveness classification is provided in appendix.

Thanks to our full order book data, we are able to know, for each order in our sample, the state of the prevailing order book. Therefore, we can easily apply our methodology and compare both price and size of any order to the relevant quote and depth. As traders do not see the amount of hidden depth, we chose to classify orders according to the displayed depth rather than the real depth.

To identify potential disparities in aggressiveness, we conducted our classifications by taking into account both the order status (client/own account/LP) and the order direction (buy/sell). Indeed, we can expect that market members submit orders differently according as whether they act as brokers, dealers or liquidity providers. Intuitively, market members are expected to pay more attention to their own orders than to their customers' orders. This could be illustrated by a greater impact of the order book state on own account orders than on client orders. Another explanation could be that some customers place their orders through a market member without asking for any advice. Again, this phenomenon could lead to a smaller influence of the prevailing order book on client order aggressiveness. The development of online trading and direct market access should lead more customers to submit their orders by themselves. In this case, they should have less experience in monitoring the market than practitioners have. Besides, when acting as liquidity providers, market members are expected to be less aggressive and less sensitive to market conditions. Indeed, it is worth recalling that liquidity providers have specific commitments when quoting two-way bid and ask prices in the order book.

For the purpose of statistical comparisons across order status, we first conducted our order aggressiveness classification trading day by trading day.¹⁵ Then, paired t-tests were performed to compare client orders or LP orders with own account orders to check the above assumptions.

¹⁵A stock by stock analysis was not relevant because only 4 stocks in our sample are subject to liquidity provider agreements.

4.2.2 Results

Table 10 reports the average unconditional frequencies of orders according to their aggressiveness level as well as the results of statistical comparisons across order status. If we analyze findings for each order status, we can observe that the most frequent events are always orders of the fifth category, whatever the order direction. Next, we can see that the proportion of liquidity taking orders is respectively about 34%, 38% and 30% for client, own account and LP orders. Not surprisingly, LP orders are on average less liquidity consuming than client or own account orders. However, about 24% of them are ranked in the first category and can be defined as very aggressive orders. Actually, when Euronext members have a liquidity provider agreement for a given stock, they pay lower explicit transaction costs for non client orders. This can explain some shift from own account to LP orders.

Concerning differences between client and own account orders, we find that all are significant at the 1% level. Although the fraction of liquidity taking orders is only slightly higher for own account orders, the distribution of orders across the first two categories (aggressive orders) as well as across the last three categories (passive orders) differs much more. For example, 36% of client orders falls into the fifth category compared with 24% for own account orders.

As for comparisons between own account and LP orders, most differences appear significant. The two most striking ones concern categories 2 and 5. Indeed, LP orders exhibit few orders in the second category (4%) but much more in the last category (40%) in comparison with own account orders (16% and 24%).

Finally, Table 10 also reports some differences between client and LP orders. The most significant ones are related to liquidity taking orders. On average, 12% (24%) and 21% (6%) of client (LP) orders fall respectively into categories 1 and 2.

4.3 Presence of hidden orders and traders' behavior

As Griffiths et al. (2000), Ranaldo (2004) and Pascual & Veredas (2003) do on other pure order-driven markets (Toronto Stock Exchange, Swiss Stock Exchange, Spanish Stock Exchange), it seems quite natural to assume that traders base their order placement upon information observable in the limit order book. However, it is well-known that monitoring the limit order book can help practitioners to detect the presence of hidden orders. So, we can wonder whether order submission can be affected by hidden depth. This issue seems even more relevant when we observe that the presence of hidden orders at the best quote often implies a quite important hidden depth. When present, average hidden depth is 4 or 5 times bigger than average displayed depth.

From Table 11 we can observe that the presence of hidden depth at the best quote is approximately equally frequent on both sides of the limit order book. In continuous

trading, hidden depth on each side is present for about 26% of time. Because traders infer the presence of hidden depth from limit order book changes, we computed the duration of these situations in *number of limit order book states*. So, Table 11 tells us that, when there is hidden depth at the best bid/ask, this situation exists for a sequence of 8.2/8.3 order book states on average. When there is no hidden depth, the duration rises to 25.5/25.4 states of the order book. Then, durations are sufficiently high to allow traders who detected hidden depth to adapt their order placement. In this context, analyzing whether the presence of hidden orders affects traders' behavior becomes a relevant issue.

4.3.1 Methodology

In order to address this issue, an ordered probit model will be used to analyze how the prevailing order book state (including the presence of hidden orders) can influence traders' behavior or, more specifically, their order aggressiveness.

So, we assume that traders' aggressiveness is a function of several elements such as spread, depth measures and the presence of hidden orders. More precisely, traders' aggressiveness (A_t) at time t is assumed to be explained as follows :

$$A_t = \beta_1 * Spread_t + \beta_2 * Depth_{1,t}^S + \beta_3 * Depth_{1,t}^O + \beta_4 * Depth_{+,t}^S + \beta_5 * Depth_{+,t}^O + \beta_6 * Hidden_t^S + \beta_7 * Hidden_t^O + \epsilon_t = X_t + \epsilon_t, \epsilon_t \sim N(0, \sigma_t^2) \quad (1)$$

Most of these explanatory variables are easily observed in the limit order book prevailing at time t . $Spread_t$ denotes the prevailing absolute bid-ask spread when the order is submitted at time t . $Depth_{1/+}^{S/O}$ is the number of shares at the first limit (1) or at the four next ones (+) on the same side (S) as the incoming order or on the opposite side (O). $Hidden^{S/O}$ are dummy variables indicating the presence of hidden orders at the best quote on the same side (S) or on the opposite side (O). These dummies are not observable but the presence of hidden orders at the best quote is expected to be inferred from the sequence of limit order book movements. ϵ_t represents the independent but not identically distributed residuals. In order to avoid correlations across depth measures, we replaced $Depth_{+}^{S/O}$ by the residuals of an OLS regression of $Depth_{+}^{S/O}$ on $Depth_1^{S/O}$.

As traders' aggressiveness is not directly observable, we can consider Equation [1] as a latent one. However, the order submitted by a trader at time t can inform us about the trader's aggressiveness. Applying the order classification described previously and based on disclosed order book information, we get an observable discrete variable Cat_t linked to the latent variable A_t . The relationship between the latent variable and the ordered response is expressed as follows :

$$Cat_t = \begin{cases} 1 & \text{if } A_t \leq \gamma_1 \\ m & \text{if } \gamma_{m-1} < A_t \leq \gamma_m, m = 2, 3 \text{ or } 4 \\ 5 & \text{if } A_t > \gamma_4 \end{cases} \quad (2)$$

Equations [1] and [2] form an ordered probit model whose parameters β_k and γ_j can be estimated. Actually, the γ_j 's are thresholds that determine what value of Cat_t a given value of A_t will map into.

Denoting the normal cumulative distribution function as $\Phi(\cdot)$, the probability that $Cat_t = 1$ is computed as follows :

$$\begin{aligned} Pr(Cat_t = 1) &= Pr(A_t \leq \gamma_1) = Pr(X_t + \epsilon_t \leq \gamma_1) = Pr(\epsilon_t \leq \gamma_1 - X_t) \\ &= \Phi(\gamma_1 - X_t) \end{aligned} \quad (3)$$

The probability that $Cat_t = m$ (where $m = 2, 3$ or 4) is computed as follows :

$$\begin{aligned} Pr(Cat_t = m) &= Pr(\gamma_{m-1} < A_t \leq \gamma_m) = Pr(\gamma_{m-1} < X_t + \epsilon_t \leq \gamma_m) \\ &= Pr(\gamma_{m-1} - X_t < \epsilon_t \leq \gamma_m - X_t) \\ &= \Phi(\gamma_m - X_t) - \Phi(\gamma_{m-1} - X_t) \end{aligned} \quad (4)$$

The probability that $Cat_t = 5$ is computed as follows :

$$\begin{aligned} Pr(Cat_t = 5) &= Pr(A_t > \gamma_4) = Pr(X_t + \epsilon_t > \gamma_4) = Pr(\epsilon_t > \gamma_4 - X_t) \\ &= \Phi(X_t - \gamma_4) \end{aligned} \quad (5)$$

Hence, parameters are estimated by maximizing the loglikelihood function for the ordered probit model consisting of Equations [1] and [2] :

$$\begin{aligned} LogL &= \sum_{Cat_t=1} \log(\Phi(\gamma_1 - X_t)) + \sum_{Cat_t=2} \log(\Phi(\gamma_2 - X_t) - \Phi(\gamma_1 - X_t)) \\ &+ \sum_{Cat_t=3} \log(\Phi(\gamma_3 - X_t) - \Phi(\gamma_2 - X_t)) + \sum_{Cat_t=4} \log(\Phi(\gamma_4 - X_t) - \Phi(\gamma_3 - X_t)) \\ &+ \sum_{Cat_t=5} \log(\Phi(X_t - \gamma_4)) \end{aligned} \quad (6)$$

In order to check the relevance of hidden depth in order placement, we also propose a slightly different probit model, where both dummies have been dropped. Replacing Equation [1] by Equation [7], we can compute the Likelihood Ratio in order to find

which model is the best one.

$$\begin{aligned}
A_t = & \beta_1 * Spread_t + \beta_2 * Depth_{1,t}^S + \beta_3 * Depth_{1,t}^O \\
& + \beta_4 * Depth_{+,t}^S + \beta_5 * Depth_{+,t}^O + \epsilon_t, \epsilon_t \sim N(0, \sigma_t^2)
\end{aligned}
\tag{7}$$

Since the information set used by buyers and sellers could be different, the model is estimated distinctively for buy and sell orders. Moreover, whether they act for a client, for their own account and within the context of a liquidity provider agreement, market members may be affected differently by market conditions. So, we repeated the analysis described above for the three different order status. Finally, traders' behavior could change throughout the day, i.e. traders may become more impatient by the end of the trading session. So, we checked whether our results are still robust for different periods of the day [Beber & Caglio (2003)]. Therefore, we also estimated the ordered probit model using orders submitted during three particular intervals: the first 30 minutes of the trading session, one hour around US markets opening, and the last 30 minutes of continuous trading.

4.3.2 Results

Table 12 reports a summary of the results for the whole sample. Tables 16 to 18 give the parameter estimates¹⁶ for the thresholds as well as for the explanatory variables. Economic intuition gives some expectations for these parameters. First, order aggressiveness (A_t) should be negatively correlated with spread since it is more difficult to have one's own order executed when the spread is narrow. Next, depth observable on the same side (i.e. bid for buy orders and ask for sell orders) should encourage traders to be more aggressive in their order placement. Indeed, if a trader submits a non marketable order, it has a lower time priority than other orders already into the system. So, he needs to improve his price condition to gain priority (competition effect). However, order aggressiveness should be negatively correlated with depth observable on the opposite side because traders are more confident about their order execution. Many quantities available at the opposite quotes are likely to match their own order (strategic effect). Finally, according to Pardo & Pascual (2004) who analyzed the market response when the presence of hidden orders is publicly revealed to the market place, hidden order execution makes traders more aggressive. So, we expect that both parameters relative to the dummy variables will be positive. Indeed, the presence of hidden depth at the best bid (ask) should encourage buyers (sellers) to submit orders at least as aggressive. A similar effect is less intuitive for the presence of hidden orders at the best opposite quote but D'Hondt et al. (2004) already evidenced this phenomenon.

¹⁶These estimates are presented for buy orders only but results are quite similar for sell orders. Results for sell orders are available on request.

They found that orders tend to be more aggressive when hidden depth is large on the opposite market side. The authors explain this finding by traders who discover that there are more shares available at the best opposite quote than they thought at first. For market participants, the presence of hidden depth involves a reduction in implicit transaction costs (a kind of depth improvement) and does not seem to be associated with informed trading.

Results summarized in Table 12 are consistent with previous literature and economic intuition. Except for Belgian stocks that are less liquid, parameter estimates often exhibit the expected sign at a 5% significance level. For example, our results confirm those of Griffiths et al. (2000) and Ranaldo (2004) evidencing that aggressive orders are more frequent when bid-ask spreads are narrow and when displayed depth at the best quote on the same (opposite) side of the limit order book is large (small). Our results about disclosed depth at the next quotes¹⁷ are also in line with the economic intuition and are consistent with the conclusions of Pascual & Veredas (2003).

The most innovative finding is the positive and significant estimate for the presence of hidden orders at the best opposite quote. When hidden orders are present at the best opposite quote, traders tend to be significantly more aggressive. Only one (less liquid) stock on the Dutch segment and several Belgian ones do not exhibit the expected sign with a significance level of 5%. As for the presence of hidden depth at the best quote on the same side, the results are less relevant. Indeed, only 27 (26) stocks exhibit the expected sign at the 5% level for buy (sell) orders.

When we check for the relevance of hidden depth in order placement, we obtain a Likelihood Ratio which is always significant at the 1% level¹⁸ for the non-Belgian stocks, indicating that the constrained model (Equation [7]) should be rejected. So, our results evidence that traders do account for the presence of hidden depth at the best quotes (at least at the best opposite quote) for their order placement strategy. An additional analysis of conditional frequencies on the presence or absence of hidden orders at the best quotes is provided in Table 13. Statistical comparisons confirm the previous results. The presence of hidden orders at the best opposite quote leads to a significant shift from non marketable to marketable orders. Focusing on the best quote on the same side, we find that the shift induced by the presence of hidden orders is limited to the fourth and fifth categories. Only traders who wish to join the order queue below the best quote are more likely to submit at the best quote to gain priority over hidden quantities.¹⁹

When splitting orders according to their status (client, own account or LP), findings for *Spread* and $Depth_1^{S/O}$ (see Table 14) are consistent with those obtained for the whole

¹⁷The computation of this depth uses the number of shares present from the second to the fifth quotes. However, let us remind that these depth measures have been replaced by OLS residuals.

¹⁸Except one AEX stock that exhibits a Likelihood Ratio significant at the 5% level.

¹⁹Traders do not need to submit within the spread (category 3) because hidden quantities have no time priority.

sample. However, for $Depth_+^{S/O}$, results are quite different. It seems that displayed depth from the second to the fifth limits are less taken into account by market members when they act for clients than when they act for their own account. This phenomenon could be explained by a larger size and/or a better market monitoring for own account orders. Similarly, client orders seem to be slightly less sensitive to the presence of hidden orders at the best opposite quote while own account orders prove to be not affected by hidden depth presence on the same market side. Results obtained for LP orders do not lead to any robust conclusion. These orders are submitted within a very specific context and should be analyzed using a larger sample of stocks with liquidity providers.

Focusing on some periods of the trading session, we find that spread, displayed depths associated with the best quotes and the presence of hidden orders at the best opposite quote still affect traders' behavior. Looking at Tables 15 and 12, we observe that displayed quantities available from the second to the fifth limits are less relevant during periods of high activity. This is particularly true during the first and the last 30 minutes of the trading session. This phenomenon could be due to several features. First, activity may prevent traders from monitoring the limit order book as they can do during less busy periods. Second, because of very frequent changes in the limit order book during these active periods, trader's response could occur when market conditions have already changed. Finally, as for the last 30 minutes of the trading session, some deadline effect could increase traders' impatience and order aggressiveness.

5 Conclusion

While most securities markets have moved towards greater transparency, there is today a patent trend to give market participants the opportunity to use hidden quantities. This paper investigates how the presence of hidden depth in the limit order book affects both implicit transaction costs and traders' behavior on Euronext.

As for implicit transaction costs, this paper reports how much the Cost of Round Trip Trade can be reduced when hidden quantities are taken into account. For example, hidden depth for French stocks involves a CRT decrease of about 32% for large order size, which is important in economic terms. So, ignoring hidden quantities in the order book substantially underestimates actual liquidity on Euronext and overestimates transaction costs incurred by traders. Since blue chips we analyzed are often listed on different market places and/or can be traded on different trading venues, the bias we evidenced can mislead traders when looking for the best execution.

About traders' behavior, this paper checked whether order submission can be affected by the presence of hidden quantities available at the best quotes. Since traders monitoring the limit order book can infer whether undisclosed depth is likely to be

present at the best quotes or not, we analyzed how this new piece of information affects order aggressiveness. Using ordered probit models, we highlighted that the presence of hidden orders at the best opposite quote significantly increases order aggressiveness. So, traders seize the opportunity to benefit from reduced implicit transaction costs due to some hidden depth at the best opposite quote (depth improvement). Consequently, traders do not seem to associate hidden orders with informed trading.

Consistent with previous papers, our results also show that order aggressiveness is negatively related to spread and displayed depth on the opposite market side while it is positively affected by displayed depth on the same side as the incoming order. When splitting orders according to their status (client, own account or LP), we obtain similar findings but client orders appear less sensitive to both displayed depth beyond the best quotes and the presence of hidden quantities at the best opposite quote. This phenomenon suggests either that market members pay more attention to their own orders or that customers have less experience in monitoring the market than practitioners have. Results about LP orders do not lead to any robust conclusion.

As a whole, this paper evidences that ignoring undisclosed quantities leads to strong biases. Then, in a market where hidden orders are allowed, complete order book data are needed to properly address issues such as market liquidity assessment or traders' behavior.

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A Appendix

Let us take a numerical example to illustrate the aggressiveness classification we proposed. We assume first that, at time t , the limit order book looks like Table 1 and we focus on displayed depth.

If we do not account for hidden quantity at the best ask price, a buy order immediately executed for a quantity equal to or greater than 300 will be ranked in the first category. Such a buy order will make the first limit disappear from the sell side and will increase the best ask. For example, although not fully executed, a buy order for a quantity of 3000 with a limit price of 52.20 will fall into this first category too.

An order to buy a quantity lower than that offered at the best ask belongs to the second category. Although not affecting the spread, such an order will result in full and immediate execution and will reduce the depth at the best ask. For example, if a trader places a *market* buy order for a quantity of 100, this order will be executed in full but will not affect the best quote. The displayed depth at the best ask will be lowered to 200.

The third category contains orders with a better limit price than competitive orders already present in the order book on the same side. This leads to a spread reduction since the best quote is improved. A buy order of any quantity with a price of 51 will belong to this category and will reduce the spread by 1 EUR.

In the fourth category, we find orders with a limit price equal to the current best quote. These orders improve the depth associated with that best limit. If a trader wishes to buy 200 shares and submits an order for that quantity with a price of 50, the displayed depth associated with the best bid will increase up to 600 but the spread will be unchanged.

Other orders fall into the fifth category. They provide the market with liquidity but to a lesser extent than those ranked in the previous categories. If a trader places a buy order for 500 at a price of 49.00, the overall depth is improved but neither the spread nor the depth at the best limit is affected.

So, categories 1 and 2 contain orders which result in immediate execution and make the opposite best quote or the depth available at that quote worse. Orders from the other categories are stored in the order book for later execution and provide the market with liquidity.

Let us notice that an order from the first category, while spoiling the opposite best quote, could result in a spread reduction. If a trader places a sell order for a quantity of 500 with a limit price of 49.80, the resulting best bid and ask will be respectively equal to 49.60 and 49.80 instead of 50 and 52.

B Tables

Order book at time t

<i>Buy Side (Bid)</i>			<i>Sell Side (Ask)</i>		
<i>Hidden Depth</i>	<i>Displayed Depth</i>	<i>Price</i>	<i>Price</i>	<i>Displayed Depth</i>	<i>Hidden Depth</i>
0	400	50.00	52.00	300	2500
1100	500	49.60	52.20	500	1250
0	250	49.50	52.30	300	0
1000	300	49.30	52.60	100	0
550	300	49.00	53.00	700	1600

Table 1: Both columns labelled *Price* contain the quotes available in the limit order book and the other columns present both hidden and displayed depths associated with each price.

Activity and market capitalization: AEX and BEL20

<i>Stock ID</i>	<i>Company</i>	<i>N</i>	<i>Size</i>	<i>Volume</i>	<i>Capitalization</i>
65996	HEINEKEN	1362	26853	36.57	15483
65997	UNILEVER	3453	55153	190.44	34409
65999	ROYAL DUTCH	5896	53429	315.01	86071
66000	KON PHILIPS ELECTR	5902	26560	156.76	19425
66002	DSM	1011	20401	20.62	4223
66005	AKZO NOBEL	1690	22068	37.3	9440
66013	TPG	1261	18223	22.98	8116
66014	KONINKLIJKE KPN	2702	26093	70.5	13028
66694	FORTIS	3042	22589	68.71	18524
66695	ABN AMRO DIVISION	4196	25767	108.12	17818
66696	AEGON	4932	23502	115.92	13918
66699	ING GROEP	6515	25905	168.77	28396
66704	AHOLD	3912	19213	75.16	11171
66708	ASML HOLDING	3878	14649	56.8	2999
66730	BUHRMANN	928	4101	3.8	690
66746	ELSEVIER	1418	19945	28.28	9064
66756	GUCCI	542	39366	21.32	8852
66757	HAGEMEYER	689	4980	3.43	876
66760	GETRONICS	1294	2796	3.62	254
66784	VAN DER MOOLEN	392	8784	3.44	662
66796	NUMICO	911	10657	9.71	1778
66838	V N U	1419	21123	29.97	5780
66850	WOLTERS KLUWER	1081	18063	19.53	5229
AEX		58424	22184	1566.76	316206
60119	SOLVAY	321	15804	5.08	5001
60128	TESSENDERLO	93	5374	0.5	708
60130	DELHAIZE GROUP	673	8207	5.53	1524
60132	KBC	507	14725	7.47	9510
60162	UMICORE	124	7874	0.98	797
60165	ELECTRABEL	450	26979	12.15	13048
60181	D'IETEREN	87	5040	0.44	747
60194	DEXIA	1397	12640	17.65	10505
60204	ALMANIJ	228	10721	2.44	6443
60236	UCB	446	12913	5.76	4340
60239	FORTIS	1597	15694	25.06	18576
60252	AGFA-GEVAERT	401	8452	3.39	2590
60263	IBA	87	1295	0.11	88
60270	COLRUYT	180	7385	1.33	1782
60273	BEKAERT	109	7654	0.83	844
60278	OMEGA PHARMA	403	8340	3.36	1097
60283	BARCO (NEW)	114	6293	0.72	457
60286	INTERBREW	690	17773	12.27	10427
60289	GBL	283	15801	4.47	5117
BEL20		8191	10998	109.54	93601

Table 2: *Stock ID* is the stock identification code. *N* is the daily average number of trades. *Size* is the average trade size expressed in euros and *Volume* is the daily average volume expressed in millions of euros. *Capitalization* is the market capitalization (expressed in millions) computed at the beginning of our sample period. For the AEX and BEL20 rows, *Size* is the simple arithmetic average of individual average trade sizes and the other variables show the sum of the individual results. Stocks with liquidity provider agreements are written in bold.

Activity and market capitalization: CAC40

<i>Stock ID</i>	<i>Company</i>	<i>N</i>	<i>Size</i>	<i>Volume</i>	<i>Capitalization</i>
223	AGF	1213	10615	12.87	4829
1526	TF1	1585	17142	27.17	4585
4150	AIR LIQUIDE	2450	20696	50.71	12652
4154	CARREFOUR	3935	25427	100.05	29158
4157	SANOFI SYNTHELABO	3052	37705	115.08	41808
4161	TOTAL FINA ELF	5930	71831	425.99	94969
4166	OREAL	3316	31300	103.77	49623
4170	ACCOR	1676	19399	32.51	5976
4178	BOUYGUES	1690	18752	31.68	8938
4180	SUEZ	4415	16747	73.93	16764
4181	LAFARGE	2738	24511	67.12	10845
4187	AXA	6069	24083	146.17	16748
4188	GROUPE DANONE	2369	36668	86.85	17350
4213	LVMH MOET VUITTON	3055	23293	71.17	18079
4230	SODEXHO ALLIANCE	1163	12950	15.07	3106
4234	MICHELIN	1238	14823	18.35	3852
4237	THALES	1356	12351	16.75	4535
4245	VIVENDI UNIVERSAL	6699	20003	134.01	12519
4250	PINAULT PRINTEMPS	1915	21245	40.68	7772
4252	PEUGEOT	1844	23898	44.06	9774
4292	SCHNEIDER ELECTRIC	1658	23612	39.15	10622
4322	SAINT-GOBAIN	3095	19757	61.16	7748
4340	CAP GEMINI	2664	16627	44.3	2026
4351	VINCI	1386	16472	22.82	5213
4353	CASINO GUICHARD	1052	16361	17.22	6190
4438	ALCATEL A	9247	9893	91.48	2924
4448	LAGARDERE	1400	14699	20.57	5420
4462	SOCIETE GENERALE A	3958	30355	120.14	18679
25743	AVENTIS	4120	40487	166.82	42492
26990	BNP PARIBAS	6270	35008	219.49	29720
29512	RENAULT	2071	23783	49.26	12295
29636	STMICROELECTRONICS	5625	26467	148.88	12155
36064	FRANCE TELECOM	8298	14903	123.67	8584
42349	CREDIT LYONNAIS	4542	19020	86.39	11529
44540	THOMSON MULTIMEDIA	2700	12780	34.51	4428
45057	DEXIA	1710	16686	28.53	10529
49388	EADS	1966	11087	21.79	8747
49471	VIVENDI ENVIRON.	1369	14984	20.51	8243
55149	ORANGE	3044	14481	44.08	22628
72275	CREDIT AGRICOLE	2346	11212	26.3	15157
CAC40		126228	21803	3001.06	619211

Table 3: *Stock ID* is the stock identification code. *N* is the daily average number of trades. *Size* is the average trade size expressed in euros and *Volume* is the daily average volume expressed in millions of euros. *Capitalization* is the market capitalization (expressed in millions) computed at the beginning of our sample period. For the CAC40 row, *Size* is the simple arithmetic average of individual average trade sizes and the other variables show the sum of the individual results.

Order book statistics: AEX and BEL20

<i>Stock</i>	<i>N</i>	<i>Relative Spread</i>	<i>Displayed Depth₁</i>	<i>Full Depth₁</i>	<i>Displayed Depth₅</i>	<i>Full Depth₅</i>
65996	192888	0.14	107129	204229	598098	949551
65997	354657	0.11	510353	666307	3604189	4200861
65999	630971	0.08	212811	321632	1304165	1725140
66000	527747	0.15	108754	221472	728328	1148541
66002	172963	0.16	85010	192738	496610	913842
66005	243371	0.17	79802	150308	466681	794806
66013	200778	0.24	69095	149266	385702	727707
66014	225470	0.23	282999	448409	2016263	2656876
66694	397536	0.18	100414	171072	617736	886669
66695	408193	0.17	127757	207901	824529	1133555
66696	418470	0.18	110349	195153	722337	1059328
66699	545291	0.14	113158	209840	741934	1117064
66704	380509	0.2	85614	153395	547004	843114
66708	373820	0.25	74865	158266	511373	808220
66730	105837	0.6	32306	54360	236036	311352
66746	291223	0.21	99184	169707	574216	835427
66756	84535	0.17	202469	388775	1220103	2005057
66757	107422	0.52	26614	48797	149883	219308
66760	91526	1.35	121151	153684	688082	768224
66784	85205	0.44	37232	55147	231767	308509
66796	149411	0.38	43248	81622	245913	378132
66838	211889	0.23	72965	182248	436809	876304
66850	177206	0.25	66475	157318	389159	773633
AEX		0.28	120424	206159	771170	1106140
60119	41113	0.31	67539	136741	435671	783787
60128	12546	0.93	19537	34875	123435	195527
60130	67050	0.45	33051	65165	204952	341945
60132	72198	0.33	43495	118238	280543	660147
60162	23499	0.64	52596	92678	234590	440958
60165	47970	0.16	120770	268595	839360	1630623
60181	14346	0.78	16236	33006	113056	201380
60194	213395	0.25	60294	96451	369089	537395
60204	72917	0.57	50773	80847	230947	359267
60236	59387	0.46	34245	83997	208104	450350
60239	284062	0.22	76115	107903	487973	643091
60252	45203	0.37	32131	76511	191887	442630
60263	7675	1.67	5682	9042	39268	50930
60270	21444	0.65	30814	75738	199938	431204
60273	20380	0.72	50720	75617	214107	317088
60278	33358	0.48	31886	77017	204125	375623
60283	13157	0.79	27380	58847	145197	276603
60286	83025	0.34	65336	140618	364335	696655
60289	44546	0.64	55495	123096	306734	636421
BEL20		0.57	46005	92367	273332	498507

Table 4: N is the number of order book states observed for a particular stock. *Relative Spread* is the time-weighted quoted spread divided by the mid-quote and $Depth_{1/5}$ is the time-weighted depth at the first limit (1) or at the five best limits (5). *Full Depth* aggregates displayed and hidden depths. Depth measures are obtained by multiplying the number of shares by the mid-quote in order to allow comparisons across stocks. Results for the AEX and BEL20 rows are simple arithmetic averages. Bold stocks are stocks with liquidity provider agreements.

Order book statistics: CAC40

<i>Stock</i>	<i>N</i>	<i>Relative Spread</i>	<i>Displayed Depth₁</i>	<i>Full Depth₁</i>	<i>Displayed Depth₅</i>	<i>Full Depth₅</i>
223	247132	0.34	41146	79889	207084	384665
1526	208830	0.24	55726	153671	287169	753148
4150	267043	0.21	106729	218638	572378	1074045
4154	397222	0.16	92016	204771	507441	957356
4157	291415	0.17	212634	386899	1222299	2029604
4161	487968	0.11	494388	739020	3591722	4959217
4166	304077	0.17	160467	316260	944776	1622328
4170	259226	0.21	56248	142682	321537	723769
4178	201458	0.22	52867	143170	306454	680859
4180	393186	0.21	68563	144281	377249	699281
4181	288795	0.19	116572	256684	651822	1266824
4187	495369	0.18	106254	236731	655698	1201712
4188	245432	0.16	220238	418569	1533608	2773609
4213	364639	0.19	71046	184664	405865	967059
4230	193941	0.33	35326	87829	183981	472046
4234	216467	0.26	57512	126177	260508	547518
4237	185809	0.26	38626	118429	215656	516632
4245	442225	0.2	87581	229372	567738	1148033
4250	209308	0.23	79409	196653	468212	996949
4252	243549	0.19	74758	169721	387197	815891
4292	230486	0.22	67643	171954	362964	827067
4322	316605	0.21	72295	196951	401891	919151
4340	281609	0.27	44397	152335	259902	699016
4351	150995	0.2	98878	240766	541901	1207806
4353	162572	0.26	74417	162191	370063	753663
4438	501891	0.29	170439	293260	1127954	1569554
4448	195910	0.23	57626	123240	287559	578952
4462	364896	0.18	153487	323352	909686	1615145
25743	384379	0.16	264842	449333	1550119	2427575
26990	531236	0.13	121362	287903	724405	1402624
29512	253285	0.19	77162	210311	426568	1003665
29636	712705	0.12	143325	234199	1017118	1299809
36064	477582	0.19	89038	221360	609207	1095269
42349	267627	0.2	193856	973366	1292024	3619315
44540	273796	0.25	52101	159010	291856	734248
45057	211001	0.25	62758	150370	376478	702471
49388	206814	0.29	43434	122880	236043	583261
49471	177317	0.29	49568	128758	272960	618331
55149	253946	0.26	105884	233384	625065	1142962
72275	218091	0.29	55789	138326	277932	600480
CAC40		0.22	105660	238184	640752	1199773

Table 5: N is the number of order book states observed for a particular stock. *Relative Spread* is the time-weighted quoted spread divided by the mid-quote and $Depth_{1/5}$ is the time-weighted depth at the first limit (1) or at the five best limits (5). *Full Depth* aggregates displayed and hidden depths. Depth measures are obtained by multiplying the number of shares by the mid-quote in order to allow comparisons across stocks. Results for the CAC40 row are simple arithmetic averages.

Order sizes: AEX and BEL20

<i>Stock</i>	<i>Upper Percentile</i>	<i>Upper Quartile</i>	<i>Median</i>
AEX			
65996	7812	1185	520
65997	10000	2023	1000
65999	12500	2500	1000
66000	25000	2680	1267
66002	5000	909	500
66005	10000	1140	588
66013	13936	1800	1000
66014	90617	8106	3000
66694	15258	2500	1366
66695	25000	3889	1695
66696	25000	3400	1500
66699	21000	2500	1113
66704	20577	2690	1161
66708	30000	3000	1500
66730	20000	2000	1120
66746	17831	2724	2000
66756	5549	1000	400
66757	8421	1620	1000
66760	75000	10000	2650
66784	5000	1000	558
66796	9226	1482	836
66838	10000	1200	600
66850	10619	1730	909
BEL20			
60119	5000	500	229
60128	3000	200	100
60130	8000	1000	500
60132	10000	1000	461
60162	5000	300	109
60165	2000	250	100
60181	1000	50	20
60194	10000	3000	1500
60204	3500	567	356
60236	10000	872	450
60239	13731	2000	1000
60252	9840	1000	353
60263	5000	500	200
60270	3000	250	100
60273	2500	279	100
60278	5132	500	200
60283	2520	200	100
60286	14904	2000	964
60289	8000	600	300

Table 6: For each *Stock*, the number of shares corresponding respectively to the *median*, the *upper quartile* and the *upper percentile* order size are presented. Each one was computed over the three-month period for the given stock. The three trade sizes will be used to compute the Cost of Round Trip Trade. Bold stocks are stocks with liquidity provider agreements.

Order sizes: CAC40

<i>Stock</i>	<i>Upper Percentile</i>	<i>Upper Quartile</i>	<i>Median</i>
223	5000	575	240
1526	10000	977	450
4150	2000	263	113
4154	7500	874	378
4157	10000	1000	500
4161	7200	1000	500
4166	5000	697	310
4170	7200	800	357
4178	10000	953	401
4180	12847	1586	603
4181	5000	500	211
4187	25000	2634	1000
4188	4870	500	200
4213	8240	800	342
4230	7417	749	330
4234	6000	715	385
4237	6339	746	300
4245	25492	2144	700
4250	5000	500	200
4252	8000	800	348
4292	5000	640	285
4322	12444	1008	500
4340	15000	1000	411
4351	5000	500	207
4353	3000	498	200
4438	51454	3183	1000
4448	5000	575	255
4462	10000	1000	400
25743	10000	1133	500
26990	15000	1624	600
29512	10000	724	302
29636	20000	2000	1000
36064	25000	1550	500
42349	10000	500	100
44540	15000	1000	500
45057	20132	2007	1000
49388	17900	1594	655
49471	10000	1380	500
55149	50000	4000	1300
72275	12418	1000	420

Table 7: For each *Stock*, the number of shares corresponding respectively to the *median*, the *upper quartile* and the *upper percentile* order size are presented. Each one was computed over the three-month period for the given stock. The three trade sizes will be used to compute the Cost of Round Trip Trade.

Cost of Round Trip Trade: AEX and BEL20

Stock	ME order size			Q3 order size			P99 order size		
	N	CRT^d	CRT^r	N	CRT^d	CRT^r	N	CRT^d	CRT^r
65996	225943	0.169	0.165	225943	0.198	0.187	225943	0.526	0.423
65997	380542	0.130	0.128	380542	0.146	0.141	380542	0.265	0.246
65999	770003	0.091	0.089	770003	0.114	0.108	770003	0.246	0.217
66000	598542	0.184	0.174	598542	0.220	0.201	598442	0.709	0.568
66002	200493	0.198	0.192	200489	0.221	0.210	200485	0.503	0.423
66005	278050	0.215	0.208	278050	0.245	0.231	278017	0.836	0.636
66013	221357	0.308	0.292	221357	0.355	0.323	221357	1.164	0.846
66014	246685	0.258	0.252	246685	0.297	0.283	245304	0.821	0.706
66694	430603	0.220	0.211	430603	0.256	0.240	430550	0.645	0.547
66695	457603	0.211	0.203	457603	0.259	0.240	457589	0.686	0.576
66696	471941	0.226	0.216	471941	0.275	0.254	471918	0.778	0.634
66699	608701	0.172	0.167	608701	0.206	0.195	608657	0.603	0.509
66704	432546	0.246	0.237	432546	0.297	0.276	432424	0.835	0.669
66708	408767	0.308	0.291	408767	0.362	0.331	408676	1.177	0.928
66730	119246	0.762	0.737	119246	0.833	0.794	119124	2.082	1.830
66746	324905	0.264	0.251	324905	0.282	0.266	324905	0.709	0.603
66756	87407	0.209	0.203	87407	0.252	0.235	87407	0.572	0.468
66757	113100	0.688	0.659	113100	0.762	0.713	112899	1.818	1.500
66760	114808	1.453	1.447	114808	1.596	1.574	114712	2.509	2.376
66784	88218	0.563	0.552	88218	0.624	0.602	88146	1.424	1.278
66796	154265	0.504	0.487	154265	0.568	0.535	154265	1.578	1.288
66838	239481	0.278	0.267	239481	0.321	0.295	239481	1.011	0.717
66850	196795	0.328	0.309	196795	0.381	0.345	196795	1.002	0.745
AEX	7170001	0.255	0.246	7169997	0.296	0.278	7167641	0.784	0.645
60119	43929	0.385	0.372	43929	0.456	0.422	43929	1.893	1.197
60128	13213	1.003	0.987	13213	1.080	1.045	13147	3.058	2.379
60130	75131	0.559	0.532	75131	0.665	0.606	75124	2.049	1.525
60132	46168	0.404	0.384	46168	0.489	0.441	46159	2.345	1.386
60162	24419	0.688	0.684	24419	0.773	0.752	23568	3.505	2.258
60165	50914	0.202	0.195	50914	0.246	0.226	50914	0.725	0.536
60181	15058	0.911	0.902	15058	1.058	1.017	13055	6.108	4.538
60194	219270	0.332	0.317	219270	0.414	0.385	219270	0.779	0.682
60204	77230	0.680	0.653	77230	0.727	0.687	77230	1.633	1.317
60236	61731	0.584	0.543	61731	0.698	0.610	61217	3.810	2.148
60239	290791	0.293	0.286	290791	0.345	0.332	290791	0.997	0.872
60252	24143	0.458	0.437	24143	0.588	0.524	24143	2.720	1.636
60263	8683	1.918	1.882	8683	2.319	2.230	8658	7.240	6.307
60270	22796	0.718	0.701	22795	0.845	0.798	22731	2.839	2.114
60273	21654	0.744	0.738	21654	0.822	0.797	21639	1.780	1.511
60278	10028	0.627	0.603	10028	0.792	0.717	10028	3.139	2.174
60283	5755	0.911	0.903	5755	1.026	1.005	5742	4.723	3.452
60286	89138	0.439	0.400	89138	0.550	0.464	88523	2.017	1.236
60289	46039	0.718	0.689	46039	0.819	0.749	45439	4.328	2.408
BEL20	1146090	0.456	0.438	1146089	0.538	0.499	1141307	1.814	1.291

Table 8: For each *Stock*, the Cost of Round Trip Trade is computed for 3 different trade sizes corresponding respectively to the median (ME), the upper quartile (Q3) and the upper percentile (P99) order size. Each one was computed over the three-month period for the given stock. N represents the number of order book states for which the CRT was successfully computed. The results are expressed in percentages and computed on the basis of both displayed ($CRT(d)$) and real ($CRT(r)$) depths. For AEX and BEL20 indexes, N represents the number of book states observed for all the stocks belonging to the index and the CRT's are simple arithmetic averages of individual results.

Cost of Round Trip Trade: CAC40

Stock	ME order size			Q3 order size			P99 order size		
	N	CRT^d	CRT^r	N	CRT^d	CRT^r	N	CRT^d	CRT^r
223	263839	0.419	0.406	263839	0.494	0.462	263813	1.792	1.321
1526	217837	0.313	0.291	217837	0.385	0.334	215409	2.042	1.048
4150	289966	0.249	0.242	289966	0.293	0.278	289637	0.808	0.642
4154	469639	0.187	0.177	469639	0.222	0.202	468900	0.664	0.474
4157	317276	0.208	0.200	317276	0.242	0.225	316586	0.832	0.629
4161	535219	0.137	0.134	535219	0.157	0.150	534843	0.375	0.325
4166	349878	0.207	0.198	349878	0.244	0.225	349518	0.615	0.479
4170	277865	0.266	0.252	277865	0.318	0.286	277865	1.124	0.730
4178	214633	0.274	0.259	214633	0.336	0.299	209729	1.427	0.867
4180	435236	0.256	0.243	435236	0.318	0.286	434000	0.944	0.696
4181	308820	0.224	0.216	308820	0.271	0.251	307205	0.976	0.693
4187	563650	0.213	0.202	563650	0.262	0.234	562127	0.826	0.593
4188	266272	0.181	0.176	266272	0.215	0.203	265762	0.634	0.471
4213	413080	0.223	0.212	413080	0.268	0.241	413077	1.002	0.656
4230	204860	0.423	0.399	204860	0.513	0.456	204851	2.400	1.377
4234	228068	0.331	0.312	228068	0.381	0.345	227790	1.432	0.915
4237	198259	0.325	0.307	198259	0.399	0.354	197421	1.420	0.911
4245	505806	0.231	0.221	505806	0.294	0.264	496712	1.008	0.707
4250	222640	0.311	0.295	222640	0.382	0.344	220451	1.507	0.987
4252	257728	0.236	0.223	257718	0.282	0.251	257323	1.157	0.702
4292	245373	0.264	0.250	245373	0.308	0.278	245348	0.985	0.626
4322	336247	0.254	0.239	336246	0.299	0.267	334829	1.267	0.802
4340	308925	0.369	0.341	308925	0.454	0.391	288374	2.341	1.254
4351	162253	0.252	0.241	162253	0.300	0.275	158877	1.005	0.700
4353	170976	0.344	0.328	170976	0.427	0.391	170965	1.365	0.989
4438	602181	0.311	0.304	602181	0.350	0.335	588020	0.923	0.763
4448	204854	0.286	0.275	204854	0.338	0.312	204636	1.186	0.827
4462	408007	0.226	0.216	408007	0.279	0.252	401201	1.027	0.714
25743	421027	0.192	0.185	421027	0.228	0.211	420339	0.689	0.528
26990	615727	0.159	0.150	615727	0.201	0.177	612310	0.700	0.472
29512	272562	0.224	0.211	272562	0.269	0.239	245955	1.303	0.748
29636	738871	0.135	0.131	738871	0.154	0.146	738683	0.400	0.353
36064	561392	0.222	0.215	561392	0.272	0.252	542552	0.955	0.701
42349	302738	0.196	0.193	302738	0.230	0.215	269817	1.076	0.608
44540	297762	0.335	0.313	297762	0.395	0.352	286931	1.792	1.130
45057	223684	0.302	0.283	223684	0.353	0.318	222420	1.366	0.974
49388	222087	0.373	0.346	222087	0.462	0.400	207049	2.015	1.176
49471	191118	0.372	0.348	191118	0.490	0.419	188801	1.762	1.109
55149	292990	0.314	0.300	292990	0.388	0.349	261252	1.385	0.971
72275	245864	0.361	0.344	245864	0.424	0.384	228185	1.553	1.027
CAC40	13365209	0.249	0.237	13365198	0.299	0.271	13129563	1.073	0.725

Table 9: For each *Stock*, the Cost of Round Trip Trade is computed for 3 different trade sizes corresponding respectively to the median (ME), the upper quartile (Q3) and the upper percentile (P99) order size. Each one was computed over the three-month period for the given stock. N represents the number of order book states for which the CRT was successfully computed. The results are expressed in percentages and computed on the basis of both displayed ($CRT(d)$) and real ($CRT(r)$) depths. For CAC40 index, N represents the number of book states observed for all the stocks belonging to the index and the CRT's are simple arithmetic averages of individual results.

Aggressiveness according to the order status

Category	Client orders		Own account orders		LP orders	
	Buy orders	Sell orders	Buy orders	Sell orders	Buy orders	Sell orders
1	12.94***	12.78***	21.08***	22.14	25.41***	23.70***
2	20.20***	23.23***	16.08***	16.50***	4.74***	7.02***
3	11.90***	10.97***	17.65***	18.22***	9.80**	9.93
4	18.61***	17.14***	21.09	19.85	19.59	18.50
5	36.31***	35.87***	24.07***	23.26***	40.44**	40.83**

Table 10: Category 1 refers to orders affecting the best opposite price. Category 2 contains orders reducing the displayed depth at the best opposite quote. Category 3 corresponds to orders improving the best price on the same market side. Category 4 refers to orders increasing the depth at the best quote on the same market side. Orders enhancing the overall depth in the order book without affecting the best limit fall into category 5. *Client orders* are orders submitted by market members on behalf of their customers. *Own account orders* refer to orders placed by market members for their own account. *LP orders* are orders submitted by market members when acting as liquidity providers. Relative frequencies are expressed in percentages. Results of paired t-tests comparing client orders with own account orders are reported in columns Client orders. Results of paired t-tests comparing LP orders with own account orders are reported in columns Own account orders. Results of paired t-tests comparing client orders with LP orders are reported in columns LP orders. *Significant at the 10% level, **Significant at the 5% level, ***Significant at the 1% level.

Presence of hidden orders at the best quotes

Index	HO_{Bid}	HO_{Ask}	Dur_0^{Bid}	Dur_1^{Bid}	Dur_0^{Ask}	Dur_1^{Ask}
AEX	23.72%	24.25%	27.0	7.8	25.5	7.5
BEL	23.46%	25.54%	28.3	7.6	27.4	8.4
CAC	28.53%	27.94%	23.3	8.7	24.4	8.7
All	26.01%	26.35%	25.5	8.2	25.4	8.3

Table 11: $HO_{Bid/Ask}$ is the proportion of time in continuous trading when hidden depth is present at the best Bid/Ask. $Dur_{0/1}^{Bid/Ask}$ is the mean duration for presence (1) or absence (0) of hidden depth at the best *bid/ask*. Duration is measured in number of order book states. Figures presented are averages across stocks belonging to the index/sample.

Summary of ordered probit model results for the whole sample

Index	N	Spread	$Depth_1^S$	$Depth_1^O$	$Depth_+^S$	$Depth_+^O$	$Hidden^S$	$Hidden^O$	LR
		< 0	> 0	< 0	> 0	< 0	> 0	> 0	
Panel A : Buy orders									
AEX	23	22	23	22	15	17	5	22	23
BEL	19	17	15	18	7	7	6	9	13
CAC	40	40	40	40	32	37	16	40	40
Panel B : Sell orders									
AEX	23	22	23	22	17	21	2	22	23
BEL	19	17	15	19	6	5	9	12	16
CAC	40	40	40	40	30	38	15	40	40

Table 12: For each explanatory variable, the expected sign is given. N is the number of stocks in the index. For the other variables, the number of stocks presenting a parameter with the expected sign at a 5% significance level is given. *Spread* denotes the prevailing absolute bid-ask spread, $Depth_{1/+}^{S/O}$ is the number of shares at the first limit (1) or at the four next ones (+) on the same side (S) as the incoming order or on the opposite side (O). $Hidden^{S/O}$ are dummy variables indicating the presence of hidden orders on the same side or on the opposite side. LR is the likelihood ratio resulting from the comparison of the general model (Equations [1] and [2]) with the model without both dummies indicating the presence of hidden orders (Equations [7] and [2]).

Comparison of order aggressiveness whether there is hidden depth or not

<i>Aggressiveness</i>	<i>All</i>	<i>HS = 0</i>	<i>HS = 1</i>	<i>HO = 0</i>	<i>HO = 1</i>
Panel A : buy orders					
1	16.68	16.63	16.83	15.76	19.13***
2	16.22	16.25	16.09	15.72	17.58***
3	17.61	17.64	17.59	17.95	16.71***
4	20.40	20.04	21.47***	20.65	19.70***
5	29.08	29.44	28.02***	29.93	26.87***
Panel B : sell orders					
1	17.18	17.15	17.26	16.28	19.48***
2	17.44	17.48	17.31	16.88	18.87***
3	17.22	17.31	17.02	17.58	16.44***
4	19.65	19.21	20.81**	19.86	19.07***
5	28.50	28.84	27.61***	29.41	26.14***

Table 13: *Aggressiveness* refers to the order aggressiveness category and *All* gives the percentage of all buy or sell orders in the category. *HS =* refers to the absence(0)/presence(1) of hidden orders at the best quote on the same side as the incoming order while *HO =* refers to the absence(0)/presence(1) of hidden orders at the best opposite quote. (*), (**) and (***) indicate a significant difference at a level of respectively 10%, 5% or 1% between proportions respectively observed in absence and in presence of hidden depth at the best quote .

Summary of ordered probit model results : analysis by order status

Index	B/S	N	Spread < 0	$Depth_1^S$ > 0	$Depth_1^O$ < 0	$Depth_+^S$ > 0	$Depth_+^O$ < 0	$Hidden^S$ > 0	$Hidden^O$ > 0	LR
Panel A : orders for clients										
AEX	B	23	22	23	23	13	0	11	21	22
AEX	S	23	21	23	23	7	5	7	21	22
BEL	B	19	16	16	16	6	5	7	8	13
BEL	S	19	15	15	19	6	5	9	11	16
CAC	B	40	40	40	40	24	18	36	37	40
CAC	S	40	39	40	40	23	25	31	38	40
Panel B : orders for own account										
AEX	B	23	22	23	21	19	20	2	22	23
AEX	S	23	22	23	22	18	22	0	22	23
BEL	B	19	15	12	14	2	5	0	10	10
BEL	S	19	17	11	15	5	5	0	6	6
CAC	B	40	40	40	40	29	40	2	40	40
CAC	S	40	40	40	40	29	40	2	40	40
Panel C : orders from liquidity providers										
AEX	B	1	0	0	0	1	0	0	0	0
AEX	S	1	0	0	0	0	0	0	1	1
BEL	B	3	3	3	3	3	0	0	0	1
BEL	S	3	2	3	2	1	1	0	0	1

Table 14: For each explanatory variable, the expected sign is given. *N* is the number of stocks in the index. For the other variables, the number of stocks presenting a parameter with the expected sign at a 5% significance level is given. *Spread* denotes the prevailing absolute bid-ask spread, $Depth_{1/+}^{S/O}$ is the number of shares at the first limit (1) or at the four next ones (+) on the same side (*S*) as the incoming order or on the opposite side (*O*). $Hidden^{S/O}$ are dummy variables indicating the presence of hidden orders on the same side or on the opposite side. LR is the likelihood ratio resulting from the comparison of the general model (Equations [1] and [2]) with the model without both dummies indicating the presence of hidden orders (Equations [7] and [2]).

Summary of ordered probit model results : analysis for specific trading intervals

Index	B/S	N	Spread < 0	$Depth_1^S$ > 0	$Depth_1^O$ < 0	$Depth_+^S$ > 0	$Depth_+^O$ < 0	$Hidden^S$ > 0	$Hidden^O$ > 0	LR
Panel A : orders during first 30 minutes										
AEX	B	23	21	22	18	10	10	1	12	13
AEX	S	23	20	21	20	9	10	1	15	17
BEL	B	19	9	9	9	1	2	1	5	6
BEL	S	19	11	9	11	2	5	1	3	4
CAC	B	40	40	39	39	18	12	6	38	38
CAC	S	40	40	37	40	20	23	2	38	38
Panel B : orders around US markets opening										
AEX	B	23	22	23	19	15	13	5	19	23
AEX	S	23	22	23	22	7	15	1	19	20
BEL	B	19	15	13	14	5	4	2	6	7
BEL	S	19	12	9	14	2	3	3	4	6
CAC	B	40	40	40	40	28	29	14	37	38
CAC	S	40	40	40	40	25	33	16	38	40
Panel C : orders during last 30 minutes										
AEX	B	23	21	23	21	11	11	6	15	19
AEX	S	23	22	22	23	15	14	3	16	17
BEL	B	19	13	10	9	5	5	1	5	6
BEL	S	19	13	11	8	2	2	1	4	6
CAC	B	40	40	40	40	17	24	11	33	35
CAC	S	40	40	40	40	23	31	8	38	39

Table 15: For each explanatory variable, the expected sign is given. N is the number of stocks in the index. For the other variables, the number of stocks presenting a parameter with the expected sign at a 5% significance level is given. $Spread$ denotes the prevailing absolute bid-ask spread, $Depth_{1/+}^{S/O}$ is the number of shares at the first limit (1) or at the four next ones (+) on the same side (S) as the incoming order or on the opposite side (O). $Hidden^{S/O}$ are dummy variables indicating the presence of hidden orders on the same side or on the opposite side. LR is the likelihood ratio resulting from the comparison of the general model (Equations [1] and [2]) with the model without both dummies indicating the presence of hidden orders (Equations [7] and [2]).

Ordered probit model estimates: buy orders for AFX stocks

Stock	γ_1	γ_2	γ_3	γ_4	<i>Spread</i>	$Depth_1^S$	$Depth_1^O$	$Depth_{1+}^S$	$Depth_{1+}^O$	$Hidden^S$	$Hidden^O$	<i>LR</i>
65996	-1.08***	-0.61***	-0.14***	0.43***	-3.5287***	0.1032***	-0.0613***	0.0170**	-0.0475***	0.0166*	0.1025***	130.4201***
65997	-0.86***	-0.00	0.23***	1.09***	-3.5885***	0.1557***	-0.1640***	0.0461***	-0.0352***	0.0576***	0.0320***	105.8929***
65999	-0.79***	-0.23***	0.18***	0.62***	-6.9377***	0.0958***	-0.0732***	0.0493***	-0.0352***	0.0250***	0.1139***	461.1353***
66000	-0.71***	-0.15***	0.23***	0.72***	-9.9760***	0.0988***	-0.0871***	0.0490**	-0.0458***	-0.0090*	0.1260***	666.2332***
66002	-1.30***	-0.81***	-0.28***	0.28***	-1.9287***	0.0849***	-0.0332***	0.0005	-0.0210***	-0.0287***	0.0618***	45.8336***
66005	-1.17***	-0.70***	-0.19***	0.37***	-3.4674***	0.0971***	-0.0421***	0.0594***	-0.0230***	0.0032	0.0714***	81.7127***
66013	-1.23***	-0.81***	-0.29***	0.40***	-5.0682***	0.1107***	-0.0484***	0.0419***	-0.0350***	0.0224**	0.1063***	155.0042***
66014	-0.79***	0.15***	0.33***	0.100***	-18.2095***	0.1110***	-0.1259***	0.0492***	-0.0327***	0.0127*	0.0351***	29.1206***
66694	-0.92***	-0.41***	0.03	0.58***	-8.8988***	0.1069***	-0.0759***	0.0141***	-0.0050	-0.0010	0.1232***	354.8889***
66695	-0.62***	0.00	0.36***	0.91***	-12.1545***	0.0924***	-0.0927***	0.0360***	-0.0469***	-0.0181***	0.0985***	281.9313***
66696	-0.58***	0.06***	0.39***	0.92***	-12.7110***	0.0917***	-0.0907***	0.0347***	-0.0219***	-0.0150***	0.1112***	432.1865***
66699	-0.66***	-0.03	0.33***	0.79***	-11.5055***	0.0998***	-0.0941***	0.0571***	-0.0506***	-0.0278***	0.1558***	1096.2937***
66704	-0.92***	-0.26***	0.08***	0.60***	-9.2730***	0.1019***	-0.0810***	0.0163***	-0.0296***	0.0134*	0.0792***	198.8832***
66708	-0.77***	-0.05***	0.25***	0.73***	-10.6415***	0.0791***	-0.0808***	0.0237***	-0.0414***	-0.0381***	0.1245***	500.5494***
66730	-1.34***	-0.46***	-0.19***	0.44***	-4.3817***	0.0664***	-0.0443***	0.0539***	0.0690***	0.0029	0.0978***	74.7404***
66746	-1.97***	-1.45***	-1.05***	-0.33***	-6.8084***	0.1590***	-0.0366***	0.0113	-0.0033	0.0438***	0.0442***	55.1794***
66756	-1.02***	-0.46***	-0.04	0.90***	-1.0551***	0.0862***	-0.0576***	-0.0214*	-0.0730***	-0.0684***	0.0590***	47.1636***
66757	-1.61***	-1.02***	-0.60***	0.08***	-2.4038***	0.0874***	-0.0250***	-0.0221***	-0.0170**	-0.0256*	0.0520***	27.3773***
66760	-1.82***	-0.28***	-0.23***	0.56***	-2.2478	0.0999***	-0.0979***	0.0274***	0.0057	0.0163	-0.0267**	7.1192***
66784	-1.49***	-0.99***	-0.33***	0.39***	-1.6937***	0.0599***	0.0155***	0.0034	0.0096	-0.0656***	0.0940***	52.4760***
66796	-1.67***	-1.24***	-0.69***	-0.01	-2.5159***	0.1200***	-0.0191***	0.0035	-0.0276***	-0.0361***	0.1150***	123.3691***
66838	-1.26***	-0.84***	-0.28***	0.33***	-2.7557***	0.1026***	-0.0392***	0.0070	-0.0201***	-0.0010	0.0994***	152.7713***
66850	-1.53***	-1.10***	-0.57***	0.13***	-3.8693***	0.1206***	-0.0299***	0.0061	0.0154**	0.0095	0.1064***	140.3744***

Table 16: For each *Stock*, estimates of the ordered probit model (Equations [1] and [2]) are given. Let us notice that every parameter estimate has been multiplied by -1 because the lower the value of order aggressiveness category (Cat_t), the more aggressive the order. So, a negative estimate for the spread parameter indicates a negative relationship between spread and order aggressiveness. The γ_i 's are the estimated thresholds. *Spread* denotes the prevailing absolute bid-ask spread, $Depth_{1+}^{S/O}$ is the number of shares at the first limit (1) or the next four ones (+) on the same side (S) as the submitted order or on the opposite side (O). $Hidden^{S/O}$ are dummy variables indicating the presence of hidden orders on the same side or on the opposite side. LR is the likelihood ratio resulting from the comparison of the general model (Equations [1] and [2]) with the model without both dummies indicating the presence of hidden orders (Equations [7] and [2]). (*), (**) and (***) indicate significant results at a level of respectively 10%, 5% or 1%.

Ordered probit model estimates: buy orders for BEL20 stocks

Stock	γ_1	γ_2	γ_3	γ_4	<i>Spread</i>	$Depth_1^S$	$Depth_1^O$	$Depth_+^S$	$Depth_+^O$	<i>Hidden</i> ^S	<i>Hidden</i> ^O	<i>LR</i>
60119	-0.82***	-0.39***	0.14**	0.68***	-0.6868***	0.0759***	-0.0664***	0.0768***	-0.0158	0.0271	0.0857***	12.9408***
60128	-1.11***	-0.64***	-0.03	0.93***	-0.1243	0.0467***	-0.0459***	-0.0325	0.0155	0.1200**	-0.0826*	9.1513**
60130	-0.61***	-0.06	0.42***	0.71***	-2.0067***	0.0599***	-0.0693***	0.0111	-0.0071	0.0925***	0.0427**	25.4691***
60132	-0.70***	-0.27***	0.36***	0.71***	-1.5768***	0.0548***	-0.0575***	0.0567***	-0.0263**	-0.0407*	0.0802***	24.0397***
60162	-1.17***	-0.83***	0.30***	0.79***	-0.5578***	0.0704***	-0.0479***	-0.0139	-0.1143	0.0668*	0.0646*	7.3237**
60165	-0.83***	-0.22***	0.28***	0.71***	-0.4402***	0.0527***	-0.0524***	0.0275*	0.0351***	-0.0141	0.0440**	5.0156*
60181	-1.27***	-0.90***	-0.19**	0.91***	0.0237	0.0180	-0.0558***	-0.0396	-0.0836***	-0.0224	0.1007***	6.7783**
60194	-1.63***	-1.20***	-0.91***	-0.49***	-1.7315***	0.0976***	-0.0506***	-0.0424***	-0.0787***	-0.2103***	0.2843***	1186.7938***
60204	-1.18***	-0.80***	-0.07	0.46***	-0.5951***	0.0764***	-0.0583***	0.0381**	-0.0358	0.0812***	0.0971***	21.4600***
60236	-0.72***	-0.45***	0.34***	0.80***	-1.1657***	0.0601***	-0.0498***	0.0166	-0.0515***	-0.0276	0.0227	3.6543
60239	-0.96***	-0.45***	0.04	0.43***	-9.9923***	0.1021***	-0.0470***	-0.0451***	-0.0141*	-0.1202***	0.2422***	433.0546***
60252	-0.90***	-0.52***	0.13**	0.52***	-1.7747***	0.0718***	-0.0480***	0.1131***	-0.0012	-0.0355	0.1166***	27.9843***
60263	-0.24	0.44***	1.04***	1.32***	-1.0970**	-0.0101	-0.1021***	0.0910**	0.1708***	-0.0654	-0.0324	0.8472
60270	-1.11***	-0.75***	0.04	0.43***	-0.3854***	0.0611***	-0.0082	0.0413**	0.0474***	0.0867***	-0.0380	8.5214**
60273	-0.91***	-0.48***	0.11	1.28***	-0.1877***	0.0523***	-0.0876***	0.0540*	-0.0102	0.0869**	-0.0399	4.9788*
60278	-0.42***	0.43***	0.79***	1.03***	-0.7030***	0.0046	-0.0873***	-0.0081	0.0086	0.0478*	-0.0093	3.6422
60283	-1.03***	-0.62***	-0.00	0.96***	-0.2685***	0.0246*	-0.0279**	0.0184	-0.1118***	0.0684	0.0749*	6.4867**
60286	-0.57***	-0.13***	0.36***	0.85***	-1.8249***	0.0534***	-0.0686***	-0.0233**	-0.0150	0.0823***	0.0232	25.9394***
60289	-0.70***	-0.42***	0.33***	0.94***	-0.4902	0.0607	-0.0729***	0.0419***	-0.0322**	0.0017	0.0153	0.5738

Table 17: For each *Stock*, estimates of the ordered probit model (Equations [1] and [2]) are given. Let us notice that every parameter estimate has been multiplied by -1 because the lower the value of order aggressiveness category (Cat_t), the more aggressive the order. So, a negative estimate for the spread parameter indicates a negative relationship between spread and order aggressiveness. The γ_i 's are the estimated thresholds. *Spread* denotes the prevailing absolute bid-ask spread, $Depth_{1/+}^{S/O}$ is the number of shares at the first limit (1) or the next four ones (+) on the same side (*S*) as the submitted order or on the opposite side (*O*). $Hidden^{S/O}$ are dummy variables indicating the presence of hidden orders on the same side or on the opposite side. *LR* is the likelihood ratio resulting from the comparison of the general model (Equations [1] and [2]) with the model without both dummies indicating the presence of hidden orders (Equations [7] and [2]). (*), (**), (***) indicate significant results at a level of respectively 10%, 5% or 1%.

Ordered probit model estimates: buy orders for CAC40 stocks

Stock	γ_1	γ_2	γ_3	γ_4	$Spread$	$Depth_{1+}^S$	$Depth_{1+}^O$	$Depth_{1+}^+$	$Depth_{1+}^-$	$Hidden^S$	$Hidden^O$	LR
223	-1.32***	-0.95***	-0.30***	0.16***	-1.3918**	0.0922***	-0.0470**	-0.0143**	-0.0892**	0.0977**	0.1161**	273.6835***
1326	-1.00***	-0.58***	0.07***	0.63***	-3.3764***	0.0870***	-0.0533***	0.0216***	-0.0490**	0.0321**	0.0908**	152.8249***
4150	-0.83***	-0.26***	0.15***	0.73***	-0.9554***	0.1041***	-0.1016***	-0.0067	-0.0238**	-0.0247**	0.1393**	430.3753***
4154	-0.73***	-0.25***	0.22***	0.71***	-3.4819***	0.0964***	-0.0886***	0.0419**	-0.0593**	-0.0206**	0.1421**	743.3721***
4157	-0.72***	-0.10***	0.26***	0.93***	-2.3813***	0.1190***	-0.1194***	0.0213**	-0.0352**	-0.0112*	0.1586**	639.1225***
4161	-0.71***	0.04**	0.29***	0.95***	-1.7987**	0.1209**	-0.1274**	0.0133**	-0.0226**	-0.0111*	0.1298**	691.4915***
4166	-0.63***	-0.04**	0.29***	0.85***	-2.1564***	0.0961***	-0.1086***	-0.0085*	-0.0237**	-0.0311**	0.1554**	671.1155***
4170	-1.39***	-1.00***	-0.44***	-0.00	-2.3662***	0.1091***	-0.0455***	0.0203**	-0.0346**	0.0461**	0.1115**	266.9831***
4178	-0.82***	-0.37***	0.15***	0.66***	-3.4170***	0.0834***	-0.0734***	0.0456***	-0.0623**	0.0425**	0.1355**	313.3505***
4180	-0.72***	-0.15***	0.24***	0.71***	-6.6859***	0.0904**	-0.0887***	0.0308**	-0.0365**	0.0197**	0.1315**	636.2095***
4181	-0.91***	-0.32***	0.06***	0.58***	-1.3389**	0.0940**	-0.0884**	0.0002	0.0021	0.0160**	0.1576**	693.2024***
4187	-0.71***	-0.14***	0.17***	0.68***	-9.9954***	0.0800**	-0.0826**	0.0268**	-0.0229**	-0.0146**	0.1573**	1235.2487***
4188	-0.68***	0.01	0.34***	1.10***	-1.3749**	0.1075***	-0.1274**	0.0177**	-0.0343**	-0.0014	0.1421**	448.6374***
4213	-0.94***	-0.50***	-0.01	0.53***	-2.9710***	0.0978**	-0.0690***	0.0125**	-0.0245**	-0.0170**	0.1450**	724.0065***
4230	-1.07***	-0.69***	0.03	0.57***	-2.3439**	0.0801**	-0.0523**	0.0354**	-0.0424**	0.0366**	0.1066**	157.6328***
4234	-1.05***	-0.62***	-0.04	0.44**	-1.9986**	0.0855**	-0.0661**	0.0309**	-0.1107**	0.0085	0.1131**	166.1776***
4237	-0.78***	-0.29***	0.39***	0.86***	-2.8710***	0.0695**	-0.0747**	0.0429**	-0.0491**	-0.0143	0.1329**	238.2852***
4245	-0.58***	0.11***	0.43***	0.82***	-8.5713***	0.0632***	-0.0820**	0.0092**	-0.0301**	-0.0028	0.1039**	525.6541***
4250	-0.73***	-0.17***	0.34***	0.82***	-1.0445**	0.0800**	-0.0902**	0.0171**	-0.0779**	0.0289**	0.0971**	183.5497***
4252	-0.98***	-0.56***	0.05***	0.57***	-2.1275**	0.0870**	-0.0586**	0.0568**	-0.0895**	0.0162**	0.1210**	281.5233***
4292	-0.97***	-0.57***	0.06***	0.66***	-1.8357**	0.0947**	-0.0703**	0.0412**	-0.0650**	0.0286**	0.1200**	264.1896***
4322	-0.68***	-0.19***	0.30***	0.80***	-3.9348**	0.0826**	-0.0859**	0.0138**	-0.0519**	0.0310**	0.1656**	856.1992***
4340	-1.10***	-0.63***	-0.10***	0.31***	-2.7963**	0.0806**	-0.0389**	0.0245**	-0.0349**	0.0447**	0.1244**	425.8205***
4351	-0.80***	-0.15***	0.20***	0.80***	-1.8039**	0.0899**	-0.1031**	0.0106*	-0.0449**	0.0032	0.0778**	82.5390***
4353	-1.19***	-0.71***	-0.21***	0.37***	-0.7318**	0.1101**	-0.0784**	0.0270**	-0.0271**	0.0591**	0.1203**	187.0504***
4438	-1.07***	0.09**	0.18***	0.66***	-9.1312***	0.0849**	-0.1116**	0.0060**	0.0124**	0.0294**	0.0623**	282.9222***
4448	-0.98***	-0.54***	0.18***	0.67***	-2.2288**	0.0862**	-0.0576**	0.0451**	-0.0751**	0.0316**	0.1042**	162.0934***
4462	-0.64***	-0.03*	0.35***	0.97***	-2.8144**	0.0928**	-0.1037**	0.0163**	-0.0467**	0.0046	0.1452**	731.9942***
25743	-0.62***	0.03*	0.31***	1.01***	-2.9914**	0.1009**	-0.1161**	0.0120**	-0.0281**	-0.0015	0.1393**	645.1030***
26990	-0.52***	0.00	0.43***	0.89***	-4.8145***	0.0799**	-0.0930**	0.0534**	-0.0670**	-0.0210**	0.1444**	1179.7257***
29512	-0.100***	-0.61***	-0.05***	0.37***	-2.2258**	0.0922**	-0.0613**	0.0241**	-0.0332**	0.0026	0.1314**	362.8968***
29636	-0.81***	-0.14***	0.13***	0.57***	-7.2047***	0.0958**	-0.1222**	-0.0582**	-0.1801**	-0.0504**	0.2393**	1990.6166***
36064	-0.73***	0.06**	0.34***	0.68***	-7.3726**	0.0597***	-0.0717**	0.0213**	-0.0162**	-0.0019	0.1073**	544.0374***
42349	-0.57***	0.03	0.54***	1.02***	-2.4995**	0.0658**	-0.0952**	0.0301**	-0.0466**	-0.0029	0.1350**	312.5102***
44540	-0.94***	-0.40***	0.06***	0.53***	-3.8089**	0.0641**	-0.0507**	0.0219**	-0.0314**	0.0089	0.0980**	202.3678***
45057	-0.71***	-0.17***	0.19***	0.61***	-9.2882***	0.0975**	-0.1030**	-0.0141**	-0.0524**	-0.0024	0.1166**	218.5280***
49388	-1.12***	-0.62***	-0.11***	0.39***	-5.4404***	0.1083**	-0.0667**	0.0229**	-0.0388**	0.0301**	0.1342**	329.9530***
49471	-0.72***	-0.27***	0.30***	0.66***	-2.3139**	0.0473**	-0.0663**	-0.0199**	-0.0613**	0.0117	0.1450**	299.8727***
55149	-1.02***	-0.33***	-0.07***	0.46***	-12.1290***	0.1044**	-0.0845**	0.0440**	-0.0304**	-0.0060	0.0719**	116.4301***
72275	-0.97***	-0.25***	0.12***	0.56***	-3.5289**	0.0636**	-0.0601**	0.0339**	0.0095**	0.0080	0.0517**	56.0228***

Table 18: For each *Stock*, estimates of ordered probit model (Equations [1] and [2]) are given. Let us notice that every parameter estimate has been multiplied by -1 because the lower the value of order aggressiveness category (Cat_t), the more aggressive the order. So, a negative estimate for the spread parameter indicates a negative relationship between spread and order aggressiveness. The γ_i 's are the estimated thresholds. *Spread* denotes the prevailing absolute bid-ask spread, $Depth_{1+}^{S/O}$ is the number of shares at the first limit (1) or the next four ones (+) on the same side (S) as the submitted order or on the opposite side (O). $Hidden^{S/O}$ are dummy variables indicating the presence of hidden orders on the same side or on the opposite side. LR is the likelihood ratio resulting from the comparison of the general model (Equations [1] and [2]) with the model without both dummies indicating the presence of hidden orders (Equations [7] and [2]). (*), (**), (***) indicate significant results at a level of respectively 10%, 5% or 1%.