Banks' strategies and cost of money: Effects of the financial crisis on the European electronic overnight interbank market

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 peculiar 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.

I. 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 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 very distinct features [1]: (i) the information on the majority of trades is not centralized; (ii) the market is highly concentrated [2]; (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 having recourse to the central bank facilities; (vi) some market participants are systematically provide liquidity and others systematically demand for liquidity; (vii) large banks typically borrow from a number of smaller creditors [3]. The interbank market can be managed in different ways: physically on the floor, by telephone calls, 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 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 interbank lending 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 systemically until the beginning of the financial crisis, with an average of 450 transactions each day and an 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 [4]. This trend has increased the value of intraday liquidity. Interbank deposits as a percentage of total assets of the banking system increased from 8% (1993) to approximately 16% (2007) [2]. Formally, e-MID is an order driven markets, providing full information regarding their order book and allowing the participants to directly act on it. In such kind of market no participant has a special status when interacting with the book; the specialists survive because of the need of injecting liquidity for some products which trading would be otherwise very penalized. But, in general, other participants can mimic the behaviour of a specialist if they find it appropriate and no rules would be against this operations, at least on the pure mechanism level. On the other hand, there are what are usually called quote driven markets, where dealers aggregate the quotes continuously giving the market best bid-ask level. In general, the participants cannot act as specialists and all trades are filtered by the dealers. Therefore, the e-MID can be seen as a pure order driven market: full access to the open book, no privileged participants and no intermediary between a market order and the book, i.e. full direct interaction. On the eMid, 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 counter party risk and each institution must apply its own criteria in selecting their trading partners. This market is indeed quote driven, but its mechanism contains some peculiarities that make appropriate the adjective "exotic". Those are mainly given by the different necessities a market of capitals presents in comparison with security markets. For example, in futures markets participants are asked to deposit a margin in order to cover partially their counterpart risk. Until the 2007 financial crisis, and above all 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 volume 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, they incentivised the creation of collateralized interbank markets, to increase the expected recovery rate and to ensure complete anonymity of trades. Central banks' responsibility is to evaluate the collateral 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 default by a participant, subsequently recovering the amount from the collateral deposited. 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, depending on their default probability and reputation as well. This outcome will prove the need for a collateralized and anonymous segment of the market, with a direct role of central banks as guarantor. 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 with a intra-day look. Section 5 addresses the analysis to volumes, and section 6 focuses the analysis to correlations between strategies, size 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 has the conclusions.

II. MARKET MECHANISM

During the period we analyse, the market starts to present its exotic structure just from the absence of classical opening and closure auctions: the trades take place only during a unique continuous trading period. A session of post-trading activity is aimed at clearing and controlling trades, but it does not affect the market dynamics.

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. As in a stock market the book is filled by both requests of lending and borrowing capitals but, here, no *aggregation* is performed. The term aggregation is referred to the set of rules determining the priorities respected during trading operations. In a stock market a marketable order is executed against the more price convenient pending orders first, and, in second instance, against orders pending for longer time. E-MID does not implement any of those kind of rules. This means that an aggressor, defined as an operator who is taking away liquidity from the book, does not have to respect any priority and, furthermore, no automatic trades are placed when orders in the book overlap. In Fig. 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-axes for the proposed rate. The black solid blocks are those posted into the anonymous section of the market. The left part of Fig. 1 shows the possible order overlap. In a usual stock-like market, where an overlapping limit order is immediately executed, this would not be possible. Furthermore, in a security market, the book aggregation is a build in feature of the mechanism but here it is reported only for comparison purposes.

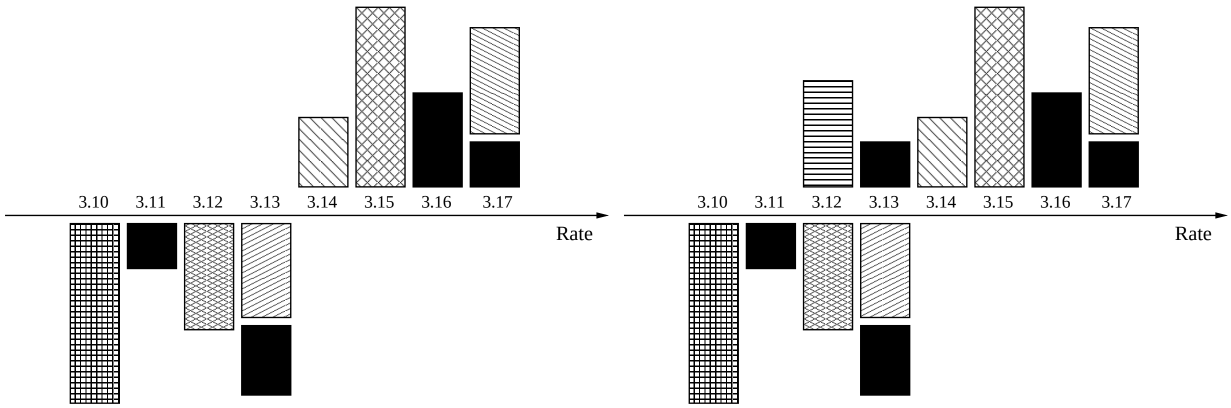

FIG. 1. Scheme of a virtual aggregation of the order book. Different textures stand for different institutions, the height for the proposed volumes and the position on the x-axes for the proposed rate. The black solid blocks are those posted into the anonymous section of the market. On the left we highlight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

Specifically, the market operators act:

- **Quotes.** As in a security market, participants send their quotes as proposal but, as mentioned, without aggregation.

- **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 pick a quote and manifest its willing to close the trade. This choice is completely done by the operator itself; he can choose the quantity, rate and counterpart he prefers, regardless of the book status.

- **Acceptance.** The quoter of an ask quote, i.e. a quoter willing to lend capital, has the options to reject an aggression. This major difference from the security market gives the participant the opportunity to choose their counterpart and reduce the credit risk.

- **Proposal.** An aggressor can subordinate her willing to close a trade to some specific requests, such as a larger or smaller volume or a different rate.

The operator posting anonymously a quote (direct order) is disclosed only by another operator aggressing the pending quote. In this case the aggressing operator has the additional option of not closing a trade after knowing the counter party. A number of rules seldom observed in security markets applies e-MID. For example, when a bid quote (operator asking for capital) is aggressed is automatically executed, but an operator can ask for the options to accept even this kind of trades and not only his ask quotes. Other less relevant rules apply for the partial execution of orders or for the cancellation and modification of quotes.

III. DATA SET

In order to clarify which information is in our hands, we describe more precisely the contents of our database. The data base 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' behaviour 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. The parts are public regardless the market section used to negotiate the transaction (transparent or anonymous); i.e. the parts are disclosed after a trade take place, even if the negotiations started from an anonymous order. The rate the lending bank will receive is expressed per year; 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/day is present between two consecutive business day. The banks are reported together with a code representing their country and a final label that indicates the class of capitalization (large, medium, small) only when the bank is Italian. A couple of example records are reported in Table I.

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 a result of some specific *proposals* (see Sec. I) 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 acting on the market. Various past studies investigated similar [5] or the same data [3, 6–10], although not always for the same length of time. In one case the whole book information was studied [11].

Market	Duration	Date	Time	Rate	Amount	StartDate
"EUR"	"ONL"	"2007-01-02"	"8:52:41"	3.60	160.00000	"2007-01-02"
"EUR"	"ON"	"2007-01-02"	"8:52:54"	3.60	50.00000	"2007-01-02"

EndDate	Quoter	GroupQuoter	Aggressor	GroupAggressor	Verb
"2007-01-03"	"IT0276"	"ME"	"IT0271"	"GR"	"Sell"
"2007-01-03"	"IT0162"	"PI"	"GR0006"	"ND"	"Sell"

TABLE I. Two example records from the data set. Quoter and aggressor are the banks participating to the trade. The groups are the classification of Italian bank regarding 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.

IV. RATE AND SPREADS

For each transaction i the symbols v_i and r_i indicate, respectively, the exchanged volumes and the rate of the transaction. As first step we classically compute the mean rate registered in each analyzed trading day as

$$\bar{r}^d = \frac{1}{N_d} \sum_{i=1}^{N_d} r_i$$

where N_d is the number of transactions in the day d. The results are reported in Fig. 2. As test we even have computed the weighted daily mean rate considering the volumes of each transaction, i.e.

$$\bar{r}^d_w = \frac{\sum_{i=1}^{N_d} r_i v_i}{\sum_i^{N_d} v_i}.$$

The results of this second estimation are extremely closed to the previous and no picture is reported. Together with the daily mean rate, Fig. 2 (bottom) reports the ECB key rates for the considered period. The ECB defines the rates as follows [12]:

- **Marginal lending facility rate (EuroMLR):** the rate fixed by the ECB for operation 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)** are 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.

Calling k_M^d, k_R^d and k_D^d the EuroMLR, EuroRPS and EuroDEP respectively (in the day d), the mean daily spreads are computed again starting from the rates r_i as

$$\bar{s}_H^d = \frac{1}{N_d} \sum_{i=1}^{N_d} (r_i - k_H^d) \tag{1}$$

where the subscript H is a general label for M, D or R. Fig. 3 shows the results of this computation (top) together with the relative mean daily spread (bottom) defined as

$$\bar{s}_H^d / k_H^d. \tag{2}$$

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

Observing the spreads it is clearly possible to isolate two different regime. The behavior in the period preceding the Lehman Brothers collapse each spread oscillates around a somehow stable value, and in the subsequent period the spreads start to oscillate much more heavily at levels much lower than usual. More specifically, after Sep. 2008 $\bar{s}_M$ assumes consistently negative values, not respecting anymore the usual ceiling level roughly defined by the EuroMLR rate itself. In fact, the way the official rate corridor is designed – all the rates are compared with the official refinancing rate – makes physiological that EuroDEP spread is positive around 1%, the EuroRPS spread negative around -1%, and the EuroMLR spread around 0%. The rationale of these values for spreads is that all the interbank rate should always remain higher (or equal) than the best borrowing rate of the central bank (EuroMLR) 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 for credit.

What Fig. 3 (left) shows is that before the financial crisis the expected values were confirmed, and before the Lehman bankruptcy, too. What really shocked the rate structure was the US investment bank collapse, when all the spread declined of about 1%. Until the end of 2009, as shown in Fig. 3, borrowing money in the interbank market did cost significantly less than refinancing from the central bank. The phenomenon lasted in 2010 as well.

This evidence shows that the European Central Bank did not cut its official rates as much as other monetary authorities (Federal Reserve above all) but did tolerate interbank rates to fall below the main refinancing rate. The huge amount of liquidity injected by the Central bank during the crisis affected so far the interest rate level.

The period between the subprime shock and Lehman collapse, when official interest rate did not significantly change, shows a good relative spread control (Fig. 3 (right), Eq. (2)), while the subsequent cut of official rates generated an exceptional increase of the opportunity cost to lend money with interbank deposits instead of put money in deposit facilities.

A. Intraday price of money

Similarly to a previous study [4], we consider the annual average of s_H, the spread against the EuroMLR, as a function of the intraday time. More precisely, for each day d we compute the instantaneous mean value $\bar{s}_d(t)$ considering the trades performed in the 30 minutes before and after t. We then averaged these quantities over all trading days (within every single year). The results are reported in Fig. 5.Our outcomes reflect the immediate liquidation of the trades. Since all overnight deposit must be regulated the subsequent business day at

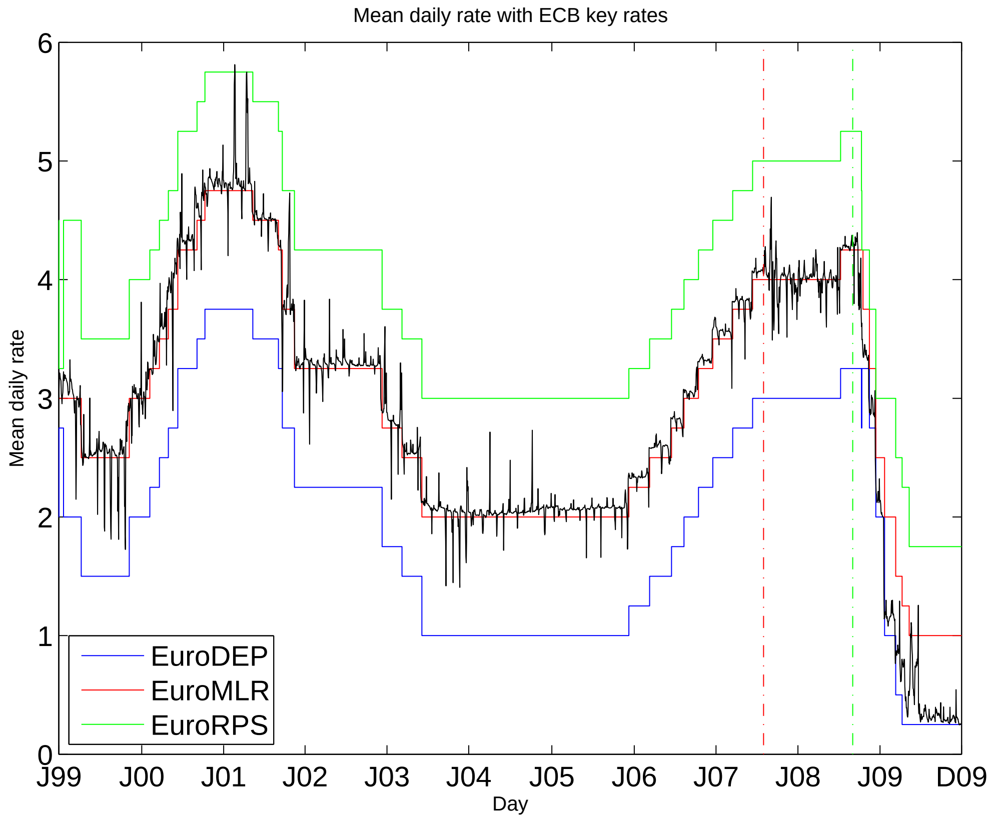

FIG. 2. Left: mean daily rate. Right: the mean daily rate is plotted together with the ECB key rates. The first vertical line marks the subprime crisis of August 2007 and the second the collapse of Lehman Brothers of September 2008.

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 use of interest rate differentials from the daily average, we compute the spread with the refinancing rate (EuroMLR) in order to insulate intraday patterns of the banks convenience to borrow money within the interbank market. For all the years considered (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 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 (Fig. 4). The spread exceeds the maximum value of 0,02 and in 2009 raises at 0,045. The phenomenon is explained by the extraordinary liquidity need of European banks during the

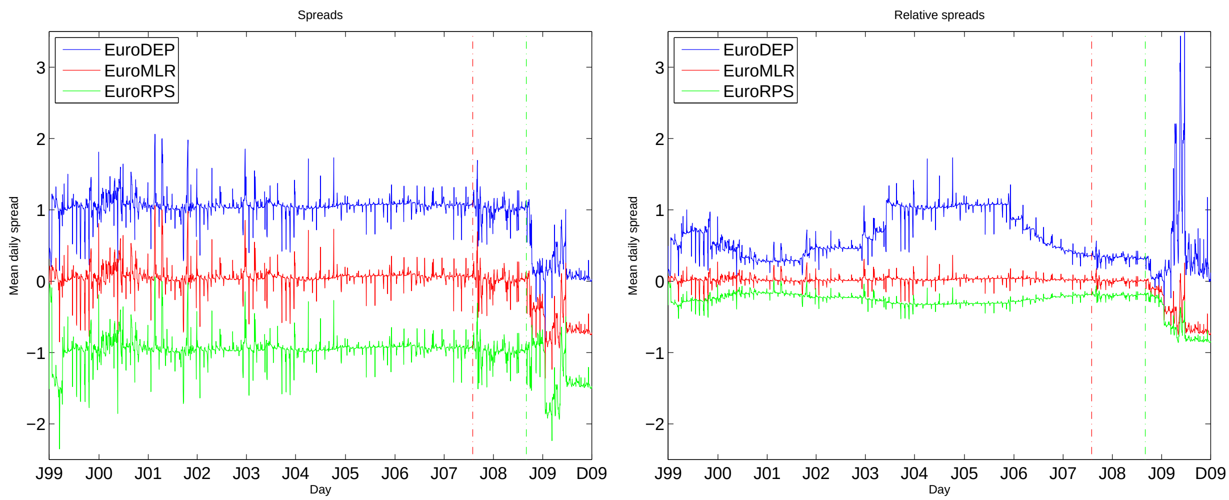

FIG. 3. 1). Left: raw spreads. Right: relative spread (Eq. 2). It is clearly possible to isolate two different behavior; one for the long period before the Lehman collapse, and one for the subsequent period.

crisis.

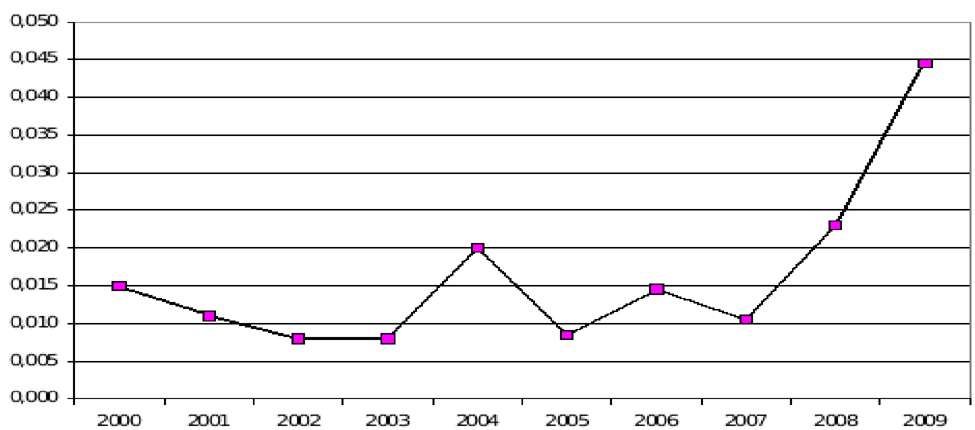

FIG. 4. Mean spread range (max-min of Fig. 5) from 2000 to 2009.

Furthermore, we observe a more regular shape during the crisis years (from 2007 to 2009). This arises a question: why should banks pay high interest rates early in the morning instead of waiting for an overnight 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 during 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 [13], 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.

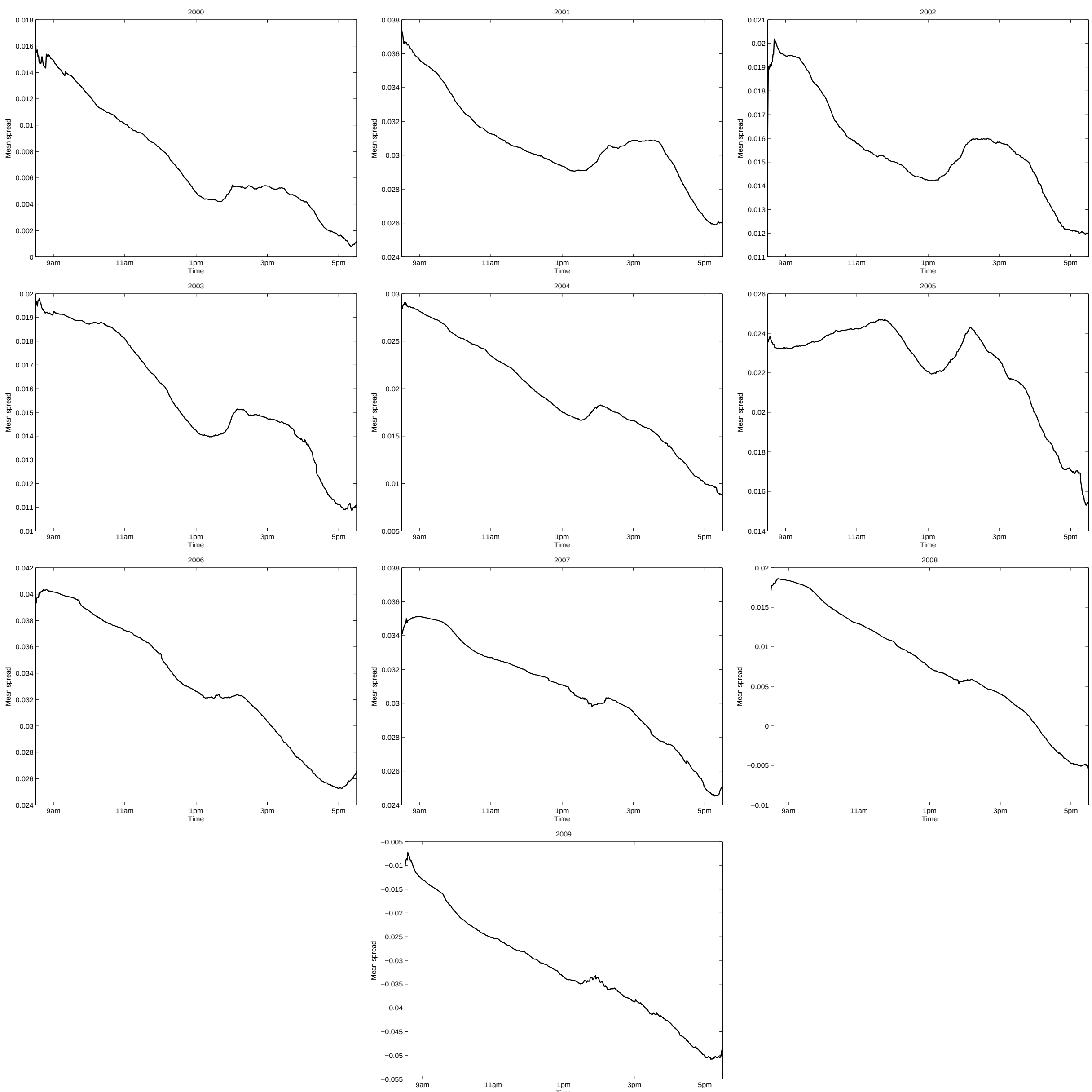

FIG. 5. $\bar{s}(t)$ as a function of the time of the day averaged over all trading days in each year with a time window of $t \pm 30$ minutes.

B. Interest rate volatility

The intra day rate pattern shows an increasing volatility during the crisis. The daily rate volatility σ^d for the is computed classically as

$$\sigma^d = \sqrt{\frac{1}{N_d - 1}\sum_{i=1}^{N_d}(r_i - \bar{r}^d)^2}$$

and its monthly average is reported in Fig. 6 (top) together with its normalized value $\sigma^d/\bar{r}^d$ (bottom). Fig. 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 (Fig. 6 left) how the monthly volatility coefficient did restore to pre crisis levels in 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 within a month (Fig. 6). Here, the volatility continuously rises from 2 to 24 per cent.

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

$$\chi_{\mathrm{MD}} = \alpha + \beta\chi_{\mathrm{OS}} + \gamma\Sigma_{\mathrm{dep}} + \theta\Sigma_{\mathrm{lend}} \tag{3}$$

corrected with autoregressive variables (one lagged period) and an error correction model factor, where:

- χ_{MD} is the standard deviation of 1 month deposit log returns;
- χ_{OS} is the standard deviation of overnight swap log returns;
- Σ_{dep} is the amount of bank liquidity deposited in EBC (million Euros);
- Σ_{lend} is the amount of bank liquidity borrowed from EBC (million Euros).

The hypothesis behind the relation between volatility and volumes are that rate volatility should be negatively correlated with the amount of deposit facilities.

Results are shown in Tab. II.

Dependent variable	Pre subprime	Post subprime	Post Lehman
χ_{MD}	02/01/2005	09/08/2007	12/09/2009
	08/08/2007	12/09/2008	26/07/2010
	Coefficient	Coefficient	Coefficient
Constant	1.24ì0^{-6}	$-$7.88ì0^{-5}	$-$3.67ì0^{-5}
χ_{OS}	0.301514**	0.104724	0.018339*
Σ_{lend}	3.73ì0^{-9}**	7.12ì0^{-9}***	7.06ì0^{-7}***
Σ_{dep}	$-$7.13ì0^{-9}**	8.12ì0^{-7}***	$-$2.32ì0^{-9}***
$\chi_{\mathrm{MD}}(-1)$	0.074614**	0.035887***	0.293388***
$\chi_{\mathrm{OS}}(-1)$	0.460955***	0.072291***	0.169428***
$\Sigma_{\mathrm{lend}}(-1)$	5.75E-09	1.20E-08***	1.25E-07***
$\Sigma_{\mathrm{dep}}(-1)$	-4.61E-09	2.56E-07*	-1.73E-09*
ErrorCM(-1)	-0.032949***	-0.037971***	-0.046397***
Adjusted R^2	0.712308	0.519221	0.545169
D-W statistics	2.241081	1.998579	1.867629
Prob (F-stat)	0.000000	0.000000	0.000000

TABLE II. One month interest rate volatility model by ECB lending and deposit facilities. Heteroschedasticity robust standard errors are reported in brackets. * means significantly different from zero at 10% level (two-tail t-test), ** at the 5% level, and *** at the 1% level. ErrorCM stands for Error Correction Model and D-W for Durbin-Watson.

Our findings show that the expected correlation are confirmed before the subprime crisis and after Lehman collapse, while in between deposit facilities and rate volatility changes, indicating the failure of policy makers to manage the interbank interest rate volatility. The power was restored after Lehman bankruptcy, when not only central banks but also US and European Governments did intervene to support banks credibility, collateralizing bond issues and interbank deposits to enhance the banking system trustworthiness.

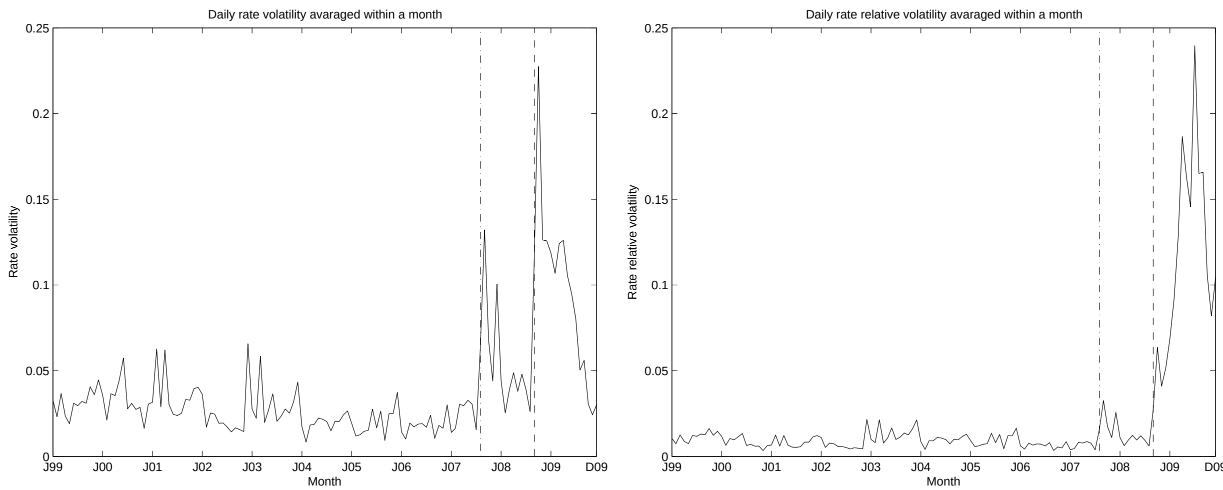

FIG. 6. Left: Daily rate volatility averaged within a month. Right: Daily normalized volatility averaged within a month. At the left two well defined peaks are present in the months following the two crisis milestones.

C. 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 [14–17], the price impact of trades [18], and volume or turnover ratio [19, 20]. Cherubini [21] 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 [22–26]. This approach is coherent with the examination procedures listed by the Federal Reserve even before the financial crisis (1998), and 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 estimate of the bid-ask spread during helps to find out the liquidity pressure during the crisis. Therefore, for each day we separate the transactions labeled as Sell from those labeled as Buy and we consider the corresponding rates. The mean values $\bar{r}_s$ and $\bar{r}_{bs}$ are then defined as

$$\bar{r}_s^d = \frac{\sum_{i=1}^{N_{sd}} r_{si} v_{si}}{\sum_{i=1}^{N_{sd}} v_{si}}$$

$$\bar{r}_b^d = \frac{\sum_{i=1}^{N_{bd}} r_{bi} v_{bi}}{\sum_{i=1}^{N_{sd}} v_{bi}}$$

where N_{sd} and N_{bd} are the number of the Sell and Buy transactions in the day d.

The *bid-ask spread* (or *sell-buy spread*) can now be easily computed as $s^d_{ba} = \bar{r}^d_b - \bar{r}^d_s$. The labels Sell or Buy of Fig. 7 indicate that the quoter bank is borrowing and the aggressor is lending in the first case, and the opposite in the second case. Fig. 7 shows its monthly average. The first non trivial conclusion we can extrapolate from the plot is the presence of this spread. The market is in fact different than the usual order book-like market we are used to. Moreover, two well defined peaks are clearly present after the crisis milestones. Their presence are a clear proxy of the diffidence the banks had during the worst moments of the crisis. Moreover, during the crisis some bid-ask spreads experience values higher than 200 basis points, when the usual pre-crisis level was around 3 basis points. Paradoxically, the liquidity stress seems to be absorbed just before the Lehman collapse, when the bid-ask spread drops below 5 basis points, 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. In addition, in both the landmark events, the spread trend appears to be absorbed in few weeks, with a strong correlation with the rate volatility pattern (figure 5 left). This is certainly due to the massive liquidity intervention of the European Central Bank, that from June 2007 to June 2010 increased their assets of about 600 billions Euros (+65%), using standing facilities, marginal lending facilities and open market operations, easing the procedures and the eligible assets required to borrow money.

V. VOLUMES, TRADES AND ACTIVE BANKS

In what follows, each time the term *monthly* appears, we strictly consider a calendar months, 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 reason, this is not the case. Moreover, 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) and the opposite (Buy label). Monthly averages of daily exchange volumes, number of trades, active banks and quoting/aggressing banks are given in Fig. 8, 9 and 10. The main difference between the pre end post crisis periods is the magnitude of the traded volumes. The traded quantities were constantly increasing until August 2007 and the rapidly collapse

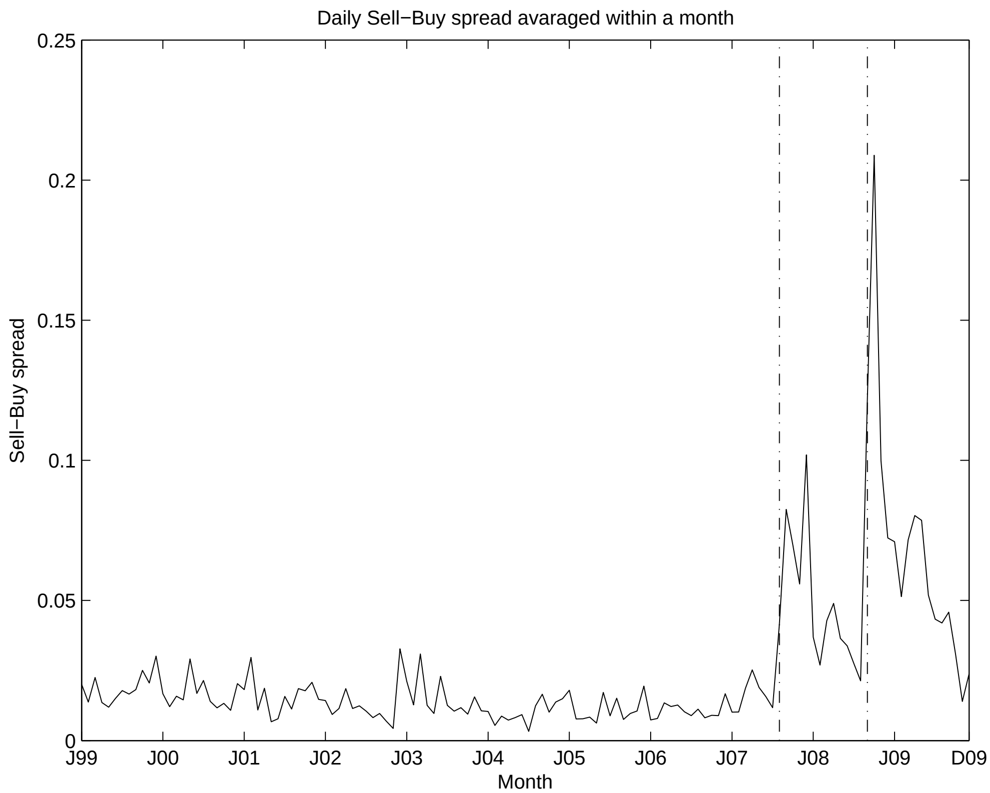

FIG. 7. Montly average of the daily sell-buy spread defined in Sec. IV C). Two well defined peaks are clearly present after the crisis milestones

after this period. It is unlikely the overnight interbank market loose all this volume of trades. Two are the 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 did prefer to avoid the disclosure of their liquidity need, in order to protect their reputation. Therefore, the interbank market volumes dropped and the grey market compensated.

VI. CORRELATIONS BETWEEN BANK'S STRATEGIES AND RATE LEVELS.

In this section we would like to understand whether the banks act on the market regardless the traded rate level or whether they take it into consideration. We restrict the analysis only to the transaction registered in the period 1999–2002 (1020 days). The restriction is justified by the fact we want 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 higher activity (number of trades).

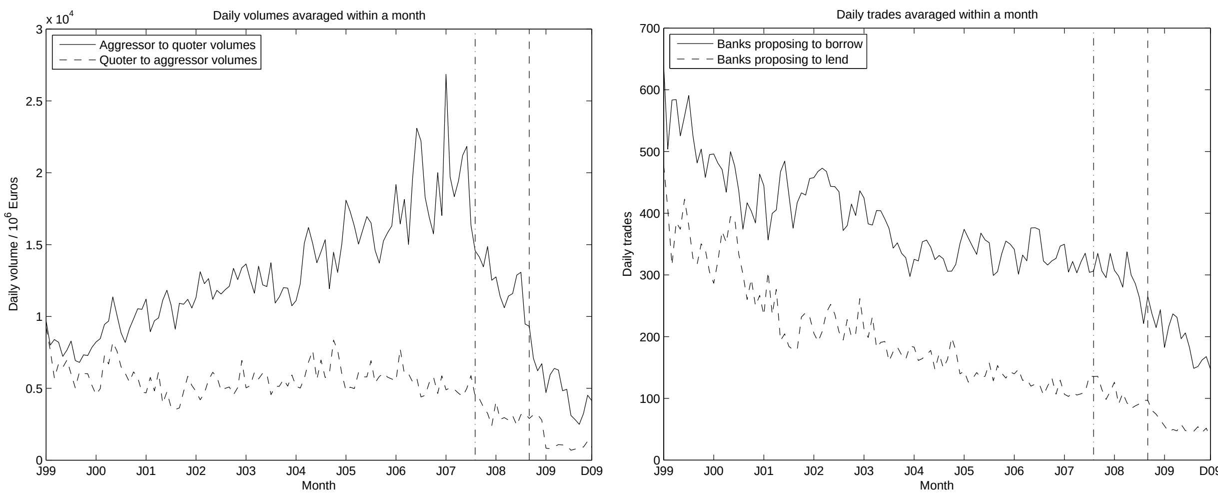

FIG. 8. Left: monthly average of daily volumes. Right: monthly average of daily trades. In both cases trades have been separated into deals where the money went from the aggressor bank to the quoter (Sell label, red lines) and the opposite (Buy label, blue lines).

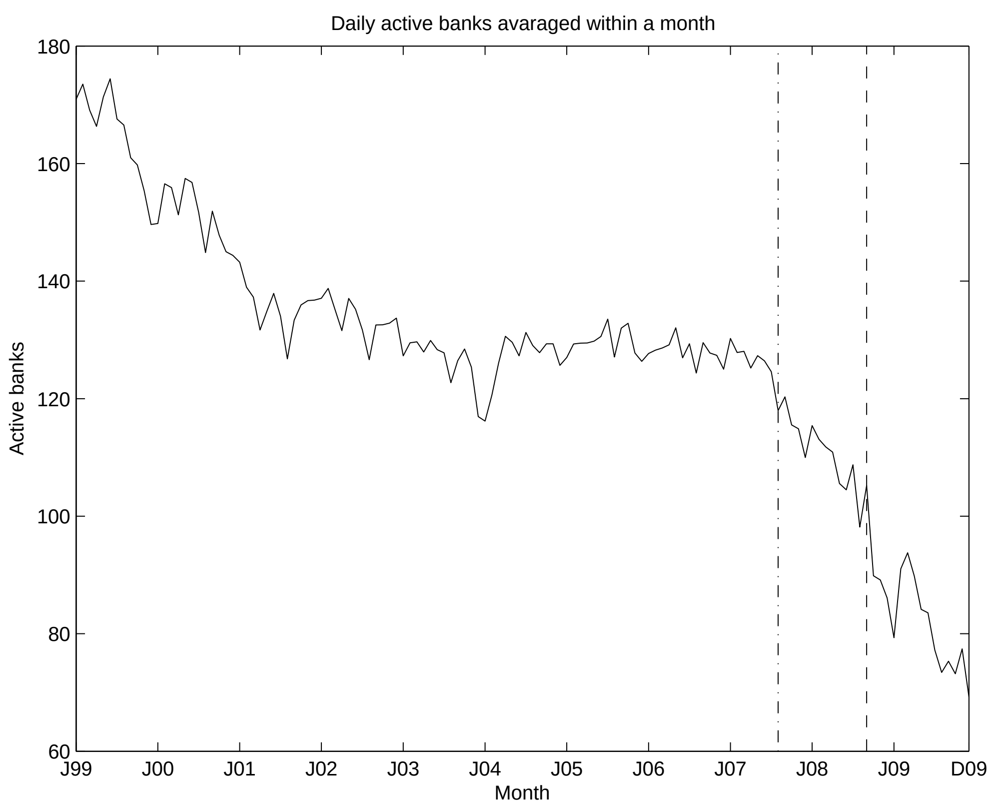

FIG. 9. Monthly average of daily active bank. A bank is considered to be active if part of at least one trade during a given day, without considering its side (quoter or aggressor).

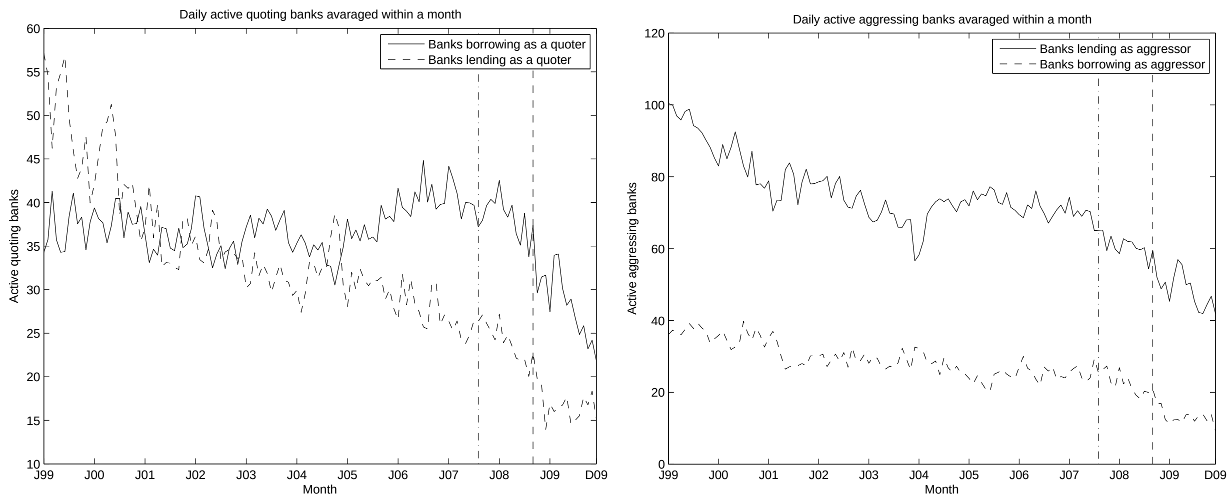

FIG. 10. Left: monthly average of the daily active banks acting as quoters. Right: monthly average of daily active banks acting as aggressors. In both cases the trades as been divided respecting the Sell and Buy label in the records, indicating that the money are flowing from the aggressor to the quoter in the first case, and in the opposite way in the second case.

In the 1999–2009 period 269 different banks participated to the market operations but most of them made very few transactions or participated only from 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 [7]. 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, [7] considers 85 banks.

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

- **The *simple* cumulative volumes:**

$$w_i^{\text{simp}}(t) = \sum_{j=1}^{N_i(t)} \nu_{ij}, \tag{4}$$

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

- **The *absolute* cumulative volumes:**

$$w_i^{\mathrm{abs}}(t) = \sum_{j=1}^{N_i(t)} |\nu_{ij}|, \tag{5}$$

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

To give the reader a qualitative idea of their behaviour Fig. 11 reports some random examples of the "simple" functions.

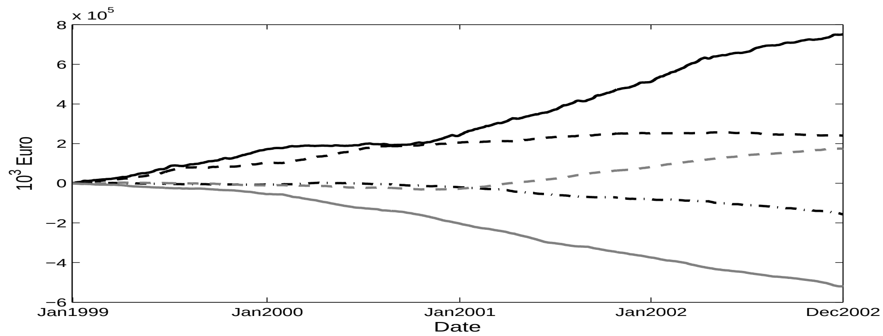

FIG. 11. Examples of the simple cumulative volume functions.

We are interested in the correlations between these functions, i.e. between the bank's strategies and interest rates. When speaking about spread in what follows we refer to the spread between the transaction rates and the EuroMLR rate.

A. Hayashi-Yoshida estimator

The Hayashi-Yoshida (HY) correlation estimator [27] for asynchronous data as those of high-frequency financial time series is

$$\rho[w_i(t), s(t)]_{\lambda_{\max}} = \frac{\sum_{h=1}^{K}(w_{ih} - \bar{w}_i)(s_h - \bar{s})}{\sqrt{\sum_{h=1}^{K}(w_{ih} - \bar{w}_i)^2}\sqrt{\sum_{h=1}^{K}(s_h - \bar{s})^2}}, \tag{6}$$

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

The HY method is a generalization of the classical Pearson estimator, consisting in how the elements w_{ih} and s_h are computed. If no events are registered in a specific bin $h \neq 1$, the values of w_{ih} and s_h are set equal to $w_{i(h-1)}$ or 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.

B. Fourier estimator

A method introduced by Malliavin and Mancino [28] uses the Fourier expansion of a time series. It is explained extensively in almost any paper that uses it (see for example Renó [29]), 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

$$c_k(w_i) = \int_0^{2\pi} \exp(ikt) dw_i(t) \tag{7}$$

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

$$c_k(w_i) = \int_0^{2\pi} \exp(ikt) d\left(\sum_{j=0}^{N_i(t)} \nu_{ij}\right), \tag{8}$$

where the explicit case of the raw 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 $d\left(\sum_{j=0}^{N_i(t)} \nu_{ij}\right) = \sum_{j=0}^{N_i(t)} \nu_{ij}\delta(t - t_{ij})$, where t_{ij} is the instant of the transaction j of bank i, and finally we obtain

$$c_k(w_i) = \sum_{j=0}^{N_i(t)} \exp(ikt_{ij})\nu_{ij}. \tag{9}$$

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

$$a_k(w_i) = \mathrm{Re}(c_k(w_i)), \qquad b_k(w_i) = \mathrm{Im}(c_k(w_i)). \tag{10}$$

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

$$a_k(\Sigma_{is}^2) = \lim_{k_{\max}\to\infty} \frac{\pi}{2k_{\max}} \sum_{j=1}^{k_{\max}} \left[a_j(w_i)a_{j+k}(s) + a_j(s)a_{j+k}(w_i)\right]. \tag{11}$$

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

$$\sigma_{is}^2 = 2\pi a_0(\Sigma_{is}^2). \tag{12}$$

Finally, the correlation is

$$\rho[w_i(t), s(t)]_{\lambda_{\max}} \equiv \rho_{is} = \frac{\sigma_{is}^2}{\sigma_{ii}\sigma_{ss}}. \tag{13}$$

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

C. Results

One main aim of ours is the analysis of the correlation $\rho[w_i(t), s(t + k\Delta t)]$ 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. $1/(2 \times 1020)$ of the whole analyzed interval, for both estimation methods, which are compared in Fig. 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 Figs. 13 and 14, where only the Fourier method is used.

Fig. 15 shows the variance of the distributions of the considered correlations vs. the lag. For both $w_i^{\text{simp}}(t)$ and $w_i^{\text{abs}}(t)$ 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.

VII. BANK'S COST OF MONEY

It is interesting to study whether some banks are able to borrow money for a lower rate than other banks and which are some market microstructure explaining factor of this phenomenon. To do so, we considered the two weighted sums

$$c_i^{\pm} = \frac{\sum_j (w_j - \bar{w}_j)\mu_{ij}^{\pm}}{\sum_j \mu_{ij}^{\pm}}, \tag{14}$$

where $\mu_{ij}^{\pm}$ are the lent (+) or borrowed (-) simple volumes defined in the section above and w_j is the relative spread of the transaction j. The mean relative spread $\bar{w}_j$ was defined in

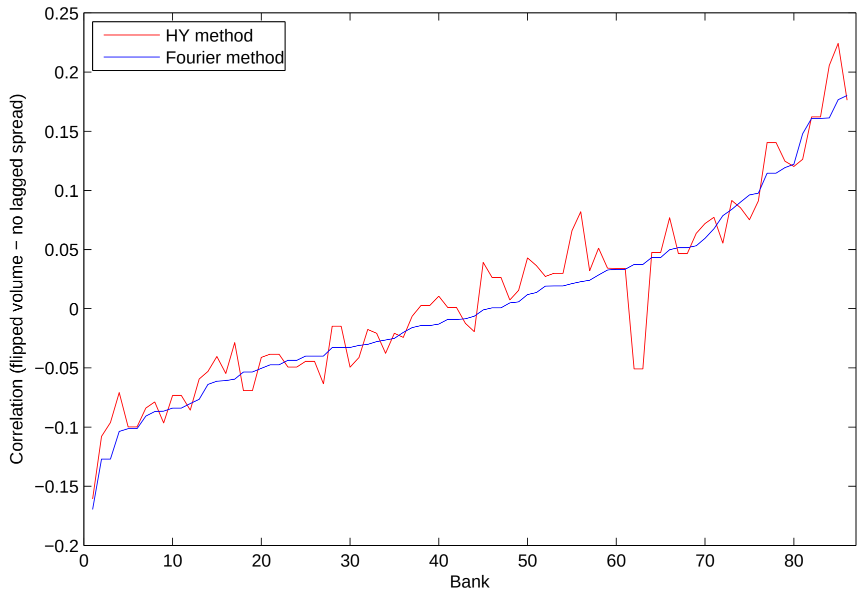

FIG. 12. $v_i^{\text{simp}}(t)$ with the spread $s(t)$, using the HY (red line) and Fourier (blue line) methods. The banks are ordered by the value of the correlation given by the Fourier method. Apart from the different noisiness, which is lower in the Fourier case, the two methods are consistent, giving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

Sec. IV A and 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

$$d_i = c_i^+ - c_i^- . \tag{15}$$

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

- **Risk rank of the firm**: each bank is implicitly ranked for the probability of default and other firms ask an higher price (rate) when lending money to a risky firm, and a lower price when lending to a safer firm.

- **Trading teams different skills**: some banks could have invested more resources in their trading teams in this market, and this reflect their capability to reach better rates.

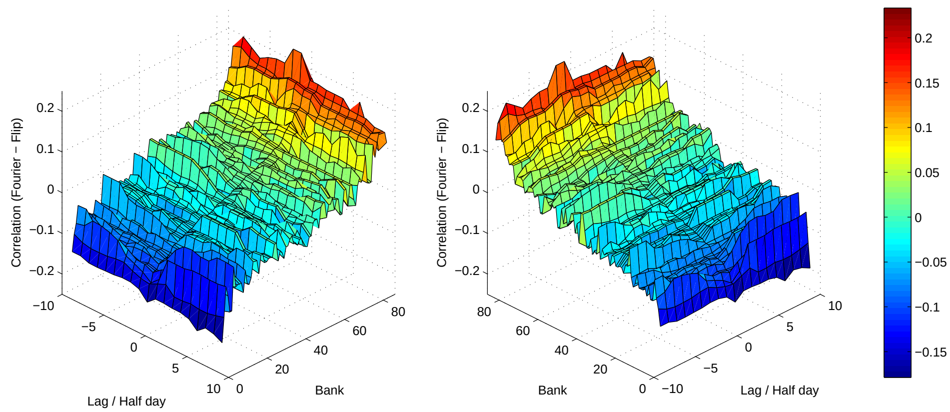

FIG. 13. $v_i^{\mathrm{simp}}(t)$ with the lagged spreads $s(t + k\Delta t)$ using the Fourier method. The banks are ordered by the value of the correlation at zero lag.

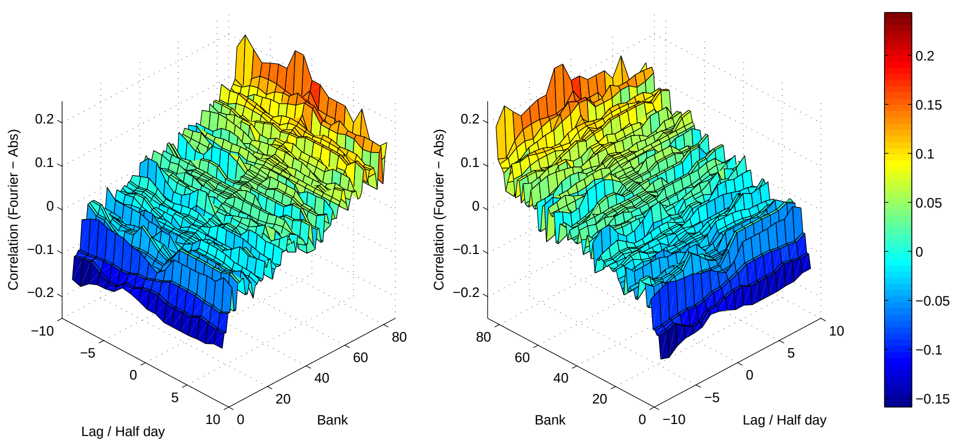

FIG. 14. $w_i^{\mathrm{abs}}(t)$ with the lagged spreads $s(t + k\Delta t)$ using the Fourier method. The banks are ordered by the value of the correlation at zero lag.

- **Taking prevalently one side of the trade**: we observed in Sec. IV C that acting as quoter instead of aggressor brings the advantage of gaining the bid-ask spread, in the same fashion as the stock market. If a firm is more capable to fulfill its needs as quoter automatically gain a better rate.

- **Different business opportunity during the day**: some banks could have better business opportunities than other during the day, so they accept to pay a bigger rate in order to quickly access funds to invest in other businesses.

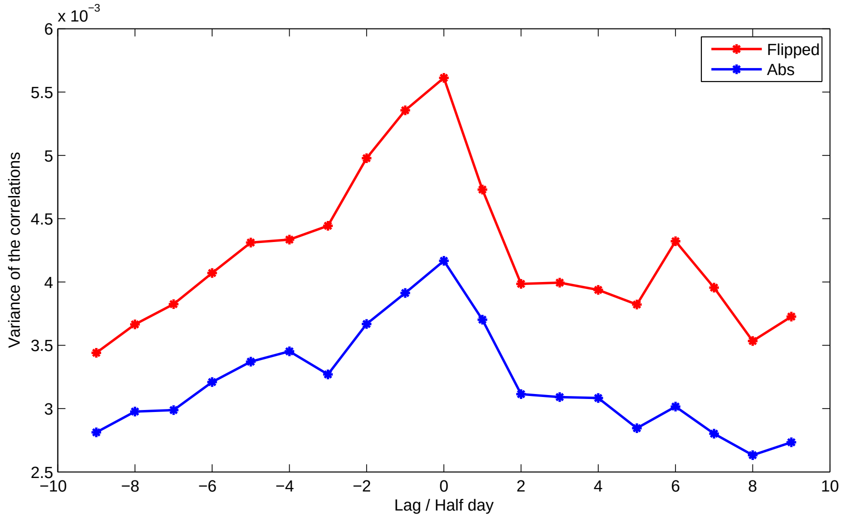

FIG. 15. Variance of the correlation values depending on the time lag. Each single value, i.e. each considered bank, is one point in the population.

	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 III. Measures of linear dependences between u_i as defined in Eq. 16 vs. d_i, as defined in Eq. 15. No difference between the periods can be isolated clearly, suggesting that acting prevalently as quoter brought similar results before and during the crisis.

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

$$u_i = a_i - q_i \tag{16}$$

we can compute its magnitude of linear dependence with d_i. If this measure is sensibly different in the three periods we can infer that trading prevalently as quoter gave more advantages during the crisis periods, explaining at least partially the different shapes of Fig. 16. Tab. III reports three measures of linear dependence and no clear pattern is recognizable. We can understand that acting as quoter is indeed connected with advantages but the magnitude of those did not changed between the pre crisis and the crisis periods.

	Pre crisis	Post crisis	Post Lehman collapse
Major	-0.0039	-0.0310	-0.0404
Large	-0.0023	-0.0398	0.0124
Medium	0.00009	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

TABLE IV. Mean cost of money for each bank group during the three analyzed periods. Performance of large banks (negatively) and non Italian banks (positively) appear to be the most effected by the turmoil.

However we can add another piece of information exploiting the label attached to each bank code, shown in Sec. III. The label can take six different values, five to indicate 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. Tab. IV gives the mean cost of money of banks in these six classes in the three periods. The main effects we can observe are a lose of performance of large banks and an increase of performance of non Italian banks.

VIII. DISCUSSION AND CONCLUSION

The e-MID electronic overnight interbank market is a peculiar example of order-driven market; its exotic 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 in a one-to-one base rather than in a disclosed market. We computed the intraday structure of the negotiated rates reflecting the effective length of the contracts. In addition, the spreads between the mean rates and the ECB key rates behave in a very different manner after Lehman Brothers collapse. In the same fashion than a stock market we can see an increase of the rate volatility and, moreover,

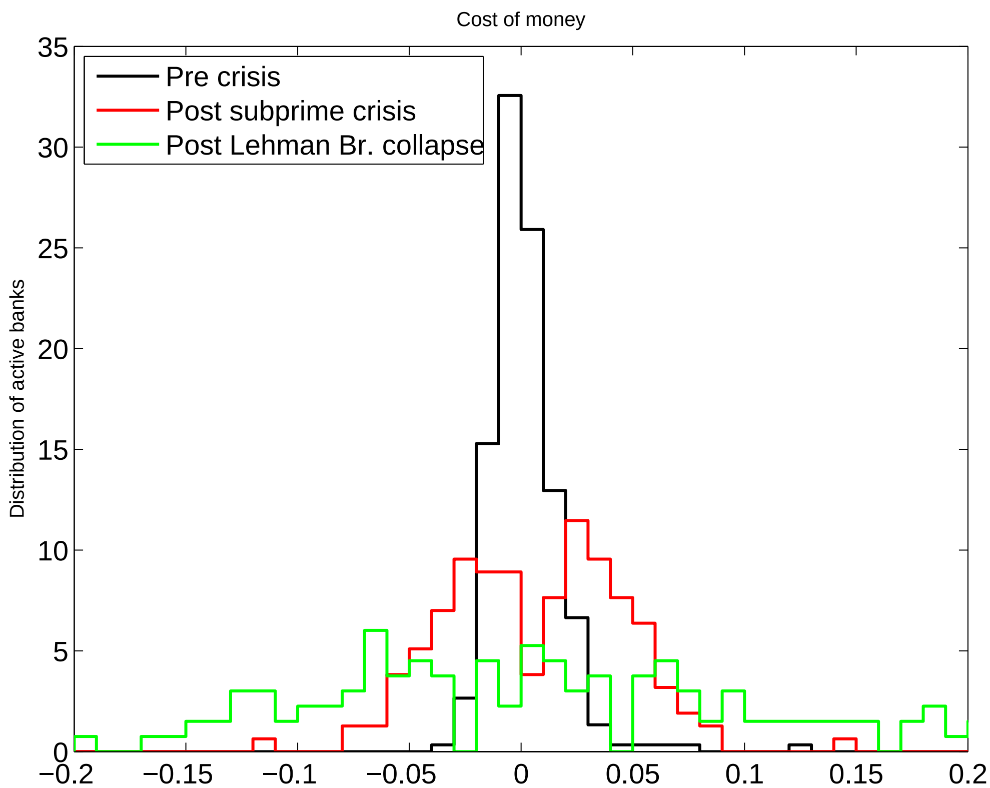

FIG. 16. Weighted differences d_i between the lent and borrowed volumes, see Eqs. (14) and (15) in Sec. VII.

we have defined a bid-ask like spread as good proxy of the market liquidity. The absence of significant correlation between the rate and the 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's level. Finally, we have shown that some banks are able to have substantially better prices when acting on the market and that the magnitude of this diversity strongly increase during the crisis phases. This advantage can be the result of more advanced trading techniques or, more interestingly, can reflect the different unofficial trust levels of each institutions.

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