Università degli Studi del Molise
Facoltà di Economia
Dipartimento di Scienze Economiche, Gestionali e Sociali
Via De Sanctis, I-86100 Campobasso (Italy)

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Order Dynamics in the Italian Treasury Security Wholesale Secondary Market

by

Chiara Coluzzi
University of Rome "Tor Vergata"

and

Sergio Ginebri
University of Molise, Dept. SEGeS

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Chiara Coluzzi[*]

Sergio Ginebri[◊]

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Abstract[°]

MTS markets are an example of quote driven electronic order book markets for Government securities. Proposals are firm, immediately executable and aggregated in a limit order book. In this paper we analyse the evolution of the interaction between the order book and order flow by exploring the determinants of the flows of limit and market orders over three years. We are able to test several hypotheses coming from theoretical models. This is, to our knowledge, one of the first empirical test of these hypotheses based on Government bond data. We find that market and limit orders show positive autocorrelation and clustering as in Biais et al. (1995). No activity is clustered as well. This diagonal effect could also explain the positive impact of book depth near the quote on the flows of new limit orders. On the contrary, depth beyond the second best price seems to play no role in book dynamics. Furthermore, increasing competition, measured as an increase in the number of operators, has a negative effect on orders. In addition, we find mild support to the theoretical prediction of a positive effect of book depth on order aggressiveness. Best spread, instead, behaves consistently with theoretical models: a larger best spread encourages new limit orders inside-the-quote.

Keywords: limit order, market order, order flow, liquidity, Government bonds.
JEL classification: G14, D44, H63, C30.

[*] University of Rome "Tor Vergata"

[◊] University of Molise; corresponding author at the following address: ginebri@unimol.it

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1. Introduction

The past decade witnessed the development of both the theoretical and the empirical literature about limit orders, the focus being the determinants and the consequences of trader' decisions. In particular, as surveyed by Parlour and Seppi (2008), the main lines of research include issues such as price formation, liquidity, order book dynamics, information aggregation and inter-market competition. This paper aims at investigating the evolution of the order book by exploring the determinants of the flows of limit and market orders using data on Italian Treasury securities, traded on the wholesale *Mercato Telematico dei titoli di Stato*, (MTS). MTS markets are, in fact, an example of quote driven electronic order book. In Italy, about 25 primary dealer continuously post their quotes on the order book.

Our theoretical framework is the literature on order book markets as in Parlour (1998), Goetller et al. (2005) and Foucault (1999). From the theoretical models in that literature, we single out some hypotheses and we test them on a unique dataset on transactions and proposals for the 10-year BTPs being traded on the MTS platform from January 2004 to November 2006. This is, to our knowledge, one of the first empirical test of these hypotheses based on Government bond data.

We find evidence of the diagonal effect as in Biais et al. (1995). Market and limit orders show positive autocorrelation and clustering. No activity is clustered as well. The diagonal effect could also explain the positive impact of book depth at the best and at the second best price on flows of new limit orders. On the contrary, the volume available beyond the second best price does not have any positive effect on new limit orders any more. It is generally non significant. Therefore, the dynamics of limit orders are differentially affected by the book depth in the two best prices and in the rest of the book. Depth in the rest of the book seems to play no role in book dynamics, to be residual. This is striking, because most of the volume in the book is generally concentrated beyond the first two best prices.

Another unexpected result is the negative effect of number of operators on limit and market orders. Number of operators indicates the number of primary dealers that are posting their quotes on the book. We would expect that an increase of that number increases the competition among them and stimulates new limit orders, better liquidity and higher trading. On the contrary, the impact of number of operators is opposite to our expectations.

Furthermore, we find mild support to the theoretical prediction of a positive effect of book depth on order aggressiveness. When book depth increases, limit orders inside-the-quote are encouraged and limit orders behind-the-quote are discouraged. Operators try to gain time priority in execution, as predicted by theory. However, new limit orders at-the-quote increase as well. This does not fit with theoretical models, and could be a consequence of the diagonal effect previously mentioned.

Finally, best spread has a positive impact on inside-the-quote limit orders. Larger best spread encourages new limit orders inside-the-quote, consistently with theoretical models. When best spread widens competition among primary dealers pushes spread down.

The present paper is organized as follows: section 2 briefly reviews the literature and singles out the hypotheses which we test, section 3 describes the market functioning and the dataset, section 4 presents the variables of interest and the estimation methodology, section 5 presents our main results and section 6 conludes.

2. Review of literature and tested hypotheses

Our theoretical framework is the literature on order book markets as in Parlour (1998), Goetller et al. (2005) and Foucault (1999). From the theoretical models in that literature, we single out some hypotheses. Some implications of these models have been tested on stock or exchange rate markets. In this section we review theoretical and empirical findings to select their main assumptions. In particular we focus on the so called "diagonal" effect, as well as on the impact of different proxies of the state of the order book as measures and indicators of bid ask spread, book depth and market volatility.

Biais et al. (1995) work on data from the Paris Bourse, which is a computerized limit order market. They find that the probability that a given type of limit or market order is larger after that the same type of order was just submitted than it would be unconditionally. They refer to this evidence as the "diagonal effect". Positive autocorrelation in order type is found on other limit order markets by many other papers: Ranaldo (2004), Ellul et al. (2007), Cao et al. (2008), among others.

The papers previously mentioned work on databases which contain the whole history of the order book in a given time interval. Their empirical methodology is based on the observation of the order submission process and they analyse each limit or market order submitted in the given time interval. An alternative methodology is present in Ellul et al. (2007). They check whether order type correlation remains constant over longer periods of time. Therefore, they analyse the number of orders aggregated over 5 minute intervals. They find that the variations in the number of orders from a time interval to the subsequent one are negatively correlated. This evidence is considered to be consistent with the theoretical model in Parlour (1998). On our data set we are going to test:

Hypothesis 1: diagonal effect in order type;

1.1 negative serial correlation, as in Parlour (1998);

1.2 positive serial correlation, as in Bias et al. (1995).

The effect of book depth on order placement is investigated in Goettler et al. (2005). They present a discrete time model of a pure limit order market for an asset, where agents endogenously decide whether to buy or to sell, whether to submit limit orders and/or market orders, and the size of each order. The Markov perfect equilibrium of the model is solved numerically. The artificial time series generated by the model show interesting features and we are going to test some of them. The effect of the book depth on order placements is empirically analysed in: Ranaldo (2004), Ellul et al. (2007), Cao et al. (2008), among others. Our tested hypotheses are:

Hypothesis 2: the book depth effect on market and limit orders;

2.1 higher depth on the bid(ask) side increases the likelihood of market buys(sells) and decreases the likelihood of limit buys(sells);

2.2 higher depth on the ask(bid) side leads to a higher frequency of buy(sell) orders, especially limit buy at quote;

2.3 increased ask(bid) depth increases the likelihood of inside the quote limit buy orders;

2.4 increased depth below the bid(ask) reduces the frequency of both market and aggressive limit buys(sells) and increases limit buys(sells) at and below the bid.

Biais et al. (1995) observe that the conditional probability of new limit orders is larger when the bid-ask spread is large. On the contrary, the conditional probability of market orders is larger when the bid-ask spread is small. The model in Goettler et al. (2005) generates similar results. The evidence in Ellul et al. (2005), Hollifield et al. (2004), Ranaldo (2004) shows the effect of spreads on market and limit orders. Therefore, we test for the presence of a bid ask spread effect:

Hypothesis 3: the bid ask spread effect on market and limit orders;

3. wide spreads decrease the probability of market orders and increase the probability of limit orders.

The effect of price volatility on bid ask spread is theoretically analysed in Foucault (1999). In this model, when the common value of the security changes, limit order submitters run the risk of being "picked off". As a consequence, an increase in common value volatility causes bid ask spread to widen. Wald and Horrigan (2005) and Ranaldo (2004) find empirical support to the previous theoretical result. Ahn et al. (2001) find that the volume of limit order submissions is increasing in price volatility as well. Parlour and Seppi (2008), however, raise the suspicion of spurious correlation between volatility and volume. On our data set we are going to test:

Hypothesis 4: the volatility effect on bid ask spread;
4. high volatility increases bid ask spread.

3. Market description and dataset

Market description

Italian Government finances its public deficit by issuing debt securities, on December 2006 they account for 80% of the public debt. The majority of trading occurs on wholesale markets. In particular, MTS is the leading market in Europe for the trading of fixed income securities with its over 1200 participants throughout Europe and average transaction volumes of up to 85 billion euro a day (single-counted)[1]. MTS was the first electronic market for Government securities and it was introduced in 1988 by the Italian Treasury as a platform for co-ordinating the activity of its primary dealer group within Italy[2].

MTS is a wholesale inter-dealer market, this means that individuals cannot access to it. We can distinguish two categories of participants, namely market makers and market takers. The former have to quote continuously two-way firm and immediately executable proposals for a selected subset of securities. The prices usually have to be posted for at least five hours per day and for a certain minimum quantity, and they are subject to maximum spread obligations depending on bonds maturity and liquidity. Each market maker can voluntarily quote other securities as well, facing in this case no constraint on price proposals. No market making obligation applies to market takers that can buy or sell at the given prices.

MTS markets are an example of quote-driven electronic order book. This implies that market makers' quotations are aggregated in a book according to price and side of the market. Since orders of round lots are executed according price priority and time priority (i.e. first in first out) and the quoted proposals are firm and immediately executable, we can say that MTS works as a limit order book. To facilitate the handling of large transactions, minimum lot sizes[3] are high and trading rules grant traders a high degree of anonymity[4]. In effect, price proposals are anonymous and the identity of the counterparty of a trade is revealed only after the trade is executed for clearing and settlement purposes. In particular, if a central counterparty (CCP) is used, counterparties will not know identities; if the trade is settled bilaterally, only the counterparties will know identities. Moreover, market makers are not required to show the maximum quantity they are willing to trade: A participant may limit the display of his proposals to a partial amount (drip quantity) between the minimum trading lot and the total amount of the proposal (block quantity). Both cash and repo transactions are admitted[5].

Even if anonymity in transactions is guaranteed, the MTS system is highly transparent since quotes and transactions go directly to data vendors. As a result, they are immediately available, at a cost, to any market participants. Moreover, data provide the information about the first five levels of the order book. Daily figures, instead, are freely available on the MTS website.

Dataset

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[1] Source: MTSGroup web site.
[2] Since the end of the nineties the MTS system expanded to other country markets and to high quality non government bond. For further details on the development of the MTS model see Coluzzi, Ginebri and Turco (2008)
[3] Proposals must be formulated for a minimum quantity equal to € 10, € 5 or € 2.5 million depending on the instrument (bucket of maturity, liquid/ benchmark security). Odd lots are admitted but they are subject to market makers' acceptance.
[4]Actually, this was not the case when MTS was founded. Indeed, in July 1997, 10 years after its inception, MTS switched to a new operation regime in which the names of market-makers who post bid and ask quotes for each security are not revealed. Scalia and Vacca (1999) analyze this change in the degree of transparency.
[5] For additional details see "MTS Regulations - Governing the Wholesale Italian and Foreign Government Bond Market" available at http://www.mtsspa.it/content/about/download/mtsmarketrules.pdf.

In the present analysis we rely on data on transactions and proposals for the 10-year BTPs being traded on the MTS platform from January 1st, 2004 to November, 13th 2006. Data are provided by the Italian Ministry of Treasury that collects them directly from the MTS Italy market. Ad hoc software allows downloading the data at the desired frequency. This data source is somehow unique since it shows all the quotes and the relative quantities that are active on the market, while market participant are allowed to see only the first five levels of the book and drip quantities.

In particular, for each day in the sample we have the on-the-run and the corresponding off-the-run security. Proposals are observed as "snapshots" at a five-minute frequency between 8:30am and 5.30pm; whereas transactions are time stamped to the second. Our dataset includes around 148,000 observations.

4. Variables of interest and empirical strategy

Variables

Since we are interested in the evolution of the order book, we start analyzing seven different order variables: new best limit bid orders, new best limit ask orders, buy market orders, sell market orders, cancellations of best bid orders, cancellations of best ask orders, no activity. New best limit orders and cancellations are computed by comparing, on each side of the book, the best size[6] in each snapshot with the size available at the same price in the previous snapshot. When the difference is positive, we assign the value of the difference at the variable new best limit orders. If the difference is negative, we assign the value of the difference at the variable cancellations of best orders. No activity is an ordinal variable taking value 1 if the best size on one side of the book is equal to the size available at the same price in the previous snapshot, value 2 if the same occurred on the other side of the book, and 0 otherwise. Finally, market orders simply add up trading volumes in the time interval between each snapshot and the previous one. Buy(sell) market orders measure the volume of contracts which were executed against the best ask(bid) limit orders available.

In our extended analysis, instead, we differentiate limit orders by the aggressiveness of limit price and introduce six new variables: new limit bid orders inside-the-quote, new limit ask orders at-the-quote, new limit bid orders at-the-quote, new limit ask orders at-the-quote, new limit bid orders behind-the-quote, new limit ask orders behind-the-quote. The six new variables substitute for the two limit order variables. Therefore, in our extended analysis we have eleven order variables. The limit order aggressiveness is assessed by comparing the best spread in each snapshot with the best spread in the previous snapshot. When best spread shrinks, new best limit orders, as defined above, are assigned, on each side of the market, to the variable new limit orders inside-the-quote. When best spread loosens, new best limit orders are assigned to the variable new limit orders behind-the-quote. Otherwise, new best limit orders are assigned to the variable new limit orders at-the-quote. The notation of limit order variables is reported in Panel A of Table 1.

In order to test the hypotheses previously posited, in our empirical analysis we use, as explanatory variables, lagged values of the order variables previously defined and a set of measures and indicators capturing the state of the order book. These latter are defined in Panel B of Table 1 and represent different dimensions of the liquidity of the order book. In particular, we rely on measures of market activity as the number of updates, the number of operators and measures of price change, as well as measures more directly quantifying how tight and how deep the order book is, as best spread and depth variables respectively. In effect, since for each quote we know the block quantity, we are able to provide particularly accurate measures of the depth of the market when distinguishing depth according to its position in the limit order book. Other measures, as steepness, capture the breadth of the limit order book, which is the variety, multiplicity of limit orders. Slope, instead, measures the increase in marginal quoted price an operator has to bear for trading an additional quantity, thus it captures both breadth and depth dimensions. Market quality index combines depth and tightness and measures the average quote quantity per percentage point of

[6] Ask(Bid) best size is the quantity available at the best price on the ask(bid) side of the book.

spread.

TABLE 1 HERE

Figure 1 displays the daily patter of some of the liquidity measures we use to capture the state of the order book. All the liquidity measures exhibit intra-day seasonality. In particular, in the top left panel best spread shows a sort of U-shaped pattern. The highest value is achieved at the beginning of the day and it is around 4 ticks, then after 9:00 it falls at 2 ticks and it gradually rises again after 15:00. This is consistent with the empirical findings of Huang et al. (2002) for the USA Treasury Interdealer Broker market (IDB) and Ranaldo (2004) for the Swiss Stock Exchange. The peak around 14:30 coincides with the opening of US financial markets. Likewise, depth variables show a hump-shaped pattern[7]. The number of market operators, instead, is higher in the morning and falls after 14:00, while the absolute price change, which can be interpreted as a proxy for market volatility, follows an opposite pattern. A similar pattern of seasonality is followed by our order variables.

FIGURE 1 HERE

To compensate for this, all the variables are deseasonalized using the method proposed by Gallant, Rossi and Tauchen (1992) and later applied by Lo and Sapp (2007). In the first step of the procedure each variable, w_t, is regressed on a set of dummy and time trend variables, x_t, which includes nine hourly dummies, one for each of the hours between 8:00 and 17:00, five daily dummies, twelve monthly dummies, and three yearly dummies:

$$w_t = x_t^{\prime}\beta + u_t .$$

In the second step, the residuals in the first step, $\hat{u}_t$, are used in the following regression:

$$\log \hat{u}_t = x_t^{\prime}\gamma + v_t$$

Then a final linear transformation is performed to calculate the adjusted variables, w_t^a :

$$w_t^a = \overline{w} + \sigma_w \left(\frac{\frac{\hat{u}_t}{c_t} - \frac{\overline{u}}{c_t}}{\sigma_{\frac{\hat{u}}{c}}} \right),$$

where $\overline{w}$ and σ_w are respectively the sample average and the standard deviation of w_t, $\overline{u}$ is the sample average of the residuals in the first step, $\sigma_{\frac{\hat{u}}{c}}$ is the standard deviation of the residuals in the first step corrected by c_t, and c_t is defined by:

$$c_t \equiv \exp\left\{ \frac{x_t^{\prime}\hat{\gamma}}{2} \right\}.$$

The procedure removes the effect of seasonality on mean and variance. However, adjusted series have the same sample mean and variance as the unadjusted ones.

Summary statistics of the variables of interest are reported in Table 2. We can note that, although the average values are statistically different at the 10% level, the bid and the ask sides of the market behave symmetrically, but the maximum values are larger on the ask side of the market. An exception is the difference between new limit ask and new limit bid, which is not statistically different from zero. When distinguishing limit orders by aggressiveness, the difference for orders at the quote is not statistically different from zero as well. As in many other studies on stock markets, for instance Biais et al. (1995), and on Government bonds, for instance Fleming and Mizrach (2007), the quantity available for trade is concentrated in the second level of the order book and beyond. In the following, we will check if this different distribution of size in the order book has an impact on the order dynamics.

[7] The behavior of the bid side size variables is analogous to that reported in the figure for the ask side ones.

TABLE 2 HERE

Empirical strategy

Initially, we estimate a system of seven equations with SUR, which allows for contemporaneous cross-equation error correlation. As each equation has the same set of explanatory variables, SUR regression coefficients are equivalent to OLS coefficients. The dependent variables are the seven order variables previously defined[8]. In all the seven equations, the explanatory variables are the first lag of the seven order variables and the first lag of the variables representing the state of the order book.

In the extended analysis we estimate a system of eleven equations to keep into account order aggressiveness. Six new order variables substitute for best limit ask orders and best limit bid orders. The new variables are new best limit ask orders inside-the-quote, new best limit ask orders at-the-quote, new best limit ask orders behind-the-quote, new best limit bid orders inside-the-quote, new best limit ask orders at-the-quote, new best limit ask orders behind-the-quote. The explanatory variables remain the same variables used in the seven equation system.

5. Results

The seven equations system

Table 2 reports the regression coefficients in the seven equation system[9]. We find evidence of the diagonal effect in Biais et al. (1995). If we consider the sub-system of the first four equations, that is we concentrate on limit and market orders, the lagged value of dependent variable is significant and the absolute value of the coefficient is generally the highest among the coefficients of the four lagged dependent variables. This shows the presence of clustering among limit and market orders.

Following the methodology in Ellul et al. (2007), we also took the first differences of the dependent variables and we estimated a new system of equations. However, we found no evidence of negative autoregressive coefficients. Therefore, hypothesis 1.1 is not supported by our data.

No activity is clustered as well. The evidence on cancellations is less clear. The diagonal effect is present on the bid side, but it is not on the opposite side. On the contrary, some regularities emerge about the effects of limit and market orders on cancellations. A thorough interpretation of such regularities is currently missing.

When turning to the depth effect, we do not find any empirical support to the above posited hypotheses 2.1 and 2.2. An increase in best size has neither any negative effect on the limit orders on the same side of the book, nor a positive effect on the limit orders on the other side. Furthermore, market orders are not affected by best size on both sides of the book. The unique empirical regularity is a positive effect of best size on new limit orders on the same side of the book. However, this could be a consequence of the diagonal effect previously mentioned.

Among explanatory variables, the volume at the second best price and in the rest of the book were included. We wanted to check whether depth beyond the best price has the same effect on order placement as depth at the best price. Interestingly, second size has exactly the same effects on limit and market orders as best size has. On the contrary, worst size, that is the volume available beyond the second best price, does not have any positive effect on new limit orders any more. The effect of worst size is generally non significant. Therefore, the dynamics of limit orders are differentially affected by the size on the two best prices and in the rest of the book. Worst size seems to play no role in book dynamics, to be residual. This is striking, because most of the volume in the book is concentrated in worst size.

Our third hypothesis relates to the bid ask spread effect. In the seven order system an increase in

[8] Table 1 summarises notation. The no_activity becomes a continuous variable after the seasonal adjustment procedure.

[9] We report only the regression coefficients in the case of on-the-run series. We estimated our system on off-the-run data and we obtained similar results. Furthermore, we divided trading day in two parts: hours of trading concentration and rest of the day. We estimated our system on both parts and we obtained similar results as well.

best spread has a negative effect both on market and limit orders. The negative effect on market orders is consistent with theory; on the contrary, the negative effect on limit orders is not. The results of the eleven order system, however, give a wider support to theory, as we will show later.

We included among explanatory variables two other liquidity indicators: slope and market quality index. None of them show the opposite effect on market and limit orders which is predicted by theory. However, slope has the expected impact on limit orders. A higher slope indicates a fall in liquidity, and, consequently, lower liquidity encourages new limit orders.

Finally, we test the volatility effect focusing on measures of price change. We do not find any impact of price change, either in absolute or in nominal value, on order placement. This evidence is not inconsistent with theory. The model in Foucault (1999) forecasts an impact of volatility on spread, not on limit orders. However, we were expecting that the effect of volatility on spreads could have some consequence on limit orders. Our expectations were not fulfilled.

We included in our analysis three other indicators of book activity: number of updates, number of operators, steepness. Number of updates measures the book modifications occurred in the previous five minutes, and, as expected, it is positively related to market and limit orders. Steepness is a measure of breadth, of variety of proposals. In a previous analysis we have shown that it is not correlated with liquidity[10] and it is strongly related with the number of market participants. Its impact on order placement is not clear. Finally, we find a negative effect of number of operators on limit and market orders. Number of operators indicates the number of primary dealers that are posting their quotes on the book. We would expect that an increase of this number increases the competition among them and stimulates new limit orders, better liquidity and higher trading. On the contrary, the impact of number of operators is opposite to our expectations[11].

The eleven equation system

Table 3 reports the regression coefficients obtained in the case of eleven equations. We concentrate on the regression coefficients of the six new order variables and we find a couple of interesting results. First, best size has a positive effect on the inside-the-quote limit orders on the same side of the book and a negative effect on the behind-the-quote orders. This seems to be consistent with hypothesis 2.3. In the theoretical model by Goettler at al. (2005), when volume at-the-quote is large, operators have an incentive to place limit orders inside-the-quote in order to gain time priority in order execution. However, we find a positive impact of best size on the at-the-quote limit orders as well. This is not consistent with theory, and, as previously mentioned, could be a consequence of the diagonal effect. Therefore, the support to hypothesis 2.3 is partial. The "jump the queue" effect is present, however, the diagonal effect seems to dominate.

Furthermore, the estimated coefficients are not consistent with hypothesis 2.4. Increased depth at second best price or in the rest of the book does not have any negative effect on market and aggressive limit orders, and does not increase limit orders at- and behind-the-quote. Moreover, size beyond best price does not show any systematic effect on order aggressiveness.

Finally, best spread has a positive impact on inside-the-quote limit orders and a negative impact on at- and behind-the-quote. This is consistent with hypothesis 3. Although the impact of best spread is negative on the aggregated volume of limit orders at the best price, a larger best spread encourages new limit orders inside-the-quote, consistently with theoretical models. When best spread widens competition among primary dealers pushes spread down.

6. Conclusion

In the present analysis we explored the determinants of order flow on Italian Treasury securities wholesale secondary market. We were able to verify some implications of theoretical models on the order book dynamics.

[10] This is clear observing Figure 1. For a more detailed analysis see Coluzzi, Ginebri and Turco (2008).

[11] A confirmation of the weak relationship between number of market participants and market liquidity can be found in Coluzzi, Ginebri and Turco (2008).

In future research we plan to focus on the dynamics of the order book behind the best quote and on the information content of the limit order about future short-term returns movements.

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Table 1. Notation

Panel A:Dependent variables	

limit_ask = new best limit ask orders;
limit_bid = new best limit bid orders;
market_buy = buy market orders;
market_sell = sell market orders;
cancel_ask = cancellations of best ask orders;
cancel_bid = cancellations of best bid orders;
no_activity = no activity;
 	
ask_inside_the_quote = new best limit ask orders inside-the-quote;
ask_at_the_quote = new best limit ask orders at-the-quote;
ask_behind_the_quote = new best limit ask orders behind-the-quote;
bid_inside_the_quote = new best limit bid orders inside-the-quote;
bid_at_the_quote = new best limit ask orders at-the-quote;
bid_behind_the_quote = new best limit ask orders behind-the-quote.	

Panel B: Explanatory variables	
Abbreviation	Definition
best_spread = best spread	difference between the lowest price on the ask side of the book and highest price on the bid side
nu_updates = number of updates	the number quotes update between two subsequent snapshots
ask_best_size = ask best size	volume of limit orders available at the best price on the ask side
bid_best_size = bid best size	volume of limit orders available at the best price on the bid side
ask_snd_size = ask second size	volume of limit orders available at the second best price on the ask side
bid_snd_size = bid second size	volume of limit orders available at the second best price on the bid side
ask_worst_size = ask worst size	volume of limit orders available on the book beyond the second best price on the ask side
bid_worst_size = bid worst size	volume of limit orders available on the book beyond the second best price on the bid side
nu_operators = number of operators	number of market operators
price_change = price change	change of the average midquote with respect to the previous snapshot
abs_price_change = absolute price change	price change in absolute value
steepness = steepness	the distance between the best and the worst price scaled by the midpoint between the two and averaged between the bid and ask sides of the market
slope = slope	the distance between the best and the worst price scaled on the difference between total volume minus the volume at the best price and averaged between the bid and ask sides of the market
mkt_qlt_indx = market quality index	average quoted quantity scaled on the average percentage spread
time = time	number of minutes since the first snapshot (i.e. 8.30am)
sqr_time = squared time	squared value of time

Note: Most of the variables are analytically defined in Coluzzi, Ginebri and Turco (2008), Appendix B.

Table 2. Summary Statistics

	num obs	mean	st. dev.	median	min	max	p-value
limit_ask	74811	20.210	27.539	9.122	-7.205	333.931	0.905
limit_bid	74811	20.227	26.830	9.596	-7.754	239.639	
ask_inside_the_quote	74811	2.417	9.987	0.003	-0.200	231.059	0.000
bid_inside_the_quote	74811	2.602	10.286	-0.010	-0.177	155.471	
ask_at_the_quote	74811	15.459	26.023	0.897	-4.139	312.920	0.698
bid_at_the_quote	74811	15.407	25.391	0.670	-4.020	234.529	
ask_behind_the_quote	74811	2.334	11.818	0.037	-0.228	237.860	0.051
bid_behind_the_quote	74811	2.217	11.375	0.092	-0.349	220.928	
market_buy	74811	1.458	5.611	0.110	-0.639	279.720	0.001
market_sell	74811	1.360	5.486	0.100	-0.539	246.769	
cancel_ask	74811	-11.233	25.383	-0.605	-641.815	4.639	0.060
cancel_bid	74811	-10.987	25.203	-0.653	-389.698	5.509	
no_activity	74811	0.201	0.500	0.012	-0.020	5.031	
best_spread	75139	0.025	0.010	0.022	-0.014	0.370	
nu_updates	75139	222.888	166.923	192.446	-107.984	2577.490	
ask_best_size	75139	37.493	30.756	28.873	-5.902	388.124	0.002
bid_best_size	75139	37.004	29.589	29.108	-4.158	258.494	
ask_snd_size	73801	73.990	38.979	73.813	-43.724	393.450	0.000
bid_snd_size	73793	76.605	39.091	77.226	-49.489	263.820	
ask_worst_size	73801	48.308	37.910	41.107	-32.456	371.157	0.000
bid_worst_size	73793	45.122	37.684	36.990	-24.627	349.408	
nu_operators	75139	19.302	7.633	20.530	-43.412	56.127	
abs_price_change	74258	0.015	0.016	0.011	-0.002	0.286	
price_change	74258	0.000	0.021	0.000	-0.277	0.288	
steepness	73261	0.025	0.007	0.025	-0.002	0.059	
slope	73261	0.029	0.029	0.023	-0.008	1.154	
mkt_qlt_indx	75139	9.433	3.795	9.379	-6.990	42.459	

Note: The table report summary statistics for the on-the-run 10 year BTPs' database at a 5-minute frequency. The p-value refers to a test for the difference in mean between the variables on the bid and ask sides of the order book.

Table 3. SUR estimation on 7 order variables

	limit_ask	limit_bid	market_buy	market_sell	cancel_ask	cancel_bid	no_activity
lag_limit_ask	**0.049**	-0.001	-0.001	-0.001	**-0.015**	-0.006	0.000
lag_limit_bid	0.011	**0.027**	-0.001	-0.001	0.004	**-0.022**	0.000
lag_market_buy	0.021	*0.040*	**0.136**	**0.030**	**-0.079**	**0.076**	**-0.004**
lag_market_sell	0.007	*0.046*	**0.049**	**0.141**	**0.080**	*-0.042*	**-0.004**
lag_cancel_ask	**-0.031**	**0.015**	0.001	-0.001	0.006	**0.013**	0.000
lag_cancel_bid	0.007	**-0.016**	0.000	0.001	0.007	**0.016**	0.000
lag_no_activity	**-0.683**	**-1.247**	-0.013	-0.087	0.248	*0.442*	**0.101**
lag_best_spread	**-216.284**	**-182.811**	**-23.955**	**-36.335**	**70.200**	*55.328*	**2.349**
lag_nu_updates	**0.010**	**0.010**	**0.001**	**0.001**	0.001	-0.001	**0.000**
lag_ask_best_size	**0.183**	0.013	0.001	0.002	**-0.044**	**-0.021**	**-0.001**
lag_bid_best_size	-0.012	**0.173**	0.002	0.003	-0.009	0.007	**-0.001**
lag_ask_snd_size	**0.034**	0.008	-0.001	-0.001	**-0.115**	**-0.024**	0.000
lag_bid_snd_size	*-0.014*	**0.029**	-0.001	-0.001	-0.005	**-0.076**	0.000
lag_ask_worst_size	-0.003	-0.012	-0.001	0.000	**-0.058**	-0.007	**0.000**
lag_bid_worst_size	**-0.040**	-0.011	0.000	-0.001	0.011	**-0.016**	**0.000**
lag_nu_operators	**-0.105**	**-0.088**	**-0.019**	**-0.015**	**0.111**	0.034	0.001
lag_abs_price_change	9.105	11.259	1.916	0.612	**22.896**	12.682	**-0.462**
lag_price_change	*12.405*	-6.932	-0.819	-0.832	*12.155*	**-18.312**	0.007
lag_steepness	-2.322	-28.152	**21.203**	17.358	-64.204	*-91.576*	**2.600**
lag_slope	**15.869**	**15.661**	**3.683**	*2.285*	**-28.824**	**-20.158**	**0.336**
lag_mkt_qlt_indx	*0.212*	0.100	*0.036*	*0.034*	**-0.311**	**-0.300**	*0.004*

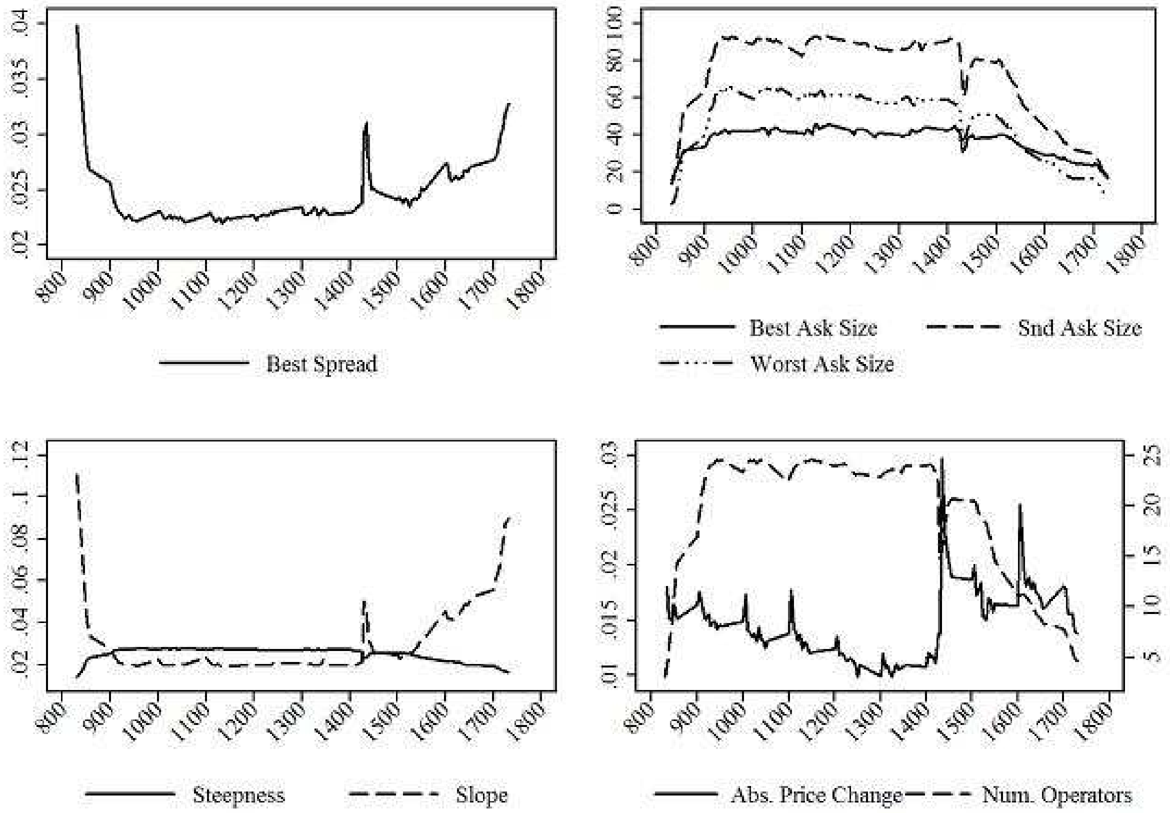
Note: Coefficients in bold are significant at 1% level; coefficients in italics are significant at 5% level. Data refer to on-the-run BTP 10 years. The Breush-Pagan test does not accept the hypothesis of independent equations.

Table 4. SUR estimation on 11 order variables

	ask_inside _the_quote	ask_at _the_quote	ask_behind _the_quote	bid_inside _the_quote	bid_at_ the_quote	bid_behind _the_quote
lag_limit_ask	**0.006**	**0.040**	0.001	0.000	-0.002	0.002
lag_limit_bid	*0.005*	0.007	0.000	0.000	**0.023**	0.002
lag_market_buy	0.007	**-0.078**	**0.094**	**0.038**	0.015	-0.010
lag_market_sell	**0.032**	-0.010	-0.015	0.001	**-0.059**	**0.097**
lag_cancel_ask	0.001	**-0.025**	*-0.005*	-0.001	**0.021**	*-0.004*
lag_cancel_bid	0.001	0.005	0.001	0.000	*-0.010*	**-0.006**
lag_no_activity	-0.004	*-0.537*	-0.099	-0.054	**-1.051**	-0.074
lag_best_spread	**101.255**	**-162.856**	**-138.493**	**106.313**	**-161.594**	**-108.273**
lag_nu_updates	**0.001**	**0.006**	**0.003**	**0.001**	**0.005**	**0.003**
lag_ask_best_size	**0.047**	**0.147**	**-0.015**	**0.028**	-0.009	*-0.008*
lag_bid_best_size	**0.028**	**-0.031**	**-0.012**	**0.062**	**0.126**	**-0.020**
lag_ask_snd_size	0.002	**0.042**	**-0.014**	**-0.006**	*0.014*	-0.002
lag_bid_snd_size	-0.004	-0.008	-0.005	-0.001	**0.037**	**-0.013**
lag_ask_worst_size	0.002	0.006	**-0.014**	**-0.013**	-0.011	**0.010**
lag_bid_worst_size	**-0.008**	**-0.038**	0.004	0.001	-0.002	**-0.014**
lag_nu_operators	-0.009	-0.046	-0.025	0.018	**-0.074**	-0.010
lag_abs_price_change	1.063	-0.127	**11.333**	2.703	6.677	3.828
lag_price_change	0.257	**18.977**	**-7.288**	-1.407	-8.265	3.910
lag_steepness	**-45.984**	-35.272	**95.283**	-29.328	-15.567	*40.986*
lag_slope	1.015	9.218	**6.108**	**5.882**	7.490	3.517
lag_mkt_qlt_indx	*-0.072*	0.089	**0.234**	-0.036	0.065	**0.128**

Note: Coefficients in bold are significant at 1% level; coefficients in italics are significant at 5% level. Data refer to on-the-run BTP 10 years. The Breush-Pagan test does not accept the hypothesis of independent equations.

Figure 1. Daily pattern of the state of the book



Note: Five minute data are averaged over the whole sample of the on-the-run 10 year BTPs. The spreads are measured in ticks. The depth measures are expressed in millions of euro. In the bottom left panel the left scale refers to the absolute price change measured in ticks and the right scale to the number of operators.