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Abstract

We present an empirical analysis of the European electronic interbank market of overnight lending e-MID during the years 1999-2009. After introducing the market mechanism, we consider the activity, defined as the number of trades per day; the spreads, defined as the difference between the rate of a transaction and the key rates of the European Central Bank; the lending conditions, defined as the difference between the costs of a lent and a borrowed Euro; the bank strategies, defined through different variants of the cumulative volume functions; etc. Among other facts, it emerges that the lending conditions differ from bank to bank, and that the bank strategies are not strongly associated either to the present, past or future spreads. Moreover, we show the presence of a bid-ask spread-like effect and its behavior during the crisis.

Keywords: overnight interbank market; subprime crisis; cost of money; e-MID.
JEL Codes: C55; C58; D53; E43; E58.

1 Introduction

Interbank markets play at least two crucial roles in modern financial systems. First and foremost, it is in such markets that central banks actively intervene to guide their policy interest rates. Second, well functioning interbank markets effectively channel liquidity from institutions with a surplus of funds to those in need, allowing for more efficient financial

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intermediation. Thus, policymakers have an interest in a financial system with a well functioning and robust interbank market, that is, one in which the central bank can achieve its desired rate of interest and one that allows institutions to efficiently trade liquidity. Interbank markets have distinct features (Beaupain and Durré, 2008): (*i*) the information on the majority of trades is not centralized; (*ii*) the market is highly concentrated (Iazzetta and Manna, 2009); (*iii*) given the close players, reputation plays an important role; (*iv*) the market is deeply influenced by the monetary policy; (*v*) banks tend to prefer to deal with other banks instead of resorting to central bank facilities; (*vi*) some market participants systematically provide liquidity and others systematically demand for liquidity; (*vii*) large banks typically borrow from a number of smaller creditors (Iori, De Masi, Precup, Gabbi and Caldarelli, 2008).

The interbank market can be managed in different ways: physically on the floor, by telephone calls, or continuously on electronic platforms. In Europe, the interbank trades are quoted in all these ways, generating high information asymmetries. The only electronic brokerage market is the Italy-based market e-MID (electronic Market for Interbank Deposits) aimed at allowing an electronic and multilateral management of banks' treasury flows. Moreover, all the trades, being of relevant size, are automatically settled in real time via TARGET 2. E-MID is a centralized market for the interbank lending of capitals in four different currencies (Euro, British Pound, US Dollars and Polish Zloty), directly or via agent banks, and for a rich set of different contract specifications, such as different maturities. However, the large majority of volumes are traded in the Euro section of the market, and, more specifically, on the overnight contracts, defined as the trade for a transfer of funds to be effected on the day of the trade and to return on the subsequent business day. The number of transactions and the volume increased systematically until the beginning of the financial crisis, with an average of 450 transactions each day and an average exposure of about 5.5 million Euros per transaction. This evolution has been explained with the trend toward real-time settlement for payments, securities, and foreign exchange transactions that took place in recent years (Baglioni and Monticini, 2008). This trend has increased the value of intraday liquidity. Interbank deposits as a percentage of total assets of the banking system increased from 8% in 1993 to approximately 16% in 2007 (Iazzetta and Manna, 2009).

The e-MID is an order-driven market, providing full information on the order book and allowing the participants to directly act on it, without any intermediary institution between potentially matching interests. Each participant lending capitals must actively accept or decline a trade with another bank; the market does not provide any built-in mechanism to consistently check the counterparty risk; credit lines at each institution must apply their own criteria and limits in selecting their trading partners. While for example in futures markets participants are asked to deposit a margin in order to partially cover their counterparty risk, until the 2007 financial crisis, and above all until the Lehman Brothers collapse, interbank markets were completely non collateralized, both because of the insignificant probability of default of the banking system and for the very short maturity of exposures. Since the beginning of the crisis, interbank trades have been characterized by reduced volumes and the exit of a relevant number of institutions. Central banks have changed their role from lenders of last resort to primary liquidity providers of the system. Moreover, to enhance

the recovery of interbank markets, central banks incentivised the creation of collateralized interbank markets, to increase the expected recovery rate and to ensure complete anonymity of trades. It is the responsibility of central banks to evaluate the collaterals provided by banks, to verify that trades comply with established limits and conditions, and to ensure the prompt settlement of transactions in the event of a participant's default, subsequently recovering the amount from the deposited collateral.

The aim of this paper is to demonstrate that the financial crisis dramatically changed the correlation between size and interest rates of interbank trades, determining large spreads among financial agents that depend on their default probability and reputation. This outcome proves the need for a collateralized and anonymous segment of the market, with a direct role of central banks as guarantors. The paper is organised as follows. Section 2 describes the mechanism of the electronic interbank market and Section 3 describes the database. Section 4 describes how interest rates and spreads change during time, particularly within an intraday horizon. Section 5 addresses the analysis to volumes, and Section 6 focuses the analysis to correlations between strategies, sizes and interest rate levels. Section 7 presents our findings on the cost of money for banks before and after the beginning of the financial crisis. Section 8 contains the conclusions.

2 Market Mechanism

The e-MID trades continuously, without opening or closing auctions, and with only a session of post-trading activity aimed at controlling and clearing the trades. There are two independent and, in principle, separate sections called transparent and anonymous. In the former each operator knows the institution behind each pending quote; in the latter the institutions are left anonymous.

The order book is filled by both requests of lending and borrowing capitals; however, as each market participant applies its own credit criteria and limits, the aggregation of the pending liquidity does not necessarily provide homogeneous tradable prices and quantities to each player. For example, an aggressor, defined as an operator who takes away liquidity from the book, is not necessarily able to trade the best pending prices as he may see a potential match denied by the candidate counterparty. Or, likewise, if the most competitive prices are posted by a counterparty feebly creditworthy for his criteria and limits, he could deliberately prefer to match a less competitive quote. Therefore e-MID does not systematically match the orders and the pending liquidity may overlap. In Figure 1 we depict a possible state of the book, using the same scheme normally dedicated to a security market. The different textures stand for different institutions, the height for the proposed volumes and the position on the x-axis for the proposed rate. The black solid blocks are those posted into the anonymous section of the market. Figure 1 (right) shows the possible overlap of orders. In a usual stock-like market, where an overlapping limit order is immediately executed as a built-in mechanism and where the players do not have to manage the counterparty risk, this would not be possible.

Specifically, the market operations are:

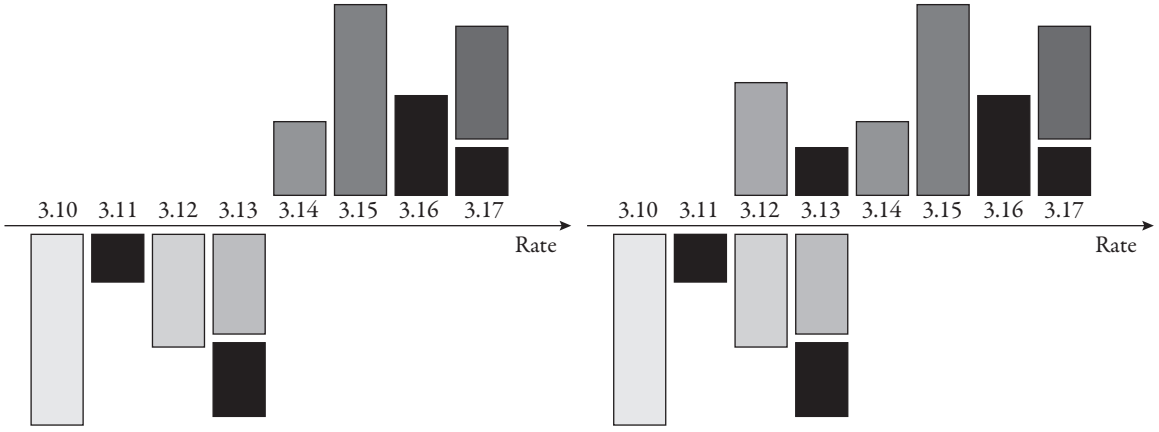

Figure 1: Scheme of a virtual aggregation of the order book. Different textures stand for different institutions, the height for the proposed volumes and the position on the *x*-axis for the proposed rate. The black solid blocks are those posted into the anonymous section of the market. On the right we show the possible virtual overlapping of orders.

- *Quote*. As in a security market, participants send their quotes as proposals. At any given time, the set of all pending quotes forms the pending liquidity.
- *Aggression*. The usual market orders are replaced by aggression: an operator willing to remove liquidity from the book, i.e. to trade immediately without the uncertainty of limit orders, can deliberately pick a quote and manifest his will to match with the opposite interest.
- *Acceptance*. The quoter of an ask quote, i.e. a quoter willing to lend capital, has the option to reject an aggression. This major difference from a security market gives a participant the opportunity to choose his counterparty and manage the credit risk.
- *Proposal*. An aggressor can subordinate his will to close a trade to specific requests, such as a larger or smaller volume or a different rate.

The operator posting a quote anonymously (direct order) is disclosed only by another operator aggressing the pending quote. Both operators have the option of not closing a trade after knowing the candidate counterparty.

3 Data Set

In order to clarify which information is in our hands, we describe more precisely the contents of our database. The database is composed by the records of all transactions registered in the period 01/1999-12/2009 in the Mercato Interbancario elettronico dei Depositi (e-MID). The period has been chosen in order to investigate banks' behavior before, during and after the subprime crisis in the Euro area. Each line contains a code labeling the quoting bank, i.e. the bank that proposes a transaction, and the aggressor bank, i.e. the bank that accepts a proposed transaction. These parts are public regardless of the market section used to negotiate the transaction (transparent or anonymous), i.e. the parts are disclosed after a trade has taken place, even if the negotiations started from an anonymous order. The rate received by the lending bank is expressed per year;

Table 1: Two example records from the data set. Quoter and aggressor are the banks participating to the trade. The groups are the classification of Italian banks with respect to their size. The label «Buy» indicates that the quoting bank is on the buy side, the label «Sell» that it is on the sell side.

Market	Duration	Date	Time	Rate	Amount	Start Date
«EUR»	«ONL»	«2007-01-02»	«8:52:41»	3.60	160.00000	«2007-01-02»
«EUR»	«ONL»	«2007-01-02»	«8:52:54»	3.60	50.00000	«2007-01-02»

End Date	Quoter	Group Quoter	Aggressor	Group Aggressor	Verb
«2007-01-03»	«IT0276»	«ME»	«IT0271»	«GR»	«Sell»
«2007-01-03»	«IT0162»	«PI»	«GR0006»	«ND»	«Sell»

the volume of the transaction, i.e. the amount of lent money, is expressed in millions of Euros. A label indicates the side of the aggressor bank, i.e. whether the latter is lending/selling («Sell») or borrowing/buying («Buy») capitals to or from the quoting bank. Other labels indicate the dates and the exact time of the transaction. Moreover, the records contain the contract the two banks are trading. The main difference between contracts is the length of the lending period. We consider only the overnight («ON») and the overnight long («ONL») contracts. The latter is the version of the ON when more than one night elapses between two consecutive business days, due to weekends or bank holidays. The banks are reported with a code for their country or a label for their class of capitalization (major, large, medium, small, minor) when they are Italian. A couple of example records are reported in Table 1.

We do not have any information regarding when and how a particular section of the market is used, i.e. whether some banks prefer to remain anonymous during the negotiation; we do not know whether a transaction is the result of a specific proposal (see Sec. 1) and, finally, we do not know the content of the order book, i.e. we do not have complete information on the state of the liquidity, its dynamics and how the banks use this information when they act on the market. Various past studies investigated similar data (Gaspar, Perez-Quiros and Rodríguez Mendizábal, 2007) or the same data (De Masi, Iori and Caldarelli, 2006; Iori and Precup, 2007; Iori, Renò, De Masi and Caldarelli, 2007; Iori, De Masi, Precup, Gabbi and Caldarelli, 2008; Delpini, Battiston, Riccaboni, Gabbi, Pammolli and Caldarelli, 2013; Zlatic, Gabbi and Hrvoje, 2015), although not always for the same length of time. In one case the whole book information was studied (Brousseau and Manzanares, 2005).

4 Rates and Spreads

The symbols v_i and r_i indicate, respectively, the exchanged volume and the rate of transaction i. As a first step we classically compute the mean rate registered in each analysed trading day d as

$$\bar{r}_d = \frac{1}{N_d} \sum_{i=1}^{N_d} r_i, \tag{1}$$

where N_d is the number of transactions in day d. The results are reported in Figure 2. As a test we have computed also the volume weighted daily mean rate

$$\bar{r}_d^v = \frac{\sum_{i=1}^{N_d} v_i r_i}{\sum_{i=1}^{N_d} v_i}. \tag{2}$$

The results of this second estimation are extremely close to the previous and thus we do not display a separate figure. Together with the daily mean rate, Figure 2 reports the ECB key rates for the considered period. The ECB defines the rates as follows (European Central Bank, 2011):

- *Marginal lending facility rate* (EuroMLR): the rate fixed by the ECB for operations where counterparties can use the marginal lending facility to obtain overnight liquidity from the national central banks (NCBs) against eligible assets. The interest rate on the marginal lending facility normally provides a ceiling for the overnight market interest rate.
- *Main refinancing facility operations* (EuroRPS): regular liquidity-providing reverse transactions with a frequency and maturity of one week. They are executed by the NCBs on the basis of standard tenders and according to a pre-specified calendar. The main refinancing operations play a pivotal role in fulfilling the aims of the Eurosystem's open market operations and normally provide the bulk of refinancing to the financial sector. The corresponding rate is here called EuroRPS.
- *Deposit facility rate* (EuroDEP): counterparties can use the deposit facility to make overnight deposits with the NCBs. The interest rate on the deposit facility normally provides a floor for the overnight market interest rate.

The mean daily spreads in day d with respect to the EuroMLR, EuroRPS and EuroDEP are

$$\bar{s}_d^E = \frac{1}{N_d} \sum_{i=1}^{N_d} (r_i - r_d^E) \tag{3}$$

where the superscript E is a label for EuroMLR, EuroRPS or EuroDEP. Figure 3 shows the results of this computation (left) together with the relative mean daily spread (right) defined as

$$\bar{w}_d^E = \frac{\bar{s}_d^E}{r_d^E} \tag{4}$$

Even though the ECB changed twice the definition of the EuroMLR, this decision does not affect the significance of our analysis.

Observing the spreads, it is clearly possible to distinguish two different regimes. In the period preceding the Lehman Brothers collapse the spreads oscillate around a somehow stable value, while in the subsequent period the spreads oscillate more heavily at levels lower than usual. More specifically, after September 2008 the EuroRPS spread assumed consistently negative values, with the mean daily rate much below the usual ceiling roughly defined by the EuroMLR rate. In fact, the way the official rate corridor is designed (all the rates are compared with the official refinancing rate) makes it physiological that the EuroDEP spread is positive around 1%, the EuroMLR spread is negative around −1%, and the EuroRPS spread oscillates around 0%. The rationale of these spread values is that

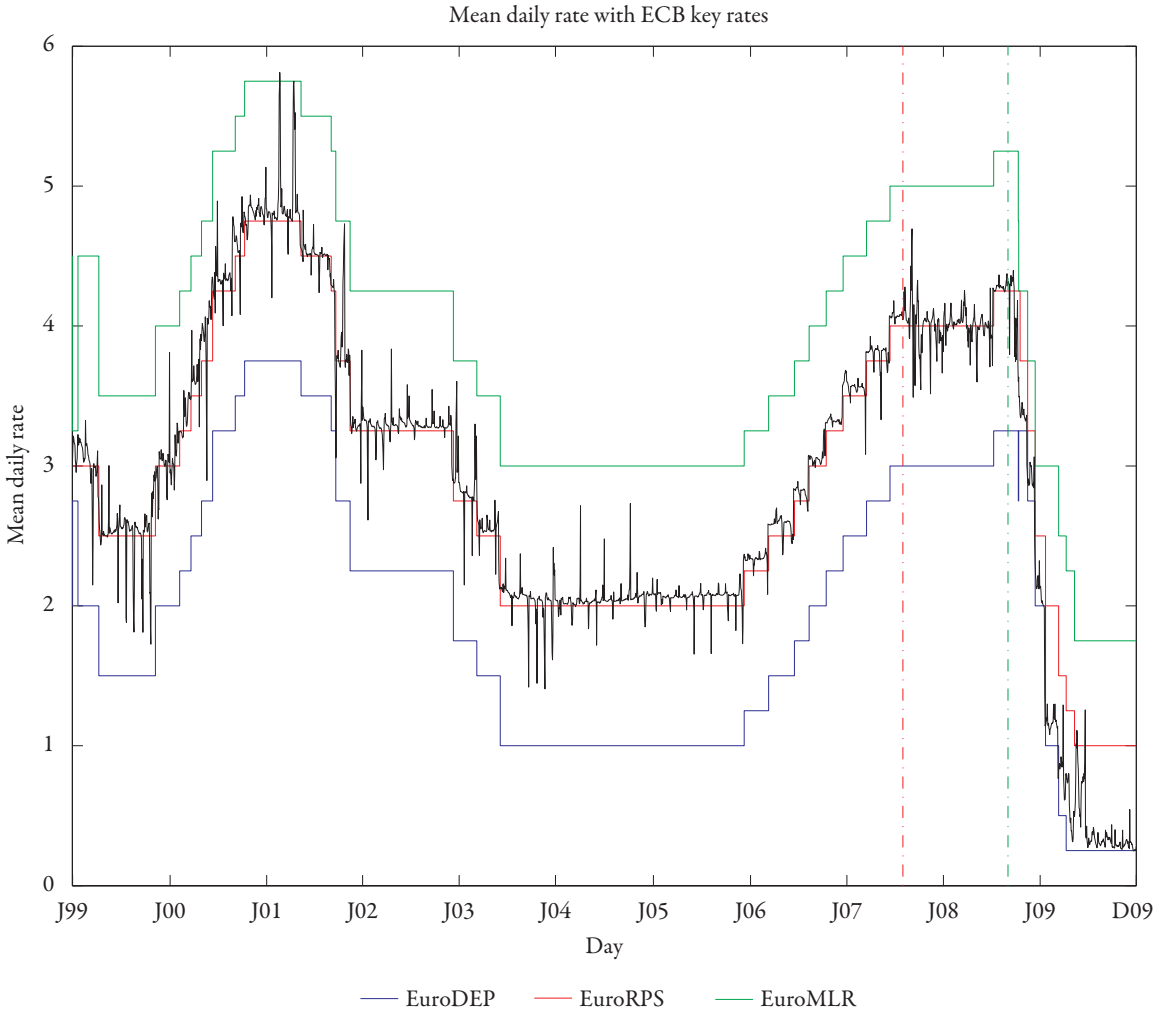

Figure 2: The mean daily rate (black) plotted together with the ECB key rates (coloured). The first vertical line marks the subprime crisis of August 2007 and the second the collapse of Lehman Brothers in September 2008.

all the interbank rates should always be higher (or equal) than the best borrowing rate of the central bank (EuroDEP) to incentive a demand for ECB funds. This way, the official rates directly shape all the credit rates, affecting both the price and the volume of credit.

Figure 3 (left) shows that before the financial crisis the expected values were confirmed, and also before the Lehman bankruptcy. What really shocked the rate structure was the collapse of the US investment bank, when all the spreads declined by about 1%. Until the end of 2009, as shown in Figure 3, borrowing money from the interbank market costed significantly less than refinancing from the central bank. This phenomenon lasted in 2010 too. This evidence reveals that the European Central Bank did not cut its official rates as much as other monetary authorities, the Federal Reserve above all, but tolerated that interbank rates fell below the main refinancing rate: the huge amount of liquidity injected by the ECB during the crisis affected so much the interest rate level.

The period between the subprime shock and the Lehman collapse, when official interest rates did not significantly change, shows a good relative spread control, see Eq. (4) and Figure 3 (right), while the subsequent cut of official rates generated an exceptional

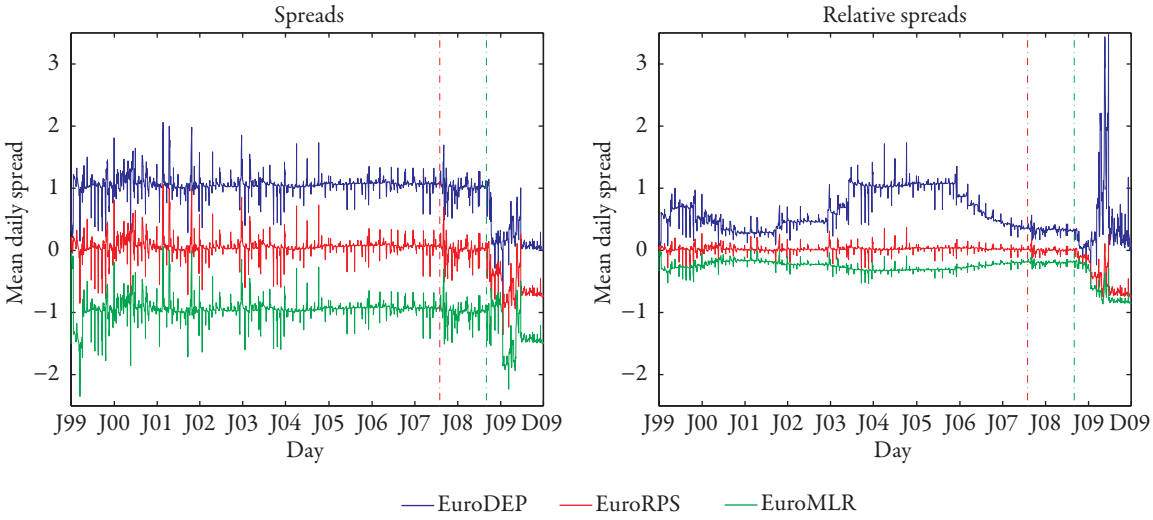

Figure 3: Left: mean daily spreads, Eq. (3). Right: relative mean daily spreads, Eq. (4). It is clearly possible to distinguish two different behaviors, one for the long period before the Lehman collapse, and one for the subsequent period.

increase of the opportunity cost of lending money with interbank deposits instead of putting money in deposit facilities.

4.1 Intraday price of money

Similarly to a previous study (Baglioni and Monticini, 2008), we consider the annual average EuroRPS spread as a function of the intraday time. More precisely, for each day d we compute the instantaneous mean value $\bar{s}_d^E(t)$ considering the trades performed in the 30 minutes before and after t. We then average these quantities over all trading days within each year. The results are reported in Figure 4. Our outcomes reflect the immediate liquidation of the trades: since all overnight deposits must be regulated the subsequent business day at 9am, their time length decreases during the trading day. A negative shape of the spread was already observed by Baglioni and Monticini (2008) for the period 2003-2004. While Baglioni and Monticini used interest rate differences with respect to the daily average, we compute the spread with respect to the refinancing rate (EuroRPS) in order to isolate intraday patterns of the banks' convenience to borrow money on the interbank market. For all the considered years (1999-2009) the pattern is negative. This validates the hypothesis that the interbank market implicitly transforms overnight loans into intraday loans, as proved by Baglioni and Monticini (2008). Since the ECB requires that all lending must be collateralized, banks could prefer to pay higher rates in the interbank market. Nevertheless, when we compare the maximum spread from 2000 to 2009, we observe a sharp change after the crisis (Figure 5). The spread exceeds the maximum value of 0.02 and in 2009 raises to 0.045. This phenomenon is explained by the extraordinary liquidity need of European banks during the crisis. Furthermore, we observe a more regular shape during the crisis years (from 2007 to 2009).

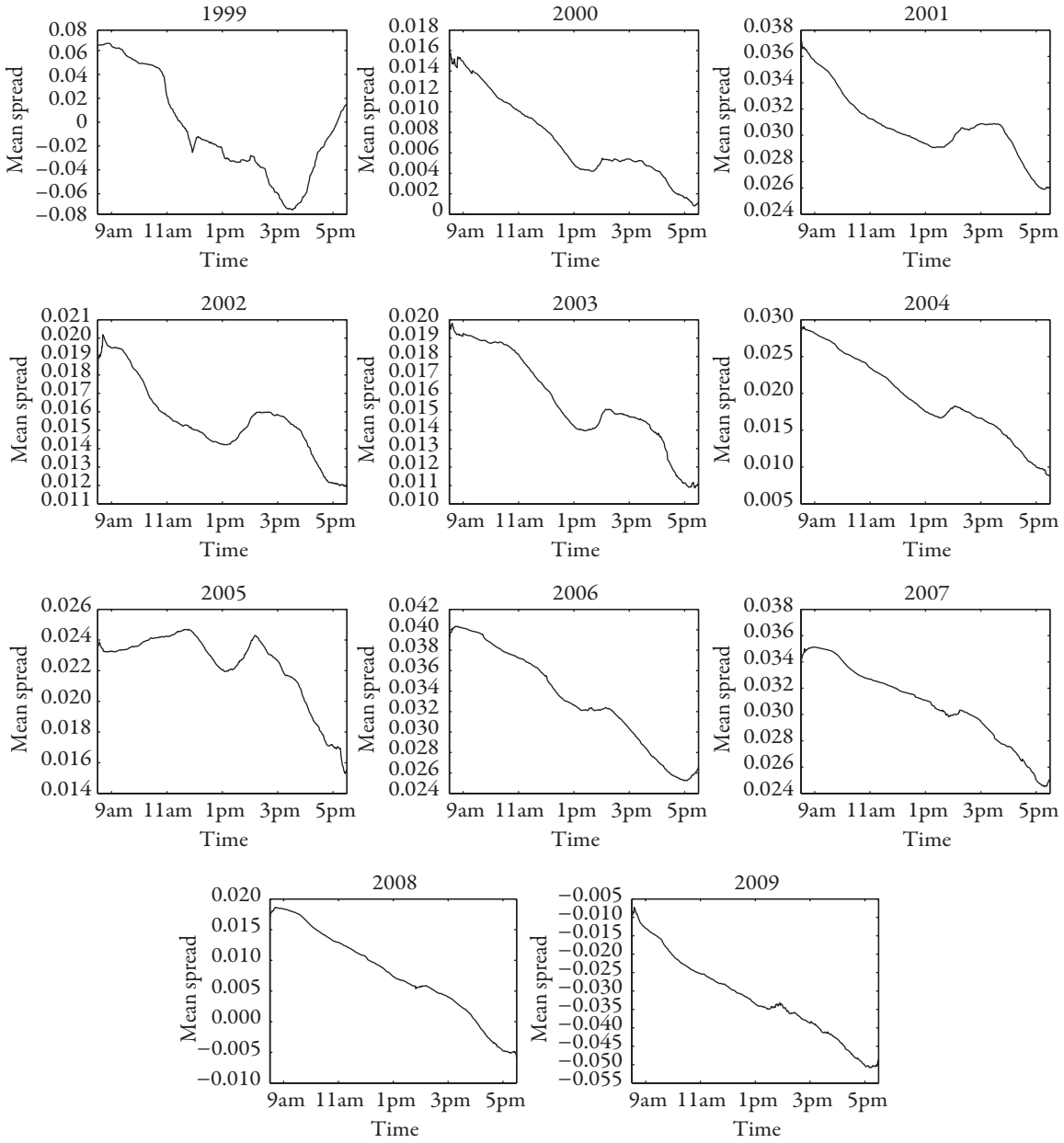

Figure 4: Mean EuroRPS spread $\bar{s}(t)$ as a function of the time of the day averaged over all trading days in each year with a time window of $t \pm 30$ minutes.

This arises a question: why should banks pay high interest rates early in the morning instead of waiting for an overnight loan traded in the afternoon? To answer we must recall the real time gross settlement introduced with the Euro and the need to pay back overnight deposits opened the day before. This means that from 8:30 to 9:00 am banks need to find money to regulate their debt. Usually, this is generated by physiological cash ins, while our results show that banks must find liquidity within the interbank market. Such a situation could be defined as hyper-speculative in a Minsky bank strategy (Vercelli, 2011), or, in other terms, a «borrow from Peter to pay Paul» strategy, as an early warning of trouble that ultimately results in undertaking a radical debt resolution scheme, bankruptcy, or even foreclosure.

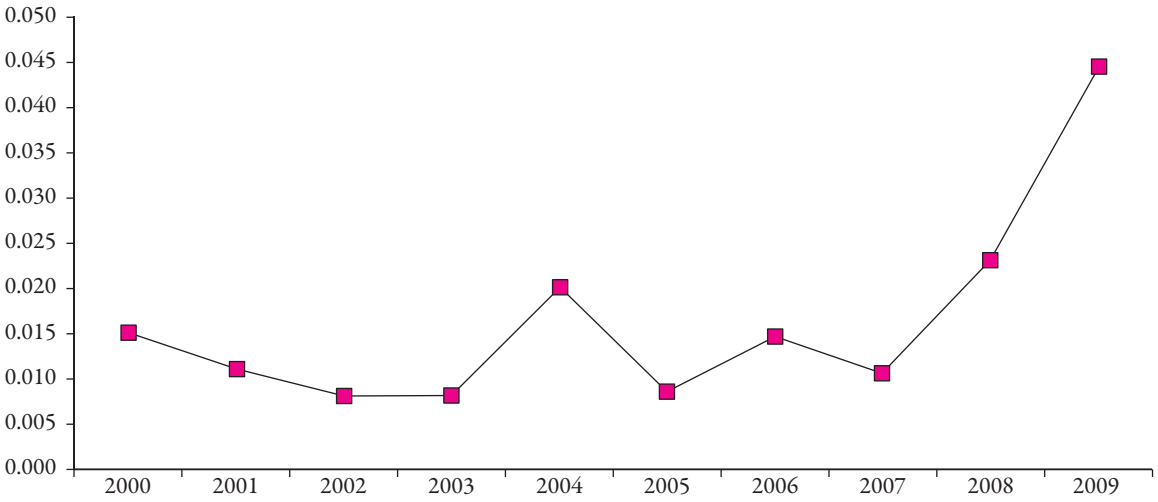

Figure 5: Mean spread range (max-min of Figure 4) from 2000 to 2009.

4.2 Interest rate volatility

The intraday rate pattern shows an increasing volatility during the crisis. The daily rate volatility σ_d is computed classically as

$$\sigma_d = \sqrt{\frac{1}{N_d - 1} \sum_{i=1}^{N_d} (r_i - \bar{r}_d)^2}. \tag{5}$$

Its monthly average is reported in Figure 6 (left) together with its normalized value $\sigma_d / \bar{r}_d$ (right). Figure 6 shows the magnitude of the interbank rate volatility after the two most critical events, respectively the subprime shock and the Lehman Brothers collapse. Two well-defined peaks are visible in the months after the two crisis milestones. Most of all, we can observe in Figure 6 (left) how the monthly volatility coefficient restored to pre-crisis levels within few weeks, thanks to a huge amount of liquidity provided by the European Central Bank. A different result appears when we estimate the normalized daily volatility averaged over a month (Figure 6, right). Here, the volatility continuously rises from 2% to 24%.

To explain the monotonic pattern of volatility and the apparently ineffective reduction of volatility between the two critical events (subprime crisis and Lehman collapse), we estimated the equation explaining the one month rate volatility with an OLS estimate of the model

$$\sigma_i^{\mathrm{MD}} = \alpha + \beta_0 \sigma_i^{\mathrm{OS}} + \gamma_0 V_i^{\mathrm{dep}} + \zeta_0 V_i^{\mathrm{lend}} + \eta_{-1} \sigma_{i-1}^{\mathrm{MD}} + \beta_{-1} \sigma_{i-1}^{\mathrm{OS}} + \gamma_{-1} V_{i-1}^{\mathrm{dep}} + \zeta_{-1} V_{i-1}^{\mathrm{lend}} \tag{6}$$

corrected with autoregressive variables (lagged period of one month, reported in Table 2 with a (−1)) and an error correction model factor, where

- σ_i^{MD} is the standard deviation of one month deposit log returns;
- σ_i^{OS} is the standard deviation of overnight swap log returns;

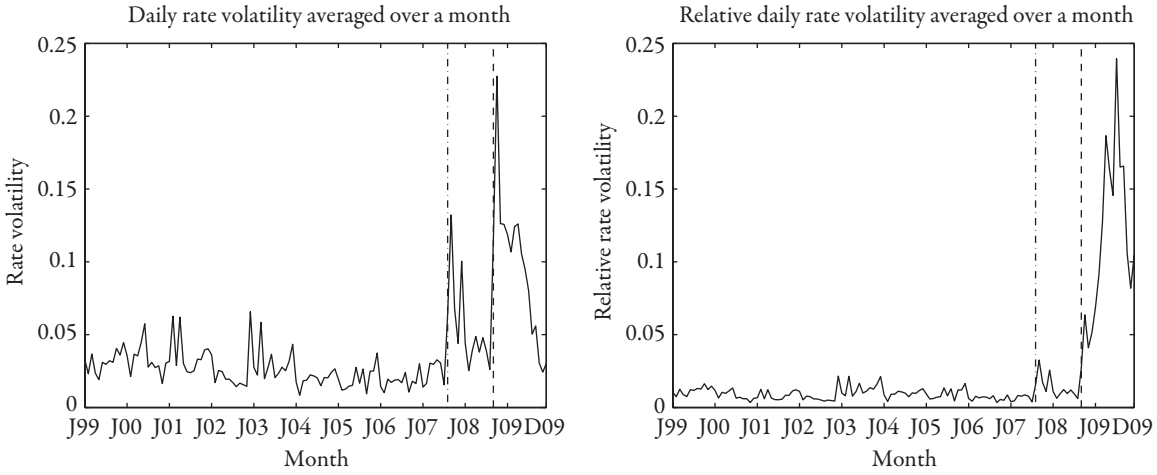

Figure 6: Left: Daily rate volatility averaged over a month. Right: Normalized daily rate volatility averaged over a month. The daily rate volatility (left) shows two well defined peaks in the months following the two crisis milestones.

Table 2: One-month interest rate volatility model by the ECB lending and deposit facilities, Eq. (6). Coefficients with subscript −1 refer to independent variables lagged by a month.

	Pre subprime crisis 02/01/2005-08/08/2007	Post subprime crisis 09/08/2007-12/09/2009	Post Lehman collapse 12/09/2008-26/07/2010
α	1.24E-6	−7.88E-5	−3.671E-5
β_0	0.301514**	0.104724	0.018339*
γ_0	3.73E-9**	7.12E-9***	7.06E-7***
ζ_0	−7.13E-9**	8.12E-7***	−2.32E-9***
η_{-1}	0.074614**	0.035887***	0.293388***
β_{-1}	0.460955***	0.072291***	0.169428***
γ_{-1}	5.75E-9	1.20E-8***	1.25E-7***
ζ_{-1}	−4.61E-9	2.56E-7*	−1.73E-9*
Error correction model	−0.032949***	−0.037971***	−0.046397***
Adjusted R^2	0.712308	0.519221	0.545169
Durbin-Watson statistics	2.241081	1.998579	1.867629
P (F-statistics)	0.000000	0.000000	0.000000

* means significantly different from zero at 10% level (two-tail t-test), ** at the 5% level, and *** at the 1% level.

- V_i^{dep} is the amount of bank liquidity deposited at the ECB (million Euros);
- V_i^{lend} is the amount of bank liquidity borrowed from the ECB (million Euros).

The hypothesis behind the relation between volatility and volumes is that the rate volatility should be negatively correlated with the amount of deposit facilities. Results are shown in Table 2.

Our findings show that the expected correlations are confirmed before the subprime crisis and after the Lehman collapse, while in between deposit facilities and rate volatilities change, indicating the failure of policy makers to manage the interbank interest rate volatility. This power was restored after the Lehman bankruptcy, when not only central banks but also the US and European governments intervened to support the banks' credibilities, collateralizing bond issues and interbank deposits to enhance the banking system's trustworthiness.

4.3 Bid-ask spread

It has been well documented within the market microstructure literature that liquidity factors are important determinants of stock and bond returns. Such returns have been found to be affected by liquidity, as measured by the bid-ask spread (Amihud and Mandelson, 1986; 1991; Kamara, 1994; Eleswarapu, 1997), the price impact of trades (Brennan and Subrahmanyam, 1996), and the volume or turnover ratio (Haugen and Baker, 1996, Datar, Naik, and Radcliffe, 1998). Cherubini (1997) modeled the liquidity risk by the proxy of the bid-ask spread in the market. Other papers based on the bid-ask spread have been proposed (Almgren and Chriss, 1999; Chakravarty and Sarkar, 1999; Hong and A. Warga, 2000; Gwilym, Trevino and Thomas, 2002; Favero, Pagano and von Thadden, 2010). This approach is coherent with the examination procedures listed by the Federal Reserve even before the financial crisis (1998), asking to obtain all management information, reviewing bid/ask assumptions in a normal market scenario and reviewing stress tests that analyse the widening of bid/ask spreads and determining the reasonableness of assumptions. The estimation of the bid-ask spread helps to assess the liquidity pressure during the crisis. Therefore, for each day we separate the transactions labeled «Sell» from those labeled «Buy» and we consider the corresponding rates. The mean values are then defined as

$$\bar{r}^s_d = \frac{\sum_{i=1}^{N^s_d} v^s_i r^s_i}{\sum_{i=1}^{N^s_d} v^s_i} \tag{7}$$

$$\bar{r}^b_d = \frac{\sum_{i=1}^{N^b_d} v^b_i r^b_i}{\sum_{i=1}^{N^b_d} v^b_i} \tag{8}$$

where N^s_d and N^b_d are the numbers of sell and buy transactions in day d. The bid-ask (or sell-buy) spread is now computed as

$$s^{sb}_d = \bar{r}^s_d - \bar{r}^b_d. \tag{9}$$

Figure 7 shows the monthly average of s^{sb}_d. The presence of this spread is the first non-trivial conclusion we can draw from the plot. The market is in fact different from more usual order-book markets. Moreover, two well defined peaks are clearly present after the crisis milestones. Their presence is a clear proxy of the diffidence that the banks had during the worst moments of the crisis. During the crisis some bid-ask spreads experienced values higher than 200 basis points, while the usual pre-crisis level was around 3 basis points. Paradoxically, the liquidity stress seems to have been absorbed just before the Lehman collapse, when the bid-ask spread dropped below 5 basis points, i.e. the resistance level empirically observed before the sub-prime shock. This allows us to remark that this illiquidity proxy does not provide any early warning signal. Moreover, in both landmark events the spread trend appears to have been absorbed within a few weeks, exhibiting a strong correlation with the rate volatility pattern in Figure 6 (left). This is certainly due to the massive liquidity intervention of the European Central Bank, that from June 2007 to June 2010 increased its assets by about 600 billion Euros (+65%) using standing facilities, marginal lending facilities and open market operations, and easing the procedures and the eligible assets required to borrow money.

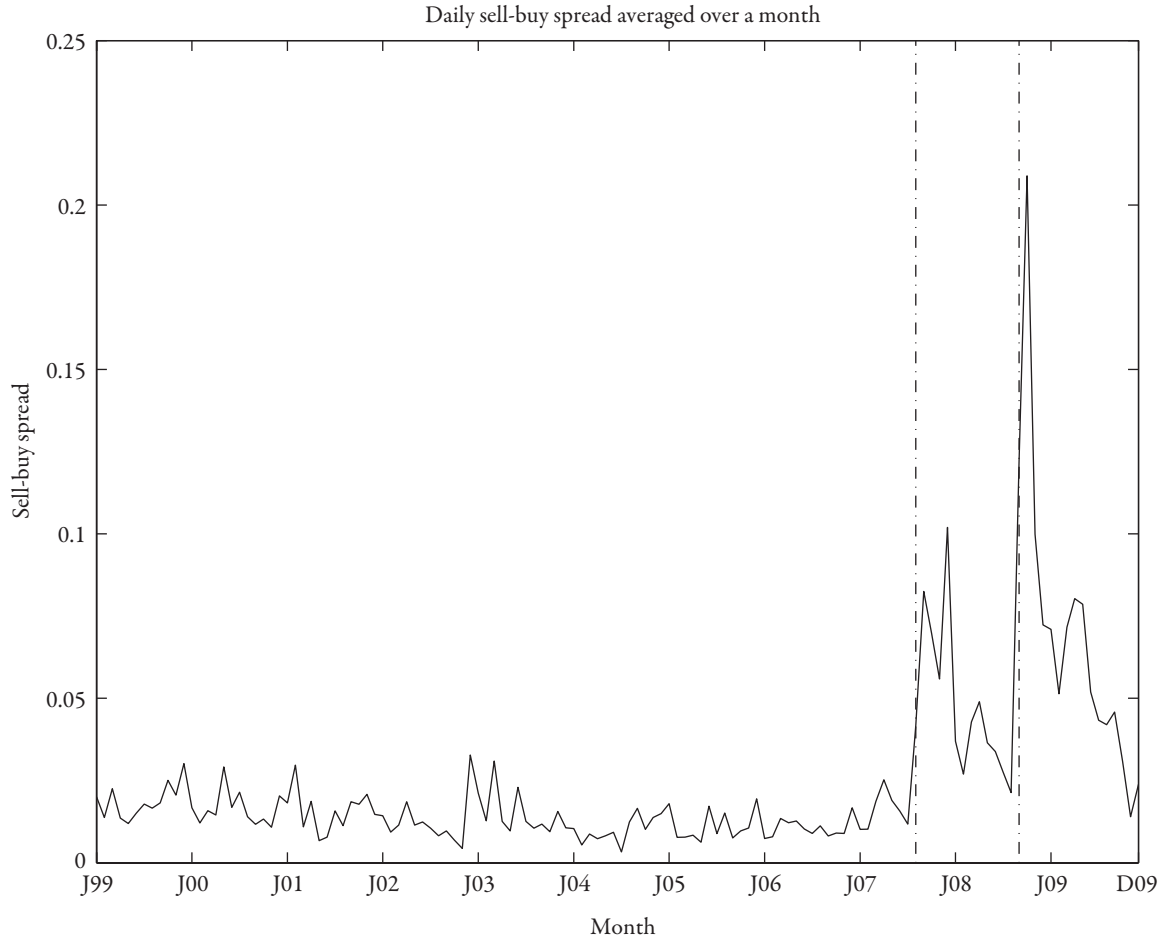

Figure 7: Monthly average of the daily sell-buy spread defined in Eq. (9). Two well defined peaks are clearly present after the crisis milestones.

5 Volumes, Trades and Active Banks

In the following the term monthly refers to a calendar month, i.e. from the 1st to the 30th, 31th or 28th (29th) day of a given month. This is an important remark because often, for accounting reasons, this is not the case. As before, the vertical lines in the figures indicate the beginning of the subprime crisis (August 2007) and the collapse of Lehman Bothers (September 2008). Moreover, the results are presented separating trades into deals where liquidity went from the aggressor bank to the quoter («Sell» label) or the opposite («Buy» label). Monthly averages of daily exchanged volumes, number of trades, active banks and quoting/aggressing banks are given in Figures 8, 9 and 10. The main difference between the pre- and post-crisis periods is the magnitude of the traded volumes. They have been steadily increasing until August 2007 and then rapidly collapsed after this time. It is unlikely that the overnight interbank market lost all this volume of trades. There are two factors: on the supply side, banks cut their exposures in order to reduce the loss-given default in a period of banking crises; on the demand side, banks preferred to avoid disclosing their need for liquidity in order to protect their reputation. Therefore, the interbank market volumes dropped and the grey market compensated.

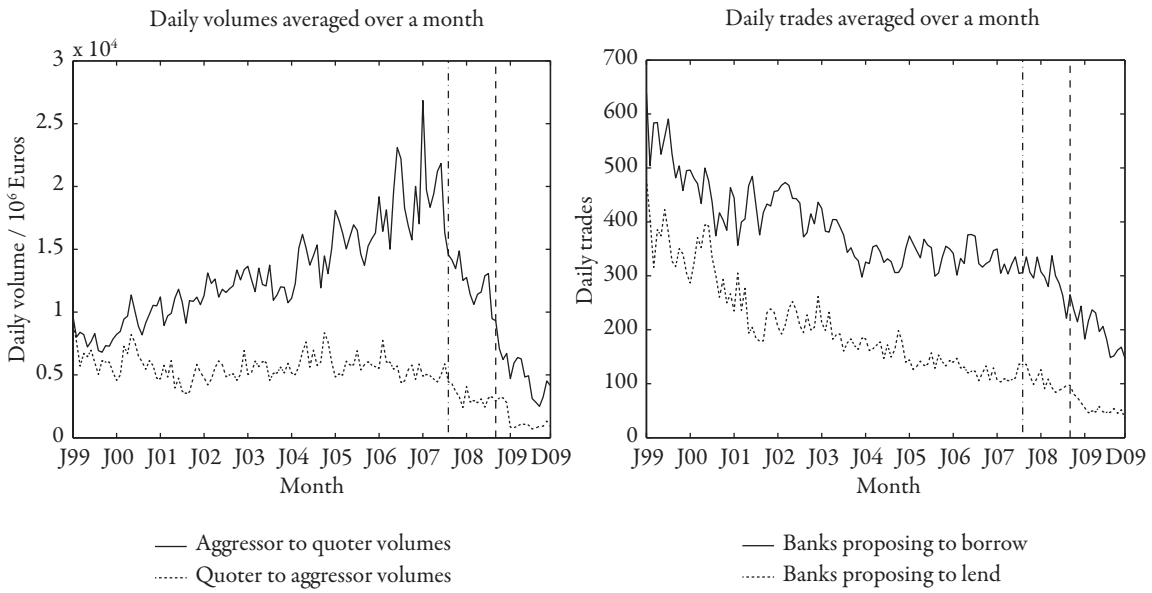

Figure 8: Left: monthly averages of daily volumes. Right: monthly averages of daily trades. In both cases trades have been separated into deals where the money went from the aggressor bank to the quoter («Sell» label, continuous lines) or the opposite («Buy» label, dashed lines).

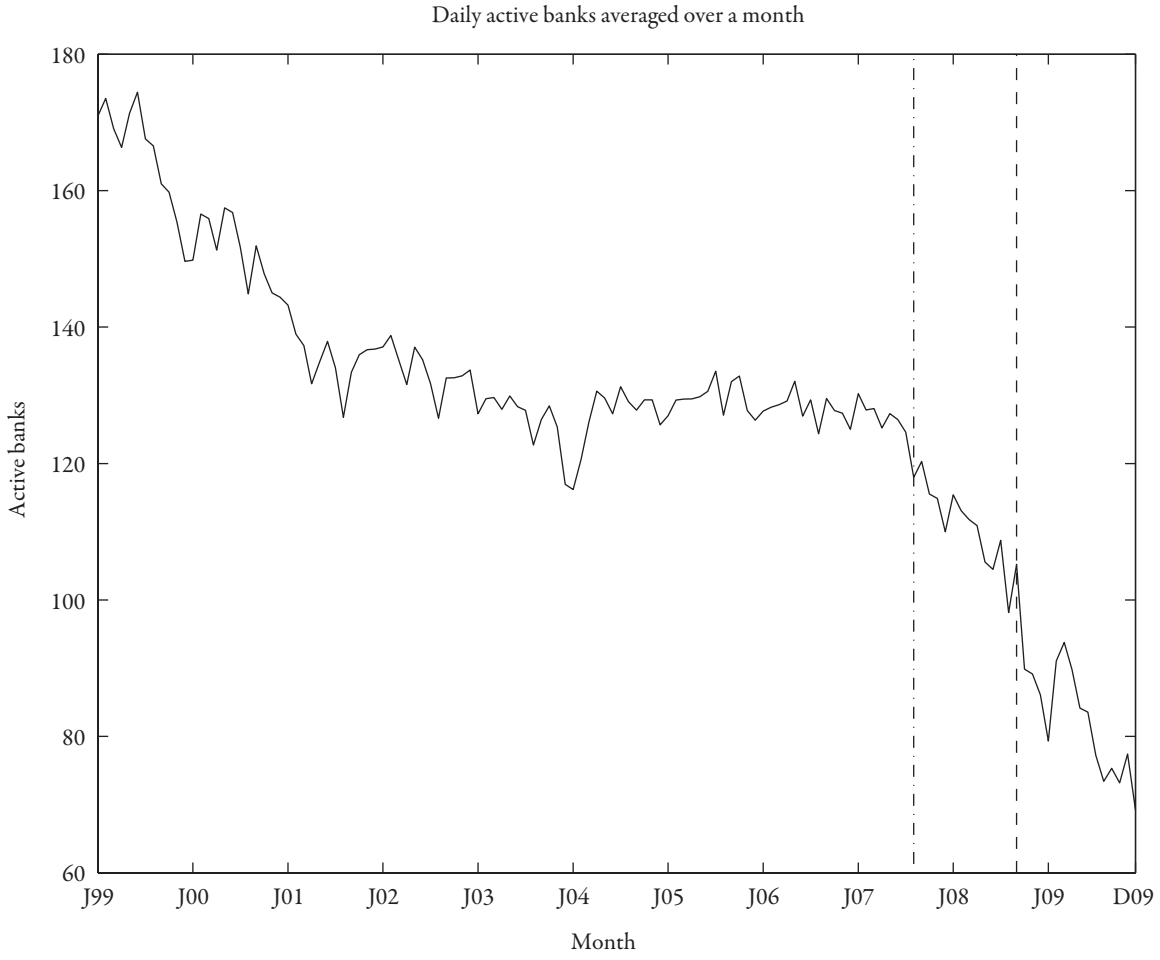

Figure 9: Monthly average of daily active banks. A bank is considered active if it takes part in at least one trade during a given day, irrespective of its side (as quoter or aggressor).

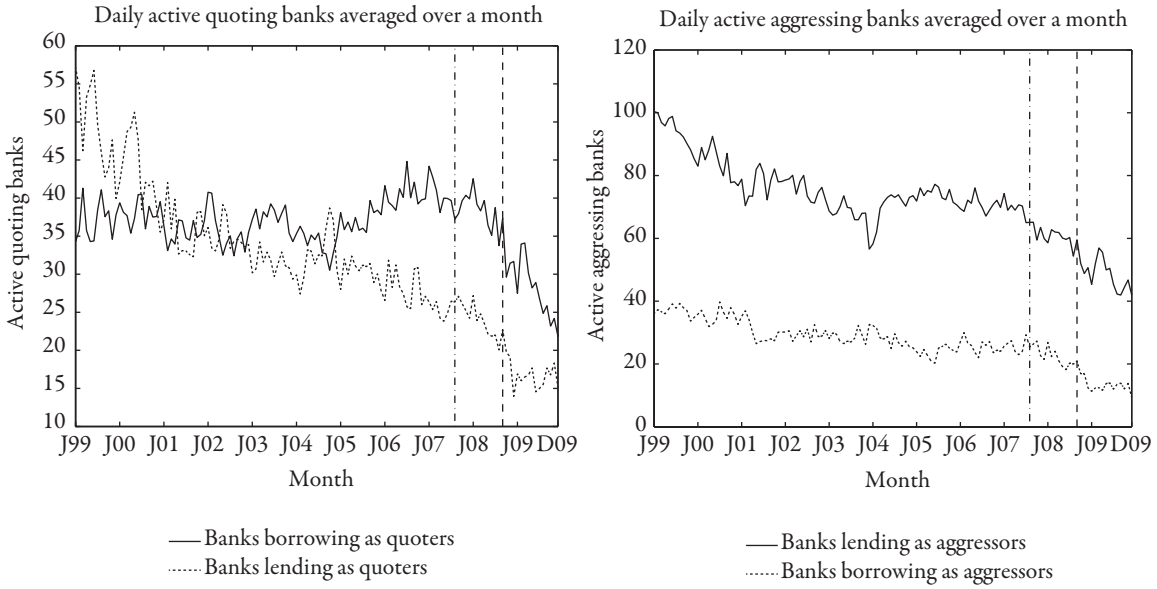

Figure 10: Left: monthly averages of the daily active banks acting as quoters. Right: monthly averages of daily active banks acting as aggressors. In both cases the trades have been divided respecting the «Sell» and «Buy» label in the records, indicating that the money flows from the aggressor to the quoter in the first case, and in the opposite direction in the second case.

6 Correlations Between Banks' Strategies and Rate Levels

In this section we would like to understand whether the banks act on the market regardless of the traded rate level or whether they take it into consideration. We restrict the analysis only to the transactions registered in the period 1999-2002 (1,020 days). This restriction is justified by the fact that we wish to discuss qualitatively the effect (or its absence) and by the nature of the statistics: for a reliable estimation we have to restrict the number of analyzed banks and use the period with the highest activity (by number of trades).

In the 1999-2009 period 269 different banks participated to the market operations, but most of them made very few transactions or participated only for a small number of days. We selected a subset of banks according to the same criteria of a previous analysis based on the same data set (Iori, Renò, De Masi and Caldarelli, 2007). Only the 86 banks that participated actively to the market for more than 900 days and with more than 1000 transactions are considered. According to the same criteria, Iori, Renò, De Masi and Caldarelli (2007) considered 85 banks.

The cumulative volume function represents the net presence in the market, i.e. the strategy of a given bank. Two variants of this function are presented and analysed here.

1. *The simple cumulative volumes*:

$$v_i^{\text{simp}}(t) = \sum_{j=1}^{N_i(t)} v_{ij}, \tag{10}$$

where $N_i(t)$ is the number of transactions performed by bank i up to time t and v_{ij} is the

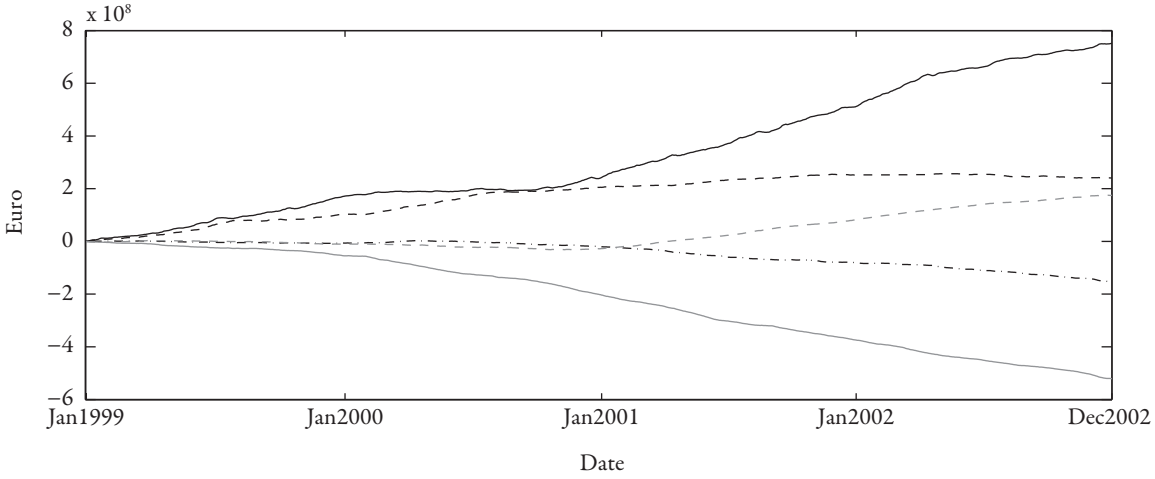

Figure 11: Examples of the simple cumulative volume functions for five banks.

(signed) volume lent or borrowed by bank i in its transaction j. Notice that the index j runs over the transactions of each single bank and not over the total number of transactions. To give the reader a qualitative idea of their behavior, Figure 11 reports a few random examples of the simple cumulative functions.

2. *The absolute cumulative volumes*:

$$v_i^{\mathrm{abs}}(t) = \sum_{j=1}^{N_i(t)} |v_{ij}|, \tag{11}$$

with $N_i(t)$ and v_{ij} defined as above.

We are interested in the correlation between the banks' strategies, measured through these functions, and the interest rates. When speaking about spread in the following we refer to the spread between the transaction rates and the EuroRPS rate.

6.1 Hayashi-Yoshida estimator

The Hayashi-Yoshida (HY) correlation estimator (Hayashi and Yoshida, 2005) for asynchronous data as those of high-frequency financial time series is defined as

$$p(v_i(t), s(t))_{\lambda_{\max}} = \frac{\sum_{h=1}^{H}(v_{ih} - \bar{v}_i)(s_h - \bar{s})}{\sqrt{\sum_{h=1}^{H}(v_{ih} - \bar{v}_i)^2}\sqrt{\sum_{h=1}^{H}(s_h - \bar{s})^2}}, \tag{12}$$

where H is the number of intervals of length $\lambda_{\max}$, v_{ih} is the increment of one of the cumulative volume functions defined above for bank i in time interval h, s_h is the mean value of the spread in time interval h, and $\bar{v}_i = \frac{1}{H}\sum_{h=1}^{H} v_{ih}$ and $\bar{s} = \frac{1}{H}\sum_{h=1}^{H} s_h$ are the sampled mean values of these quantities.

The HY method is a generalization of the classical Pearson estimator, consisting in how the elements v_{ih} and s_h are computed. If no events are registered in a specific bin $h > 1$, the values of v_{ih} and s_h are set equal to $v_{i(h-1)}$ and s_{h-1} respectively; if $h = 1$, their values are set equal to zero. The symbol $\lambda_{\max}$ for the bin width has been chosen to emphasize the connection between this estimator and the Fourier method explained in the following subsection.

6.2 Fourier estimator

A method introduced by Malliavin and Mancino (2002) uses the Fourier expansion of a time series. It is explained extensively in almost any paper that uses it, see for example Renò (2003), but it is worth to write it once more here in a different more compact way that brings us directly to a simple formula to compute the Fourier coefficients.

Rescaling the time by a factor $2\pi/T$ to the interval $[0, 2\pi]$, where T is the length of the time series, for our purpose we can define

$$c_k(v_i) = \int_0^{2\pi} \exp(ikt)\, dv_i(t) \tag{13}$$

where $v_i(t)$ is one of the cumulative volume functions defined above. From the definition of $v_i(t)$ it is possible to write

$$c_k(v_i) = \int_0^{2\pi} \exp(ikt)\, d\left(\sum_{j=0}^{N_i(t)} v_{ij}\right), \tag{14}$$

where the explicit case of the simple cumulative volume function has been taken as example. Continuing with the manipulation in order to obtain a simple tool for the estimation, we note that $d\left(\sum_{j=0}^{N_i(t)} v_{ij}\right) = \sum_{j=0}^{N_i(t)} v_{ij}\delta(t - t_{ij})$, where t_{ij} is the time of transaction j of bank i, and finally we obtain

$$c_k(v_i) = \sum_{j=0}^{N_i(t)} \exp(ikt_{ij})\, v_{ij}. \tag{15}$$

Usually these coefficients are reported as the coefficients of the cosine and sine transforms, $a_k(v_i)$ and $b_k(v_i)$, respectively, i.e. the real and imaginary parts of $c_k(v_i)$,

$$a_k(v_i) = \mathrm{Re}\, c_k(v_i), \qquad b_k(v_i) = \mathrm{Im}\, c_k(v_i). \tag{16}$$

The real parts of the Fourier coefficients of the covariance matrix elements Σ^2_{is} of the cumulative volume function $w_i(t)$ and the spread $s(t)$ can be obtained as

$$a_k(\Sigma^2_{is}) = \lim_{k_{\max}\to\infty} \frac{\pi}{2k_{\max}} \sum_{j=1}^{k_{\max}} \left[a_j(v_i)a_{j+k}(s) + a_j(s)a_{j+k}(v_i)\right]. \tag{17}$$

The elements σ^2_{is} of the integrated covariance matrix of the two time series can then be obtained as

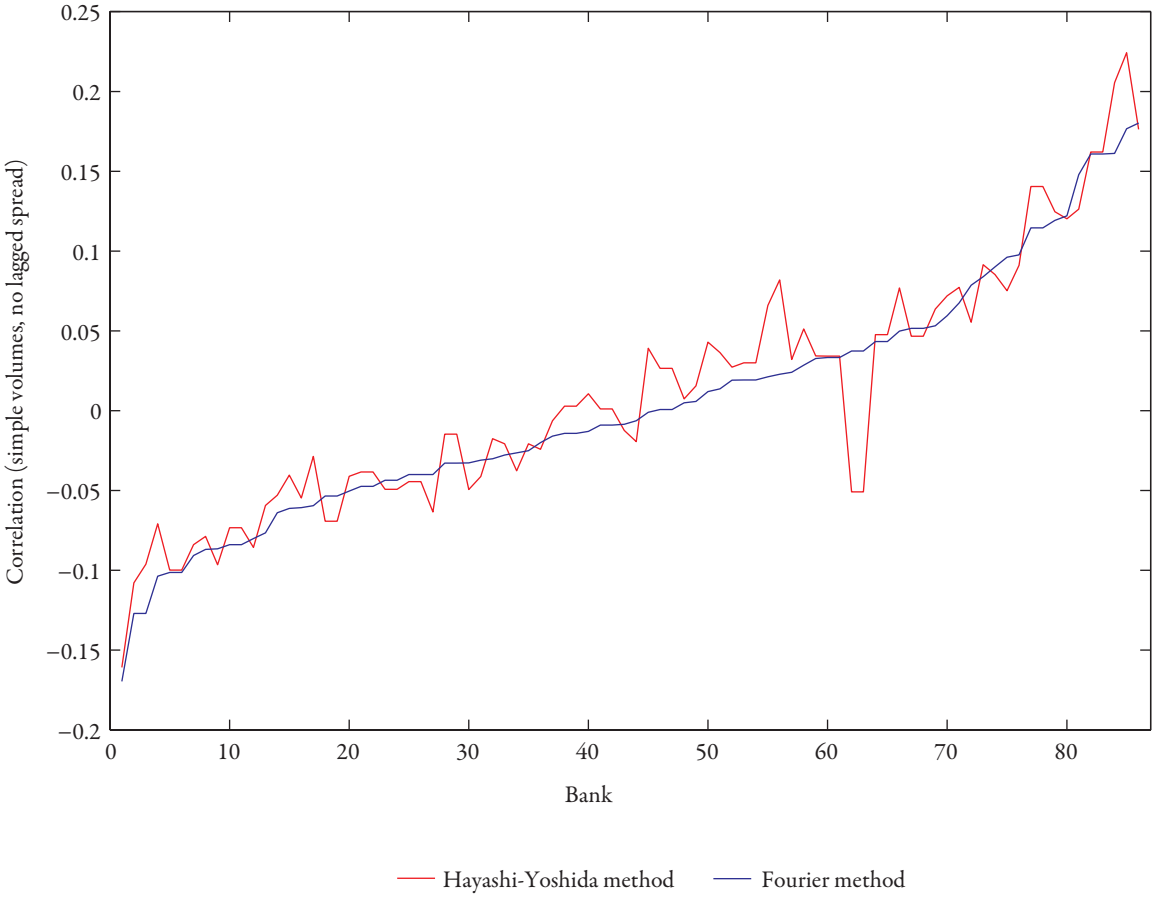

Figure 12: Correlation of the simple cumulative volumes $v_i^{\text{simp}}(t)$ with the spread $s(t)$ using the Hayashi-Yoshida (red line) and Fourier (blue line) methods. The banks are ordered by the value of the correlation given by the Fourier method. Apart from the different noisiness, which is lower in the Fourier case, the two methods are consistent, giving similar results and thus validating each other.

$$\sigma_{is}^2 = 2\pi a_0(\Sigma_{is}^2). \tag{18}$$

Finally, the correlation is

$$\rho(v_i(t), s(t))_{\lambda_{\max}} \equiv \rho_{is} = \frac{\sigma_{is}^2}{\sigma_{ii}\sigma_{ss}}. \tag{19}$$

In each application, $k_{\max}$ is finite and defines the time scale $\lambda_{\max} = T/(2k_{\max})$ at which the correlation is observed. Notice the correspondence between this value and the bin width in the definition of the HY estimator.

6.3 Results

One of our main aims is the analysis of the correlation $\rho(v_i(t), s(t + k\Delta t))$ between the cumulative volume functions previously defined and the past, present or future spreads, for an integer k and some time interval Δt. We fixed Δt and $\lambda_{\max}$ to half a day, i.e. $1/(2 \times 1{,}020)$ of the whole analyzed interval, for both estimation methods, which are

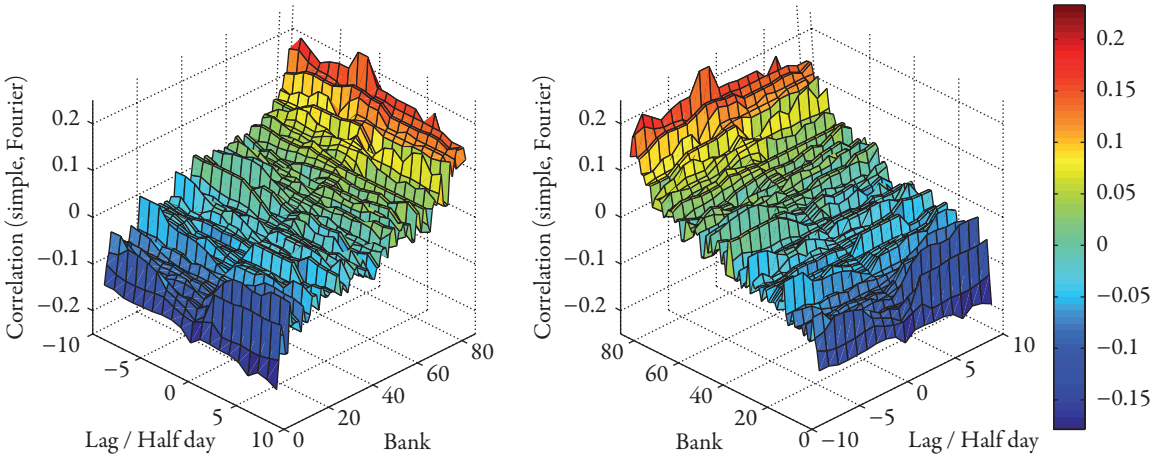

Figure 13: Correlation of the simple cumulative volumes $v_i^{\text{simp}}(t)$ with the lagged spreads $s(t + k\Delta t)$ using the Fourier method. The banks are ordered by the value of the correlation at zero lag.

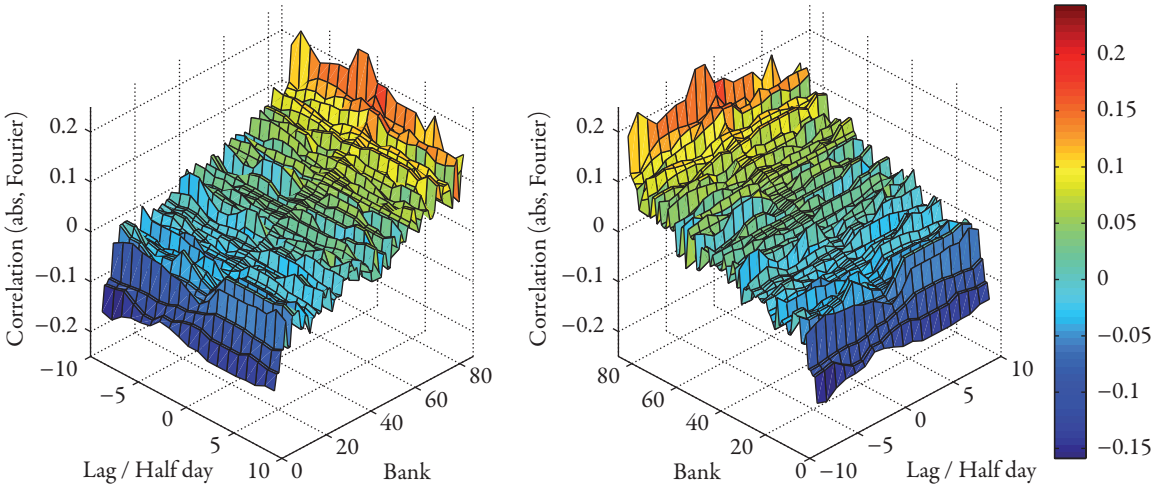

Figure 14: Correlation of the absolute cumulative volumes $v_i^{\text{abs}}(t)$ with the lagged spreads $s(t + k\Delta t)$ using the Fourier method. The banks are ordered by the value of the correlation at zero lag.

compared in Figure 12 using the simple volumes and $k = 0$. A different choice of these parameters does not change the qualitative behavior of the results, which are shown in Figures 13 and 14, where only the Fourier method is used.

Figure 15 shows the variance of the distributions of the considered correlations versus the lag. For both $v_i^{\text{simp}}(t)$ and $v_i^{\text{abs}}(t)$ the variance has a maximum at zero lag and decreases for both positive and negative lags, i.e. for both future and past spreads, without showing substantial difference in the two directions.

7 Bank's Cost of Money

It is interesting to study whether some banks are able to borrow money for a lower rate than others and which market microstructure factors may explain this phenomenon. To do so, we consider the two weighted sums

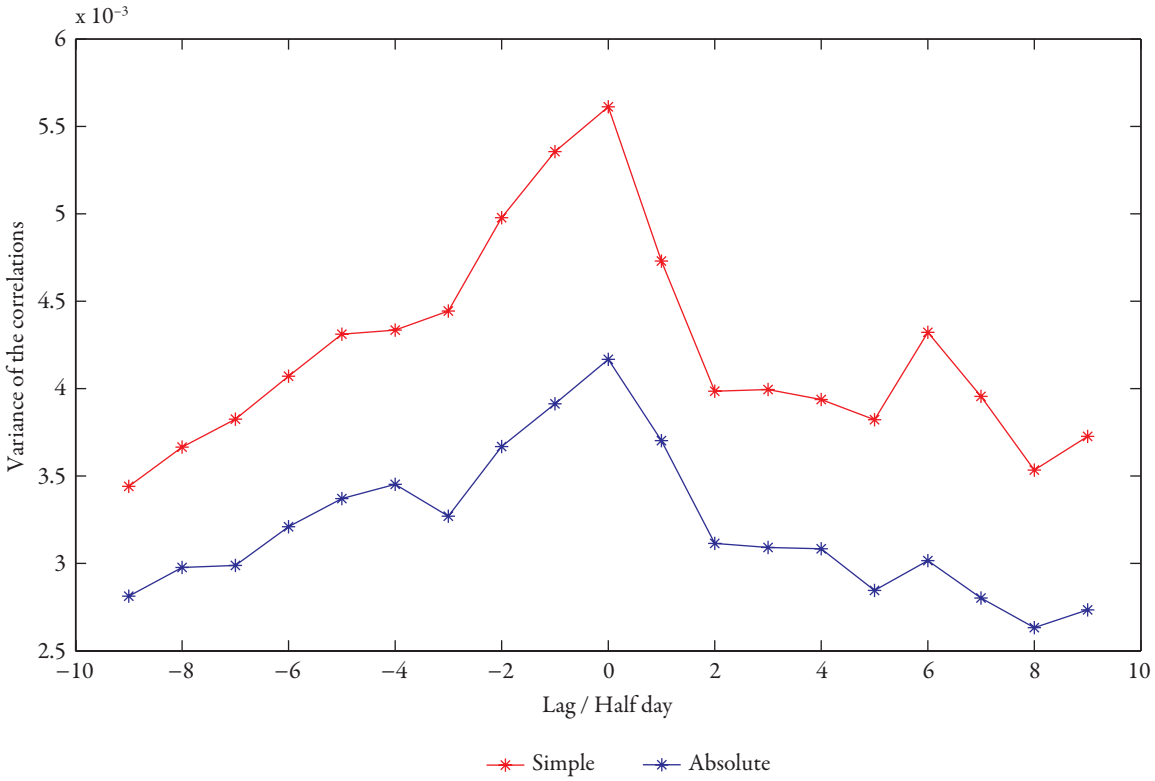

Figure 15: Variance of the correlation values depending on the time lag. Each single value, i.e. each considered bank, is one point in the population.

$$c_i^{\pm} = \frac{\sum_j v_{ij}^{\pm}(w_j - \bar{w}_j)}{\sum_j v_{ij}^{\pm}}, \tag{20}$$

where $v_{ij}^{\pm}$ are the lent (+) or borrowed (−) simple volumes, see Eq. (10), and w_j is the relative spread of transaction j, see Eq. (4). The mean relative spread $\bar{w}_j$ uses a 30 minutes window. As before, i labels the different banks. Here the interesting quantity is the difference d_i between these two weighted sums,

$$d_i = c_i^{+} - c_i^{-}. \tag{21}$$

The results are summarized in Figure 16, which shows that some banks are able to obtain substantially better rates, while others obtain substantially worse rates. This may be due to:

- *Risk rank of the firm*: each bank is implicitly ranked by its probability of default; other firms ask a higher price (rate) when lending money to a risky firm, and a lower price when lending to a safer firm.
- *Trading team skill*: some banks could have invested more resources in their trading teams in this market, and this may improve their capability to obtain better rates.
- *Taking prevalently one side of the trade*: we observed in Sec. 4.3 that acting as quoter instead of aggressor brings the advantage of gaining on the bid-ask spread, in the same fashion as in a stock market. If a firm is more capable to fulfill its needs as quoter it automatically gains better rates.

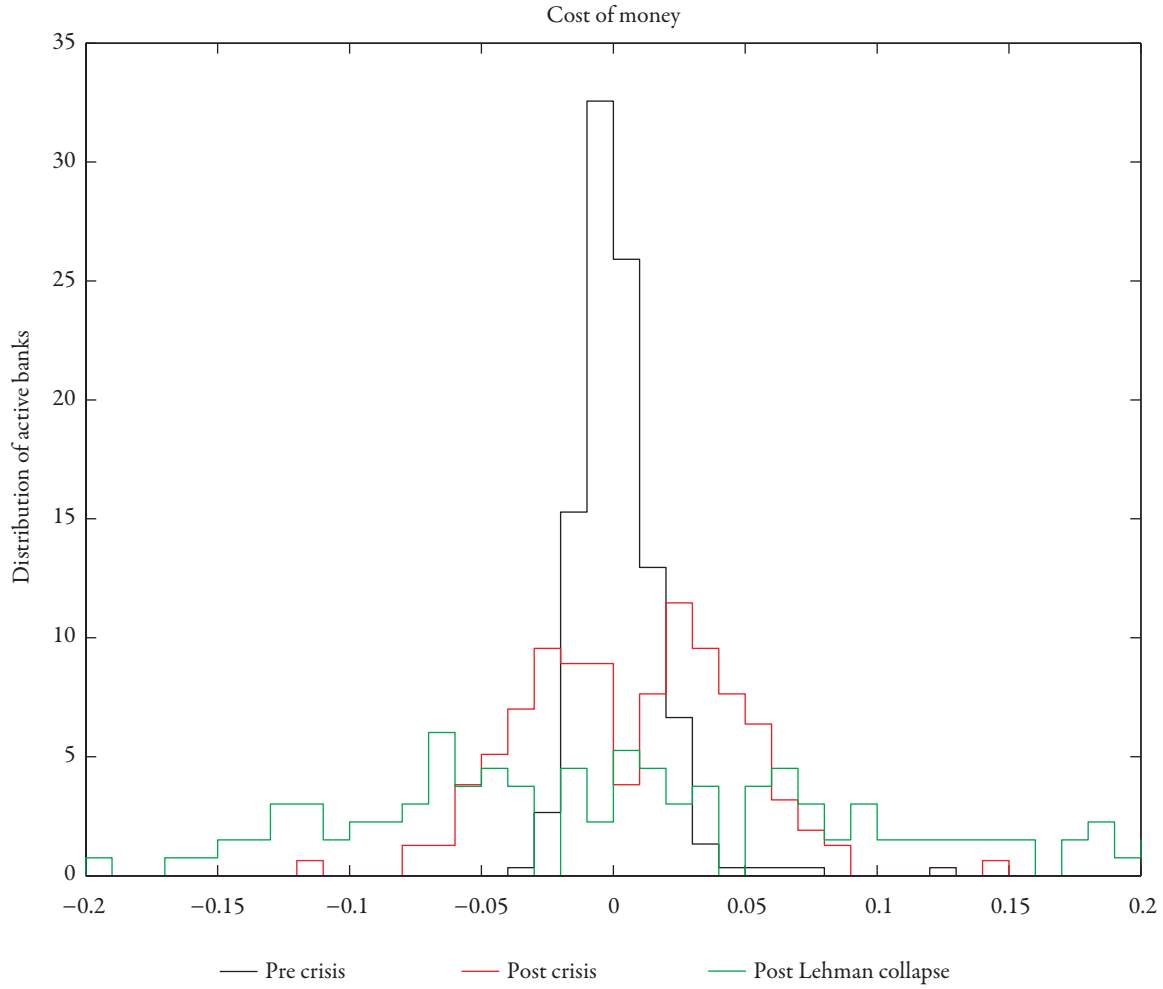

Figure 16: Weighted differences d_i between the lent and borrowed volumes, see Eqs. (14) and (15) in Sec. 7.

• *Business opportunities during the day*: some banks could have better business opportunities than others during the day, so they accept to pay a higher rate in order to quickly access funds to invest in these opportunities.

Calling q_i and a_i the number of times the bank i concluded a trade respectively as quoter or aggressor and defining the difference

$$u_i = a_i - q_i \tag{22}$$

we can compute the magnitude of its linear dependence on d_i. If this measure is sensibly different in the three periods we can infer that trading prevalently as a quoter gave more advantages during the crisis periods, explaining at least partially the different shapes of Figure 16. Table 3 reports three measures of linear dependence and no clear pattern is recognisable. We understand that acting as a quoter is indeed connected with advantages, but their magnitude did not change between the pre-crisis and the crisis periods.

However, we can add another piece of information exploiting the label attached to each bank code, as shown in Sec. 3. The label can take six different values, five to indicate

Table 3: Measures of linear dependence of u_i as defined in Eq. (22) on d_i as defined in Eq. (21). No difference among the periods can be isolated clearly, suggesting that acting prevalently as a quoter yielded similar results before and during the crisis.

	Pre crisis	Post crisis	Post Lehman collapse
Pearson	−0.2166	−0.4302	−0.3622
Kendall	−0.3578	−0.3396	−0.3363
Spearman	−0.5015	−0.4778	−0.4895

Table 4: Mean cost of money for each bank group during the three analyzed periods: the turmoil affected mostly the performance of major/large banks (negatively) and of non Italian banks (positively).

	Pre crisis	Post crisis	Post Lehman collapse
Major	−0.0039	−0.0310	−0.0404
Large	−0.0023	−0.0398	0.0124
Medium	0.0001	0.0099	0.0047
Small	0.0161	0.0305	0.0232
Minor	0.0070	0.0074	0.0092
Non Italian	0.0051	0.0166	0.0347

the bank size by total assets according to the classification scheme of the Bank of Italy («MA» for «maggiori» i.e. major, «GR» for «grandi» i.e. large, «ME» for «medie» i.e. medium, «PI» for «piccole» i.e. small, «MI» for «minori» i.e. minor) and «FB» for «foreign bank» when the bank is not Italian. Table 4 gives the mean banks' cost of money for these six classes in the three periods. The main effects we can observe are a loss of performance of major/large banks and an increase of performance of non Italian banks.

8 Discussion and Conclusion

The e-MID electronic overnight interbank market is an example of order-driven market; its features are built with the purpose of making the operators able to choose their counterparties and protect their identity. We have shown a collapse of the traded volumes during the crisis, which is a probable indication of a more risk-adverse behavior: the firms prefer to negotiate their overnight positions on a one-to-one basis rather than in a disclosed market. We computed the intraday structure of the negotiated rates reflecting the effective length of the contracts. The spreads between the mean rates and the ECB key rates behave in a very different manner after the Lehman Brothers collapse. In the same fashion as in a stock market we can see an increase of the rate volatility. Moreover, we have used a bid-ask spread as a good proxy of the market liquidity. The absence of significant correlations between rates and banks' strategies suggest that the institutions use the interbank market considering mainly external factors, i.e. their trading activities is not highly conditioned by the rate level. Finally, we have shown that some banks are able to obtain substantially better prices when acting on the market and that the magnitude of this diversity strongly increases during the crisis. This advantage may be the result of more advanced trading techniques or, more interestingly, may reflect the different unofficial trust levels of the institutions.

9 Acknowledgements

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