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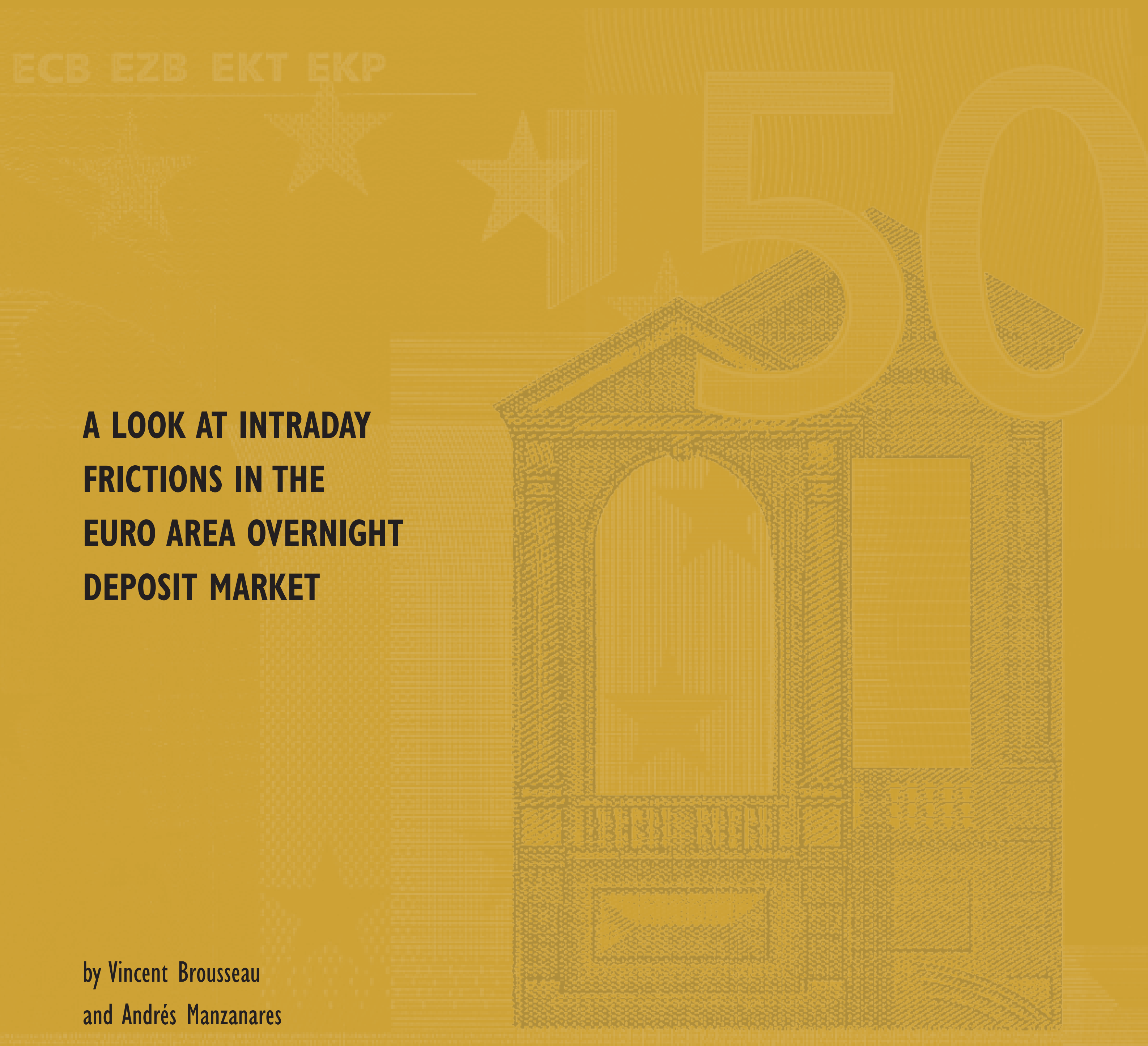

A LOOK AT INTRADAY FRICTIONS IN THE EURO AREA OVERNIGHT DEPOSIT MARKET

by Vincent Brousseau
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In 2005 all ECB publications will feature a motif taken from the €50 banknote.

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[1] *The views expressed in this paper are those of the authors and do no necessarily reflect those of the ECB. The paper has benefited from useful comments provided by Leonor Vereda. We also wish to thank Lorenzo Cupido (e-Mid) for the kind provision of the main source data.*

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Abstract

This paper studies frictions in the euro area interbank deposit overnight market, making use of high frequency individual quote and trade data. The aim of the analysis is to determine, in a quantitative way, how efficient this market is. Besides a comprehensive descriptive analysis, the approach used defines a measure of the friction arising for each single transaction, by which we understand an (small) initial loss accepted by a counterparty, and the corresponding gain made by the other counterparty. The evolution of total daily frictions is then put into perspective comparing it with the frictions arising if flows corresponded to the optimal solution of a "cash transportation problem". The main conclusions of this exercise are that overall frictions, although small in absolute size, tend to increase strongly whenever the overnight rate becomes volatile. Some tentative explanations for this are given, relying on the introduced methodology.

Keywords: Financial market microstructure, Money Market, Market friction, Network optimization problems

JEL classification: D4, E52, C61

Non-technical summary

This paper studies frictions in the euro area interbank overnight market, making use of high frequency individual quote and trade data. The aim of the analysis is to determine, in a quantitative way, how efficient the *euro area interbank overnight market* is, taking into account the multiple uses of central bank money, as the basis of RTGS payment systems and as the tool for setting the policy rate.

The first part of the study focuses on the general patterns in spreads, volatility and traded volumes, which seem to confirm, in line with previous studies, that conditions are stable and the market is liquid, apart from few exceptions well explained by theoretical considerations.

The second part attempts to go beyond the descriptive analysis, applying a methodology that has, to our knowledge, never been used in this context. In the approach used, a measure of the friction arising for each single transaction is defined. Trades are viewed as the superposition or the sum of, firstly, exchanges taking place at the fair value and, secondly, small corrective terms representing a payment made by one counterparty to the other one. Those small corrective terms are our so-called “frictions”, which are, simultaneously initial gains and losses, depending on which counterparty’s point of view one adopts.

The value of this friction depends, as one might expect, on the characteristics of the two banks involved in the trading, in particular of their relative market power. It also depends of which one takes the initiative of the transaction, following the motto that the bank taking the initiative pays, and its passive counterparty receives, a small fee, implicitly contained in the agreed trading price.

For each pair of banks, an estimate of the friction associated with a certain volume and direction of a trade is thus obtained. The evolution of total daily frictions is then put into perspective comparing it with the frictions arising if flows corresponded to the optimal solution of a “cash transportation problem”, assuming that all banks cared about was their end-of-day current account position.

The main conclusions of this exercise are that overall frictions, although small in absolute size, tend to increase strongly whenever the overnight rate becomes volatile, i.e. generally on the last days of a maintenance period, or when market conditions are uncertain. On those days, the characteristics of the market, with relatively few banks acting as market-makers and re-distributing liquidity, and doing so at higher prices charged, seem to lead to higher global frictions than on normal days. This supports the view that the external benefits of accessing the money market even on “bad days”, such as guaranteeing a smooth fulfilment of payment obligations, outweigh the costs described. In other words treasurers at commercial banks likely consider such frictions as negligible in absolute size, and would rather not jeopardise their core goals for the sake of minimising costs usually measured in a few basis points.

1. Introduction

The implementation of monetary policy in the euro area relies on an operational target, the level of the interbank overnight rate, as the starting point for the setting of the monetary policy stance of the ECB. A series of institutional instruments, the so-called operational framework, allow the central bank to control relatively well both the level and the volatility of this rate. The goal is to implement in a smooth way rate decisions, which should be reflected in market rates at any time. Refinancing costs for credit institutions represent the first step in the monetary transmission mechanism and should optimally be free of frictions and reach the whole economy in a homogeneous way.

Numerous studies have been devoted to both the dynamics theoretically driving the overnight rate and to the empirical characteristics of the euro area overnight market. The combined stabilising effect of a reserve requirement system, standing facilities defining a symmetric corridor and open market operations conducted for matching supply and demand for liquidity[1] has inspired an increasing number of central banks to modify their framework in this direction. The well-known martingale hypothesis, stating that the overnight rate at any point in time should be equal to the expected overnight rate at the end of the maintenance period due to inter-temporal arbitrage[2], rests on the intuition that under the averaging provision, account holdings on different days of the period are perfect substitutes. This intuition is not completely true, as discussed in Perez-Quirós et al. (2001). They present a model where rational banks have an interest in delaying their current account holdings in order to avoid an early fulfilment of reserve requirements entailing high costs. Other factors that would cause a breakdown in the martingale rate behaviour would be risk aversion and market frictions, as argued for example in Bartolini et al. (2000). However, due to the prevailing high level of reserve requirements, a rate behaviour very close to the martingale-like can in fact be roughly observed in the euro area, despite some deviations owing to institutional features such as calendar effects, temporary large current account deficits or other exceptional events that may reduce liquidity demand elasticity[3]. The literature has in fact rather comprehensively explored the empirical behaviour of the overnight rate (Würtz, 2003) and developed explanatory models for the remaining slight departures from the theoretical rate dynamics in this market, for example on account of possible market segmentation as in Gaspar et al. (2004). The main conclusion is that current account holdings, or what is usually called liquidity in this context, is correctly priced in the euro area, i.e, that its price

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[1] In the present context the term "liquidity" refers to current account holdings with the central bank. The characteristic of a market on which large transactions can be made rapidly and efficiently with no deterioration of the terms of trade will be referred to as "market liquidity" in order to avoid confusion.

[2] In concrete terms, the martingale hypothesis would state, defining by i_t and Φ_t the overnight rate and the information available at time t, respectively, that: $i_t = E[i_{t+h}|\Phi_t]$.

[3] The high level of reserve requirements ensures that banks' demand for working balances to serve as a buffer against liquidity shocks remains practically always below the requirements, as argued in Bindseil et al. (2002).Only on some few occasions, notably in mid March 2003, expectations of a rate cut triggered such a severe lack of bids at the ECB's main refinancing operation that aggregate liquidity in the following days might have been under this minimum buffer, explaining the observed spike in the overnight rate.

at each point in time corresponds roughly to its marginal value and that changes in this marginal value are nearly unpredictable.

This theoretical and empirical analysis of the overnight rate has been based on models where the intraday liquidity position does not play a role, since the smoothening effect of reserve requirement fulfilment obligations works through end-of-day positions. However, as pointed out in Angelini (2000), gross settlement systems have generated a substantial demand for intraday monetary base. Treasurers typically need, in order to face payments related to all other activities of the bank, to target certain levels of account holdings at different times of the day. The fact that the money market also covers these needs has generally not been the focus of study, since only a significant distress in the market affecting the aggregate overnight market rate, usually related to payment system disruptions or exceptional events, becomes a relevant issue for policy makers. [4]

The goal of this paper is to fill this gap and shed some light on how important global transaction frictions are in the euro overnight deposit market and where they originate. For this purpose, transaction frictions beyond those caused by the necessity to keep a targeted end-of-day reserve position will be estimated. The main idea is to compare actual frictions that arise through interbank transactions with "optimal" frictions obtained by assuming that only net positions at the end of a day are targeted by each bank. In this context, any transaction taking place at a price other than the fair price should be seen as the symptom of some friction. Any such transaction implies a cost for one of the two counterparties, which is a benefit for the other counterparty. Hence, it is relevant here to define a measure of the frictions as the sum of those costs, or equivalently of the corresponding benefits, over some lapse of time. The set of transactions that allow the banks to reach their observed end-of-day reserves over some day has generated some so-defined friction, which may or may not have been the minimum possible one assuming that the unit cost incurred by each couple of counterparties is fixed. The "optimal" frictions, in turn, are calculated as the solution to a classical network minimum cost flow problem where unit transaction costs are estimated from the data.

This decomposition of total frictions should not be interpreted in a normative way as necessarily indicating that the difference between actual and the estimated "optimal" frictions is entirely due to inefficiencies that could be easily avoided. On the contrary, the residual frictions could well reflect the intangible benefits stemming from the elimination of intraday credit risk through RTGS payment systems and the smooth satisfaction of intraday payment obligations, which is after all the main job of any treasurer, as well as true inefficiencies derived from structural features of the market like lack of depth or co-ordination problems.

The data used were kindly provided by e-MID, an electronic trading platform whose importance has been growing in the last years and where banks trade a significant share of the total euro area money

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[4] Note, however, that the importance of central bank money as the settlement asset for intra-day interbank credit operations and the consequent necessity to provide sufficient liquidity so as to avoid potential financial instability has been a

market turnover. In particular, two data sets containing time stamped effective trades and one- or two-sided price quotes posted in the system from October 2003 to April 2004 (both included) were considered.

The paper is organised as follows. Section 2 describes the main characteristics of the data, at the aggregated level and, most interestingly, at the individual level, exploring some of the conjectures about the functioning of the market. In section 3, the methodology for defining transaction frictions is presented and its results on the data are shown. The application of the network flow minimisation approach is then formulated and solved in section 4, together with the interpretation of the results. Finally, section 5 concludes.

2. Main empirical features of overnight liquidity flows

This section gives an overview of the data. E-Mid is a screen-based system where participating banks belonging to a panel of mostly euro area credit institutions[5] trade in money market deposits and swaps. Our data refer to overnight deposits corresponding to the two segments of the e-Mid market dedicated to this maturity, since larger trading volumes (over EUR 100 million) are classified as a different instrument in the system, compared to trades and quotes of a smaller size. The trading protocol is as follows. The system shows on a screen all available quotes, identifying as well the banks posting them. After a quote is hit by an interested potential counterparty, the trade is not automatic but rather flexible, thus allowing for credit line checking and also for re-negotiation of trade volume and rate. The latter feature offers a possibility to study individual costs and premia, always bearing in mind that this market is probably especially competitive in terms of margins, because of its transparency. Indeed, we have two different data sets, namely the quotes, i.e. all bid or ask *offers*, and the trades, i.e. actual transactions conducted. Quotes include both prices and volumes offered, either on the bid or the ask side, or both. Trades include the volume and the price of each transaction taking place. The availability of every single quote and trade makes this study possible in the first place compared to the rest of the deposit interbank market, where trading takes place mostly over-the-counter (OTC)[6]. In particular, every observed trade can be matched with quotes immediately preceding it, in order to compare prevailing market conditions with the terms of the transaction and measure costs and benefits for the two sides involved.

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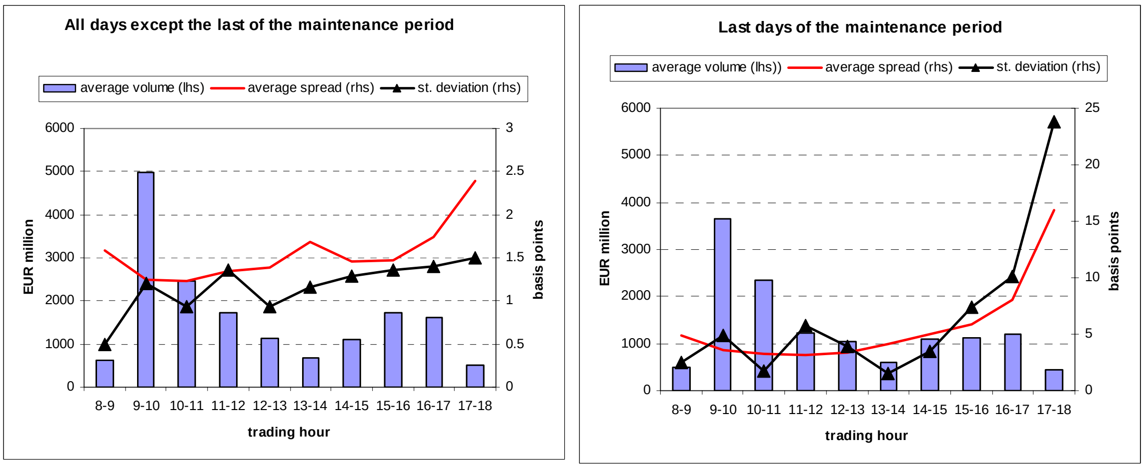
driver in the recent changes to the monetary policy implementation framework of the Bank Of England. See www.bankofengland.co.uk/speeches/speech225.pdf

[5] e-MID was originally designed, in 1990, as an electronic trading system for the Italian lire interbank market. It has now evolved to become the only pan-european money market trading platform to date. The number of members was close to 200 in June 2004, out of which around 125 are Italian banks. There are around 60 non-Italian euro area banks and 15 non-euro area banks (British, Swiss, Danish and Norwegian). The interested reader may look in the web site of e-MID at www.e-mid.it for further details.

[6] Gaspar et al. (2004) use the relatively less detailed data of the EONIA panel of banks compiled by the European Banking Federation.

Several studies on the intraday properties of the overnight market based on e-Mid data have been conducted, in particular Angelini (2000) for the Italian market before the monetary union, Hartmann et al. (2001) and Barucci et al. (2003) for the euro area wide market. All of them point to similar patterns in trade volumes, spreads and volatility, persistent both over time and across countries[7]. These stylised facts are confirmed by our data, as shown in **chart 1**. Regarding the intraday pattern of turnover[8], the differences between end of maintenance period days are minor, the level being generally lower on end of MPs. There is a two-humped pattern with a very high volume from 9 to 10 a.m., related to payment activity once banks have estimated their liquidity needs for the day derived from pending in- and outflows. A lower peak is observed between 3 and 5 p.m., when banks adjust their end-of-day position after observing their liquidity forecast errors. As for average hourly spreads, a roughly constant spread of around 1.5 basis points can be observed on all days excluding end of MP days. Only at the very end the spread increases to around 2 basis points. This contrasts with the higher spreads observed on the five ends of maintenance period in the sample, which remain close to 5 basis points during most of the day, with an increasing trend that peaks at around 15 basis points before the TARGET and standing facilities closure. Volatility, measured by the standard deviation with respect to the hourly mean rate, follows roughly the same pattern as the spreads, remaining quite stable except on end of maintenance period days, when it explodes in the afternoon reflecting the strong rate movements on those days.

Chart 1: Intraday patterns of the e-Mid overnight market, by position of day within the maintenance period



Note: The calculation of hourly spreads and volatilities is based on the methodology for defining instant market bid and ask prices described in section 3.2. Hourly volatility is here defined as the standard deviation of the set of trade prices for all transactions, not weighted by transaction volume nor by time.

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[7] These patterns are most likely very close to those of the overall overnight market. For instance, a volume-weighted average daily price measure made available by e-Mid is generally quite close to the official EONIA fixing.

[8] Turnover is defined as the total volume traded. Hence, double counting is precluded.

The daily series of total turnover and average volume per transaction shows that on end-of-maintenance-period days the total volume and also the average size of transactions clearly decrease. This could hint at a certain lack of market liquidity on these days, which will be investigated further in the next sections.

The most interesting features can however be observed from the individual data. Turning to liquidity flows, it turns out that a relatively small number of banks concentrate most of both the borrowing and the lending activity. **Figure A** in annex 1 gives a graphical representation of these flows by means of multidimensional scaling (MDS). The distances separating each couple of banks in figure A approximately correspond to the inverse of the traded volume between the two. Of course, since it is not possible to exactly represent the distances defined in such a way as Euclidean distances on a plane, a numerical procedure is applied in order to obtain an approximation (Kruskal et al., 1978)[9]. The result indicates graphically that the most active banks (the thickness of the point indicates average gross turnover of the corresponding bank) tend to be in the centre of a unique, roughly circular-shaped cluster. It appears, at first glance, that there is no segmentation of the market, with some larger banks catering exclusively for the needs of a subgroup of smaller institutions, since in such a case we would observe an array of distinct clusters.

If we look at the net lending and borrowing of each bank during the sample period, it is easy to verify that there is a very clear characterisation of banks into those with a structural liquidity surplus and those with a deficit, as can be seen from **chart 2**. Indeed, most of the banks lie along one of the two axes, i.e., trade overwhelmingly on only one of the sides, while there are few trading for relatively large amounts on both sides. This is likely a reflection of the varied profiles among panel banks, where typically those with large depositor bases enjoy excess liquidity supplies, while other banks with different business activities, such as investment banks find themselves with a liquidity deficit to be covered. However, a glance at the time series pattern of banks' trading reveals that the structural liquidity position of banks does not fully explain this trend to trade on one side. In fact, the percentage of banks trading on both sides on any given day seems to be fairly but not totally stable over time. A distinct trait is apparent, namely that the last day of each maintenance period witnesses an increase in the number of banks trading on both sides of the market, as can be observed in figure B in annex 1.

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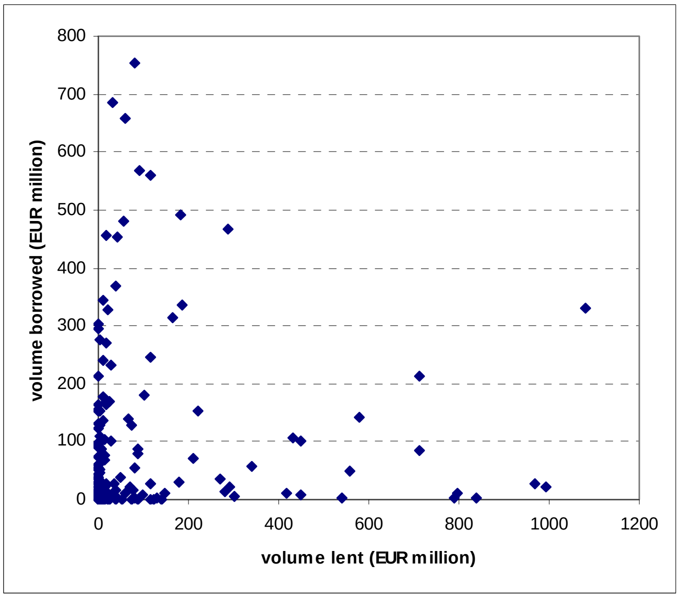
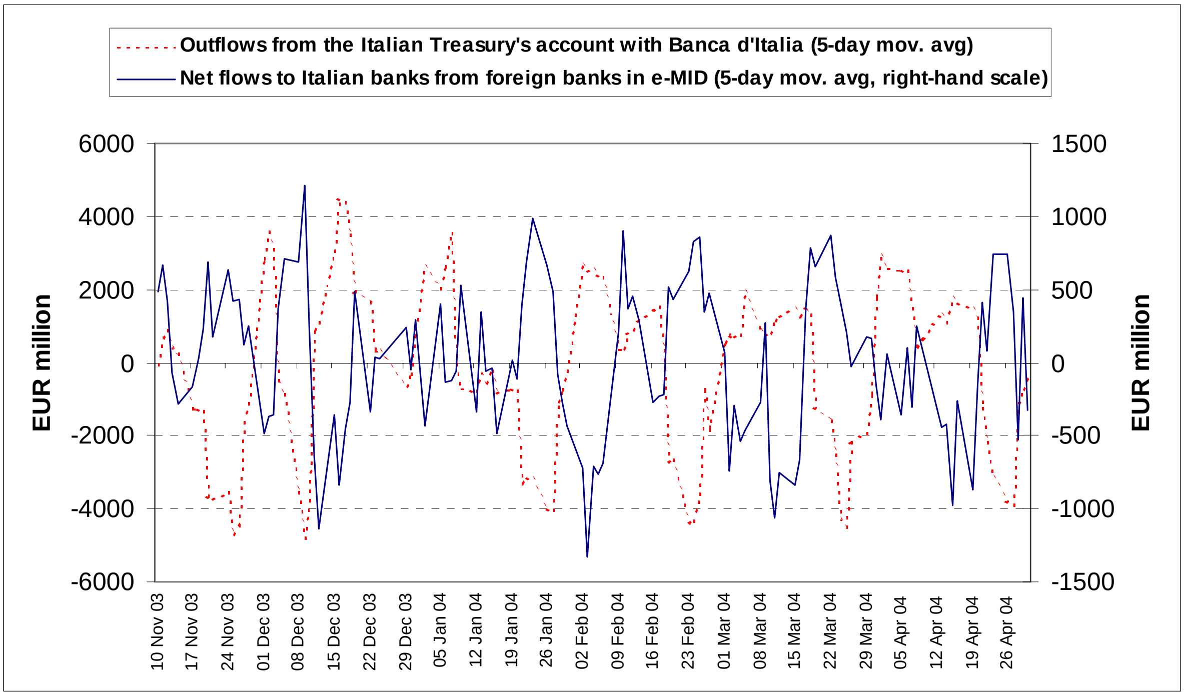
[9] It should be noted that this graphical representation is akin to the result of a factor analysis in the sense that only distances are meaningful, while the orientation of the axes is arbitrary. Indeed, any isometry (such as a rotation or a shift) applied to it yields the same interpretation.

Chart 2: Average daily gross lending and borrowing by bank



The fact that most of the banks in e-MID are only active on one side of the market does unfortunately not allow for a definitive inference about the overall money market structure and concentration. It might just reflect that banks generally active in telephone trading could use e-MID primarily on those occasions where their liquidity positions are clearly biased on one side. Moreover, the specific traits of the Italian money market are important to understand this finding. The liquidity flows to and from the accounts of the Italian Treasury with Banca d'Italia, stemming mainly from tax receipts, salaries and pension payments and bond issuance and redemption activities represent the single most volatile autonomous factor affecting the overall liquidity situation in the euro area (Bindseil (2001)). Each unexpected overall shock to liquidity due to these activities of the Italian Treasury is most likely to affect Italian banks in a relatively homogeneous way over time and hence lead to a persistence in the sign of these single liquidity positions. See annex 2 for details. Excess liquidity in the Italian banking system caused by a reduction in the account holdings of the Treasury with Banca d'Italia should, in a well-integrated euro area market, lead to a net "export" of funds to non-Italian banks. **Chart 3**, showing a negative correlation between Italian Treasury deposits and net outflows from Italian banks in e-MID proves that this platform is indeed to some extent used for such a re-distribution (about one fourth). Barucci et al. (2003) reached a similar conclusion on the existence of communicating vessels by regressing the difference between the EONIA rate and the average transaction rate on e-MID on inflows to Italy.

Chart 3: Italian Treasury deposits with Banca d'Italia and net inflows into the Italian banking system through e-MID



Another proof of the high degree of integration in the market is, as any dealer active in the money market will have observed, that the overnight rates quoted by brokers across the euro area are always consistent with each other except for the case of a technical contribution problem. In fact, our own data recording of the contributed quotes of seven main brokers show that the discrepancy among them is a tiny 1 basis point most of the time during the day, except if this day is the last one of a period (in which case it can reach a still moderate 2 basis points).

An interesting question relates to the existence of relationship banking. Relationship banking has been defined in the literature as the tendency to borrow from a single or a limited number of banks. This behaviour would be explained by asymmetric information[10], namely because the long-standing lender possesses more information than other banks about the credit worthiness of the borrower and this information is translated into a better offered rate. A first answer, from the descriptive analysis, is that a relatively low degree of counterparty selection takes place within the platform. For this purpose, we have analysed the concentration of the volumes lent (borrowed) to (from) all other banks in the panel by a given bank. This concentration can be measured, for instance, by the well-known Herfindahl index. We measure, for each bank and trade direction, the corresponding concentration that indicates whether this bank tends to choose its trade counterparties in an even, “equitable” way or rather picks them according to certain private information. In **chart 4**, we observe that the lion’s share (80%) of the volume borrowed is borrowed by banks choosing their lending counterparties in a random way. In

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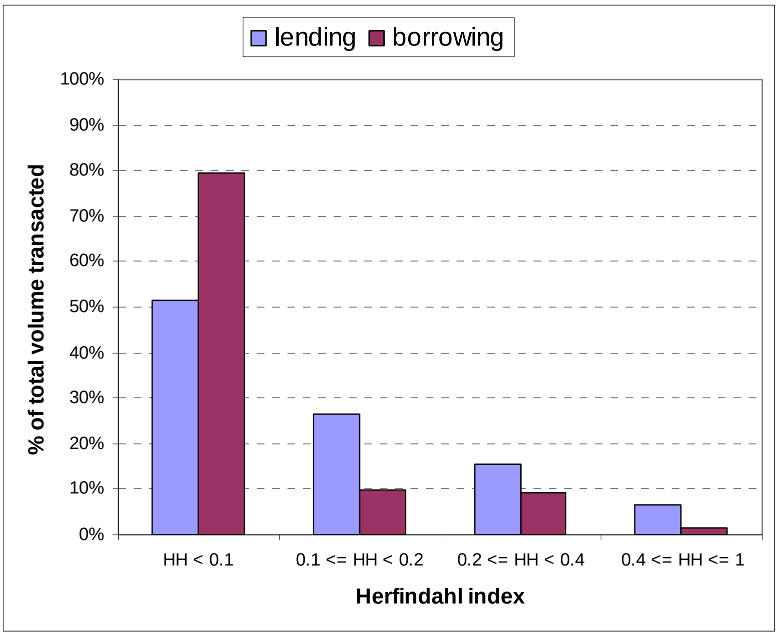
[10] See, for instance, Furfine (1999) and references inside.

contrast, most likely due to credit risk considerations, concentration indices are generally higher on the lending side, i.e. some banks appear to avoid lending to certain counterparties. In fact, from the data it seems clear that larger banks barely discriminate when borrowing and seldom when lending. The same is not fully true for less active banks. However, overall no strong evidence can be seen of relationship banking, since counterparty selection is also low for small banks on the lending side.

Chart 4: Percentages of volume lent/borrowed by banks classified according to how equitably they chose their counterparties



3. Definition of transaction frictions

The notion of “transaction friction” or simply “friction” will play a key role in this paper. By those frictions, we understand (generally small) transfers of wealth that occur with and are caused by a transaction between two counterparties. Being a transfer of wealth, such a friction is a gain for one of the counterparty and a loss for the other counterparty. In most cases, it can be interpreted as the remuneration of the counterparty that provides the liquidity (in the sense of market liquidity) by the counterparty that makes use of this liquidity. The first one acts as a market-maker and the second one acts as its customer.

The present section focuses on this notion of friction. It is divided in three subsections. The first one discusses the economic or financial content of this notion, presents the motivation for its introduction and examines how it applies in the specific context of the overnight cash market. The second subsection deals with the technicalities: It presents the effective construction of the relevant measure of those transaction frictions. The third subsection examines how this initial transfer of wealth occurring at dealing time relates to the entire transfer of wealth caused by the transaction, which only becomes known as soon as the EONIA rate index is itself known.

3.1 How and why to measure frictions

The difficulty in the treasurer's job will be measured by the transaction frictions he or she globally incurs. Transaction frictions summarised by bid/ask spreads should be considered, from a monetary policy perspective, as a global loss of welfare (especially since credit risks are generally low in such a short maturity). However, it can be argued that some frictions are unavoidable for the correct functioning of the framework. Firstly, major banks intervening in the overnight market could abandon their role of bidding at ECB operations and redistributing the funds if their earnings from this activity were deemed to be insufficient. Secondly, spreads and volatility are both a consequence of uncertainty. Even though the ECB's changes in the operational framework effected in 2004 aim precisely at reducing volatility and stabilising refinancing costs, coping with uncertainty in the flow of payments is unavoidably part of the treasurers' job.

The core issue is that we need to find an appropriate measure of aggregate frictions incurred by banks in order to manage their liquidity position. In so doing, we will not consider the costs/benefits stemming from changes in the rate within a maintenance period and the corresponding potential possibility to arbitrage through the averaging provision. These changes can in fact only be exploited for speculative purposes by individual non risk-averse banks but such an arbitrage is not possible from an aggregate point of view, since it is the central bank that almost fully determines the overall liquidity position through its open market operations.[11] Hence, the fact that total current account holdings on a day with a higher EONIA rate than the maintenance period average are not zero, as would be implied by a perfect aggregate arbitrage, can not be considered as a high cost or lack of efficiency in the market. Indeed, our measure of frictions should be independent of the evolution of the rate, also from its intraday changes, because costs derived from individual loss-making short or long positions do not reflect any welfare loss, but rather the underlying mechanism of reserve averaging. Therefore, what interests us is the cost in terms of price paid by some bank relative to the "market price" at the same instant.[12] Assuming a "market price" is defined at the time where a transaction takes place, if the transaction price differs from the "market price", there will obviously be a side obtaining a profit and another making a loss. We can even be more specific and say that in nearly all the cases, the side making the loss is the side having taken the initiative of the deal, for any exception would correspond to the exploitation of a true arbitrage opportunity, and such opportunities are rare in liquid markets. Needless to say, these profits/losses net out in the aggregate. For our purpose however, the signed nature of the profit/loss is irrelevant and globally any deviation from the market price reflects a constraint or a friction to the smooth flow of liquidity in the system. Hence the absolute value of this

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[11] Obviously, the use of standing facilities represents a source of noise in the liquidity supply which is not controlled by the central bank but by the banks themselves. However, due to the penalty rates applied, its impact in terms of volume is marginal.

[12] In fact, anecdotal evidence from interviews with some market participants indicate that few treasurers actively seek speculative gains in the deposit market. Generally, the role of the treasurer is limited to the smooth management of liquidity with, if at all, a very narrow margin for speculative action by means of running down (building up) daily holdings on certain

deviation will be our key measure of friction costs of a transaction, obviously summing up over all transactions and weighting by the volumes transacted.

3.2 Construction and computation of the frictions

We will define the market price at the instant of a trade using a dynamical filtering in a similar way as Brousseau (2005) (in § 2.2) and the associated trading frictions for each side following the lines of microstructure studies on equity markets, like, for instance, Yadav et al. (2003).

The dynamical filtering aims at obtaining at any point in time the "fair price", i.e., "where the market stands". For this purpose, we select a set of quotes that can reasonably be presumed as being currently valid. This set contains only presumed valid quotes at a given instant because the set of truly valid can of course not be determined with entire certainty and at every instant. However, provided that the market is liquid enough and therefore has frequent quotes -the average number of quotes per hour between 8 AM and 5 PM amounts to 106 in our sample- we can safely assume that if the market shifts, a new quote will be posted relatively quickly and we will not be misled by outdated quotes. The construction of the set of "currently valid" quotes can be done following some computationally simple steps:

1. Select all quotes *preceding* the instant t of the trade.
2. Sort the selected quotes in chronological order, starting from the most recent.
3. Compute the best (highest) bid and the best (lowest) ask successively for the k first quotes of the ordered list. This is done for increasing k until…
4. The best bid is equal or higher than the best ask, for the first k quotes. Then we eliminate this last incorporated k^{th} quote and we keep the k-1 most recent ones as the "currently valid" quotes[13].

The rationale behind this method is clear: quotes that precede the trade are accepted as valid until, when going backwards, we find the first quote that is inconsistent with the rest since it would imply an arbitrage opportunity. This quote serves as cut-off and all preceding ones are dropped as outdated. This describes the dynamical filtering method as such, whose construction implies going backwards in time within the order book, but does not require to scan laterally this order book, yet.

The dynamical filtering is a prerequisite, as it allows to fairly re-construct the market price from quoted prices (instead of traded prices)[14]. However it is only a pre-requisite and the measurement of the costs/benefits involved for each side of the trade requires considering the entirety of the currently

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days within the maintenance period where the prevailing rates are higher (lower) than their central expectation of the average rate over the period.

[13] In case this k^{th} quote is the most recent one containing a price for one of the two sides (i.e., all other more recent quotes refer to the other side) and this price equals the best price of the other side, then the kth quote is not discarded, and we assume that the best spread had length 0 at instant t.

[14] This belief in the virtues of the dynamical filtering is grounded on the experiment reported in Brousseau (2005), that pertains to the euro-dollar exchange rate market. It was shown that the market price, represented by EBS best bid and best ask, could be accurately recovered by applying the dynamical filtering to the quoted prices, represented by the Reuters contributed bid-ask spreads.

valid order book, with prices and sizes associated with those prices. In other words, it requires scanning laterally the order book, in the way that we will now describe.

Once the valid quotes at the time of each trade are available, a measure of the cost/benefit for each side of the trade could easily be computed as the difference between the midpoint of the best spread and the actual trade price. However, this would not take into account the possibly limited liquidity offered at the best price of each side. Each quote is accompanied, in the system, with an amount offered at the corresponding price. In fact, a treasurer may not be able to find the whole desired amount at the best price, but be forced to accept second best offers for some part of the sought volume. Hence, we define the friction in a way that takes into account both the trade and the quoted volumes.

Definition:

At instant t, let the "currently valid" quotes be contained in the matrix $\begin{pmatrix} p_b^{(1)} & p_a^{(1)} \\ p_b^{(2)} & p_a^{(2)} \\ \dots & \dots \\ p_b^{(n)} & p_a^{(n)} \end{pmatrix}$, with $\begin{pmatrix} v_b^1 & v_a^1 \\ v_b^2 & v_a^2 \\ \dots & \dots \\ v_b^n & v_a^n \end{pmatrix}$ as corresponding offered volumes. Bid and ask prices, p_b, p_a, are sorted so as to form nested intervals, with $p_b^{(1)}, p_a^{(1)}$ corresponding to the tightest, i.e. the best spread, $p_b^{(2)}, p_a^{(2)}$ the second best one, and so on.

Let the actual trade price and volume be denoted by p and v, respectively. The *effective bid price* for this trade is then defined as:

$$p_b^t = [p_b^{(1)} \cdot \min(v, v_b^1) + I_{\{v > v_b^1\}} p_b^{(2)} \cdot \min(v - v_b^1, v_b^2) + \dots + I_{\left\{v > \sum_{i=1}^{n-1} v_b^i\right\}} p_b^{(n)} \cdot \min(v - \sum_{i=1}^{n-1} v_b^i, v_b^n)] / v$$

Analogously, the *effective ask price* is defined as:

$$p_a^t = [p_a^{(1)} \cdot \min(v, v_a^1) + I_{\{v > v_a^1\}} p_a^{(2)} \cdot \min(v - v_a^1, v_a^2) + \dots + I_{\left\{v > \sum_{i=1}^{n-1} v_a^i\right\}} p_a^{(n)} \cdot \min(v - \sum_{i=1}^{n-1} v_a^i, v_a^n)] / v$$

Notice that, provided a deal is feasible, the effective price for this deal is always well defined because the volumes that can effectively be hit exceed the volume of the trade (which otherwise would not be feasible).

Finally, the trading cost per volume unit for the borrowing bank would amount to:

$p - \frac{p_b^t + p_a^t}{2}$, while the opposite, i.e. $\frac{p_b^t + p_a^t}{2} - p$, would be the trading cost for the lending bank. (A negative cost just means a profit. However, as already mentioned, from the global perspective of system transaction frictions, the absolute value will be used).

The example below illustrates this definition. Let us consider a trade in our data sample with the following characteristics:

Date	Time	Quoting bank	Ordering bank	Volume	Price	Side
26-Feb-04	10:00:05	B021	B045	25	2.05	Buy

Looking at the quotes posted in the system at the time of this trade, we follow the steps described above. The most recent quote with respect to the time of the trade was posted at 9:59:41 and was two-sided. Hence the spread implied, 2.03-2.05, will be the starting point. Now we go backwards, quote by quote. The next two quotes, posted at 9:59:33 and 9:59:15, do not modify our reconstructed best spread, since the ask prices are higher than 2.05. However, the following, posted at 9:58:52, had a better bid price. Therefore, the implied best spread was 2.04-2.05. We continue going backwards and finally we exclude all quotes posted prior to 9:58:07. We do this because the quote posted at 9:57:49 is most likely out-of-date at the time of the trade, since it gave a bid price, 2.05, equivalent to the best ask price at that instant.

Date	Time	Quoting bank	Bid price	Bid volume	Ask price	Ask volume
26-Feb-04	9:57:32	B134	2.04	35	0	0
26-Feb-04	9:57:49	B003	2.05	70	0	0
26-Feb-04	9:58:07	B104	0	0	2.09	10
26-Feb-04	9:58:52	B021	2.04	70	2.06	13
26-Feb-04	9:59:15	B122	0	0	2.07	80
26-Feb-04	9:59:33	B122	0	0	2.06	100
26-Feb-04	9:59:41	B081	2.03	10	2.05	5
26-Feb-04	10:00:24	B013	2.04	60	0	0
26-Feb-04	10:01:01	B056	2.04	45	2.07	100

Hence, the resulting effective bid and ask prices would be:

$$p_b^t = [2.04 \cdot 25 / 25] = 2.04$$

$$p_a^t = [2.05 \cdot 5 + 2.06 \cdot 20] / 25 = 2.058$$

The friction would amount to $\frac{v}{36000} \cdot \left| p - \frac{p_b^t + p_a^t}{2} \right| = \frac{25}{36000} \cdot \left| 2.05 - \frac{2.04 + 2.058}{2} \right| = \frac{0.025}{36000}$ (mio EUR), i.e. around 0.70 EUR.

Once we have defined this cost/benefit associated to each trade, the next section tackles the main question, i.e. how to decompose total friction costs arising on a daily basis as liquidity flows across the market. But before that, let us outline how the friction just defined compares with the profit/loss calculation that every liquidity manager works with, i.e, financing costs measured against the EONIA benchmark.

3.3 Comparison between the frictions and the ex-post profits and losses

It is natural to examine how this initial transfer of wealth occurring at dealing time, the friction, relates to the entire end-of-day transfer of wealth caused by the transaction. The latter, which is by far easier to calculate than the former, is known as soon as the EONIA rate index is itself known. As a matter of fact, if

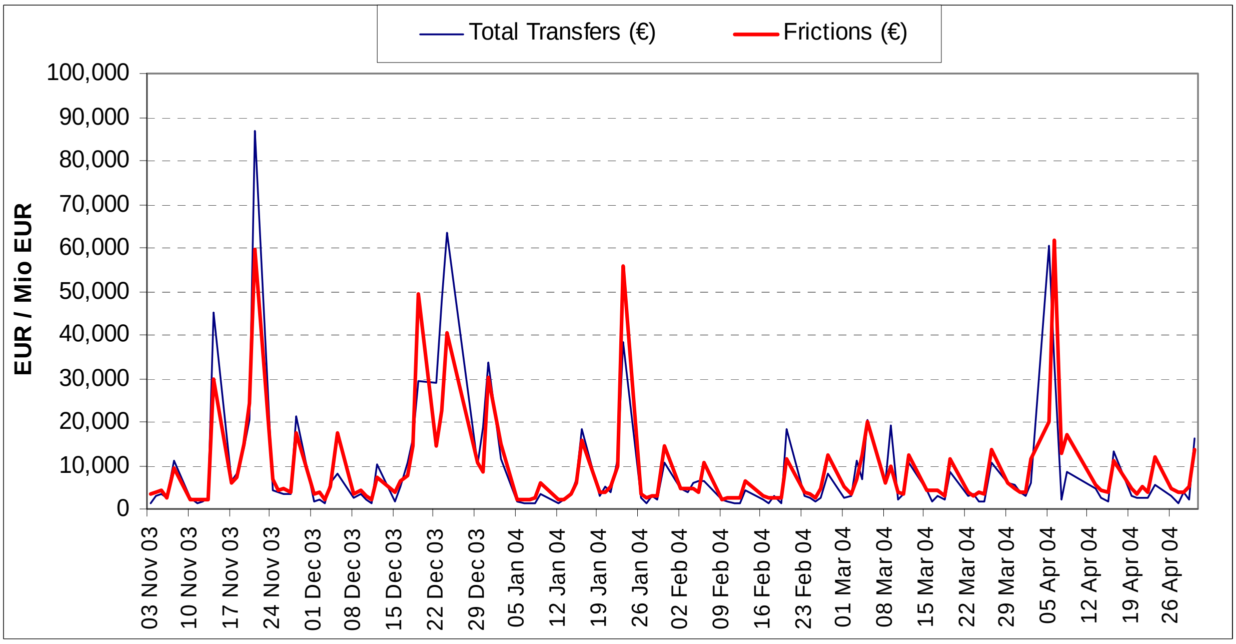
- *nd* is the length of the operation, expressed in days (usually nd=1, but over week-ends nd=3, and it becomes up to nd=5 due to holiday effects in December)
- *v* is the amount of money that is lent (borrowed),
- *r* is the interest rate of the operation of overnight lending (borrowing),
- and *e* is the EONIA to be officially fixed a few hours after the deal itself,

then the deal produces a profit or a loss *p* which is expressed by $t=v*(r-e)*nd/36000$. (If r is bigger than e, the lender has earned a profit and the borrower makes the corresponding loss, while of course it is the way around if e is bigger than r).

We will call this final outcome of the transaction the total transfer (of wealth) and denote it with *t*. This total transfer *t* is the sum of the initial effect which we have called the friction and will be denoted with *f*, and of a complementary effect that results from the motion of the overnight rate. The overnight rate moves from the fair value that it had at the instant of the deal to the final value of the EONIA, which is a daily average index; this evolution produces a financial effect, gain for a counterparty and loss for the other one. We call this complementary effect the *speculative effect* and denote with *s*. The final outcome p of the transaction is the algebraic sum of the friction and of the speculative effect: $t=f+s$.

It is a priori unclear whether, in this sum, one term dominates the other. To examine this question, one can simply compare the friction and the total transfer, for if they resemble each other, then the friction explains most of the total transfer and thus the speculative effect is dominated by the friction. This is indeed what occurs. **Chart 5** shows that the (sum of absolute values of) total transfers occasioned by the transactions observed in one day is very close to the (sum of) frictions. This result is remarkable because each of these two variables is obtained in a very different way. Indeed, while the determination of the friction involves the complex calculations described in section 3.2 – but involve no data of the realised EONIA, - the determination of the total transfer is contained in the very simple formula $t=v*(r-e)*nd/36000$. Nevertheless, the two series evolve in a strikingly parallel way:

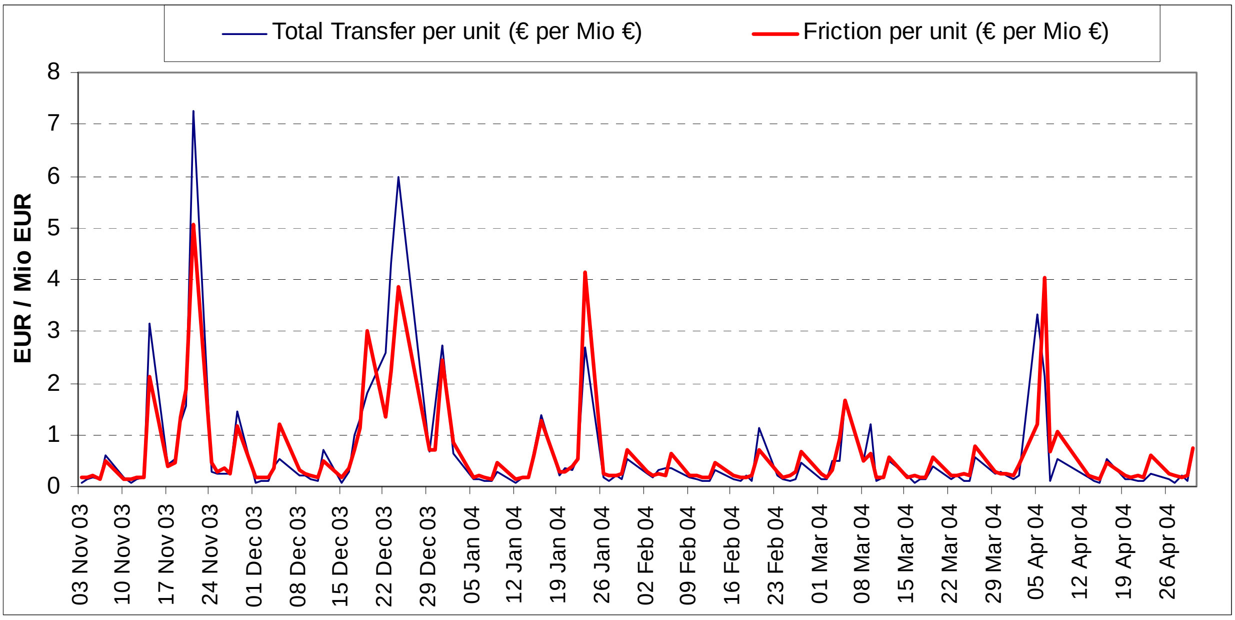
Chart 5: Total transfers of wealth compared with the frictions (in absolute terms, in euros)



This parallel development in the two curves in Chart 5 delivers the unambiguous message that the transfer of wealth can be primarily attributed to the frictions. Only a residual part is actually the consequence of market prices changes, i.e. the product of hedging and speculation.

Normalising the total transfers and the frictions by dividing them by the total daily turnover yields the relative transfers and frictions per EUR million transacted, shown in **Chart 6**. The pattern is very similar.

Chart 6: Total transfers of wealth compared with the frictions (in relative terms: EUR per million EUR)



Hence, there is no clear trace of a noticeable speculative behaviour by some market participants. Indeed, if a significant proportion of banks deemed their information, say on the last day of a maintenance period, better than the market's information reflected in the rate, they would anticipate and make speculative deals that would only be contained in the speculative effect, but not in the friction. This does not seem to be the case, judging from the results shown and the fact that the absolute size of speculative profits achieved can be considered as quite low.

4. The network flow approach

The aim is to identify the minimal aggregate friction that arises from the necessity to trade in order to achieve a given end-of-day net position for every bank. Any actual friction in excess of this minimal friction can be thus attributed either to intraday payment constraints that treasurers need to comply with and which make extra trading necessary or to market imperfections.

4.1 The actual transportation cost and the statement of the minimisation problem

The starting point is a large amount of transactions, an average of around 438 per day, with an average (median) volume of EUR 38 (15) million per transaction[15]. For each transaction, a market price is determined, following the method described in the previous section. Then, the unit friction is determined as the average absolute difference between actual transaction price and the market price, as defined in the previous section. Hence, for each pair of banks A and B, the unit friction associated with a loan from A to B is computed as the volume weighted average of the difference between actual and market price over all transactions in which A lent funds to B. Its unit is percentage per annum. In this unit friction, idiosyncratic factors such as relative size, credit rating and market power of the two banks involved are reflected, since the quoting bank is always in a position to refuse a trade once an order arrives, the order itself can differ from the quoted offer and the terms of the transaction are thus the result of a negotiation. These factors leading to a deviation from the market price will be considered as exogenous and dependent on the two banks involved. Moreover, unit frictions seem to depend on the general market situation, especially in terms of volatility and spread with respect to the ECB target rate. **Chart 7** shows that aggregate frictions invariably increase on days with unusually high spreads EONIA versus minimum bid rate. These days coincide in the sample exactly with end of maintenance periods, an episode of underbidding in mid-November and a period of tight liquidity conditions and high demand in December 2003[16]. Hence, as could be expected, on days where there is

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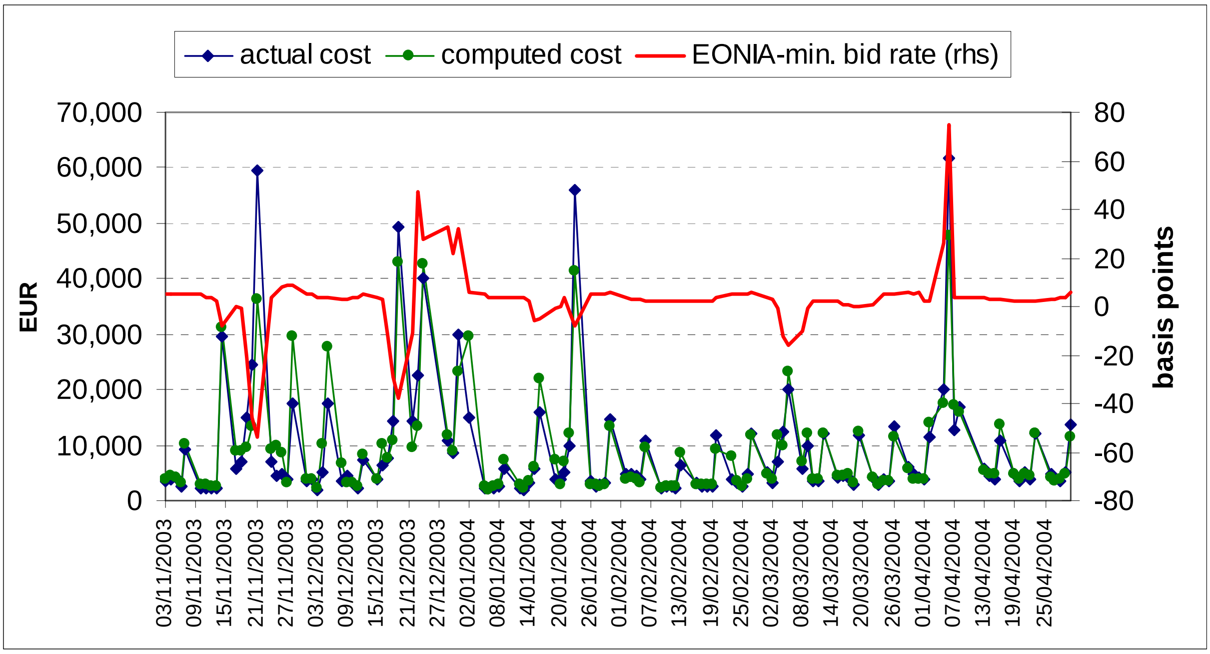
[15] The large difference between the mean and median transaction volume is explained by the skewness of the distribution. There is a relatively low percentage of high-volume transactions: 2.6% of the transactions involved more than EUR 200 million. The largest transaction amounted to EUR 2 billion.

[16] After the allotment of the main refinancing operation on 16 December, EONIA fell below the minimum bid rate, due to expectations that the maintenance period would end with net recourse to the deposit facility. As a result of very large autonomous factor forecast errors on 22 and 23 December, the maintenance period actually ended with a net recourse to the marginal lending facility of EUR 11.1 billion. Consequently, EONIA increased to 2.47% on the last day. During the

high volatility and high dependence of the rate on liquidity conditions, both the spreads and the margins paid or received by banks with respect to the market price increase, in contrast with days where the smoothing effect of the averaging provision drives the rate[17]. Uncertainty about the marginal value of liquidity seems to play an important role, generally triggered by aggregate liquidity conditions or doubts about the reaction of the ECB, as in mid-November and end of December 2003. Otherwise, on days with no such uncertainty, costs tend to be very stable, apart from the obvious effect of weekends, multiplying by 3 the cost of Friday transactions.

Chart 7: Aggregate daily frictions and EONIA vs min. bid rate spread



In fact, for each (ordered) pair of trading banks, unit frictions are relatively stable over time, once we take account of this volatility effect. In other words, once we divide the total sample in two subsamples, one for "normal days" with aggregate daily unit cost lower than EUR 0.28 for every EUR 1 million transacted and "high cost days" with aggregate daily unit friction above this threshold[18], the variability of the unit frictions transacted between two given banks is low within each of the sub-samples. Hence, whenever bank A lends to bank B the above-defined friction per million euro transacted is similar within each sub-sample and thus a matrix of bilateral unit friction costs can be estimated just by taking the volume-weighted average over all transactions where A lends funds to B. **Chart 7**, also showing how the actual aggregate daily frictions compare with the aggregate daily

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following days, EONIA remained at relatively high levels reflecting the rather tight liquidity conditions and the higher liquidity demand from Christmas to New Year. After a large MRO allotment and settlement on 30 December, overnight rates started to decrease.

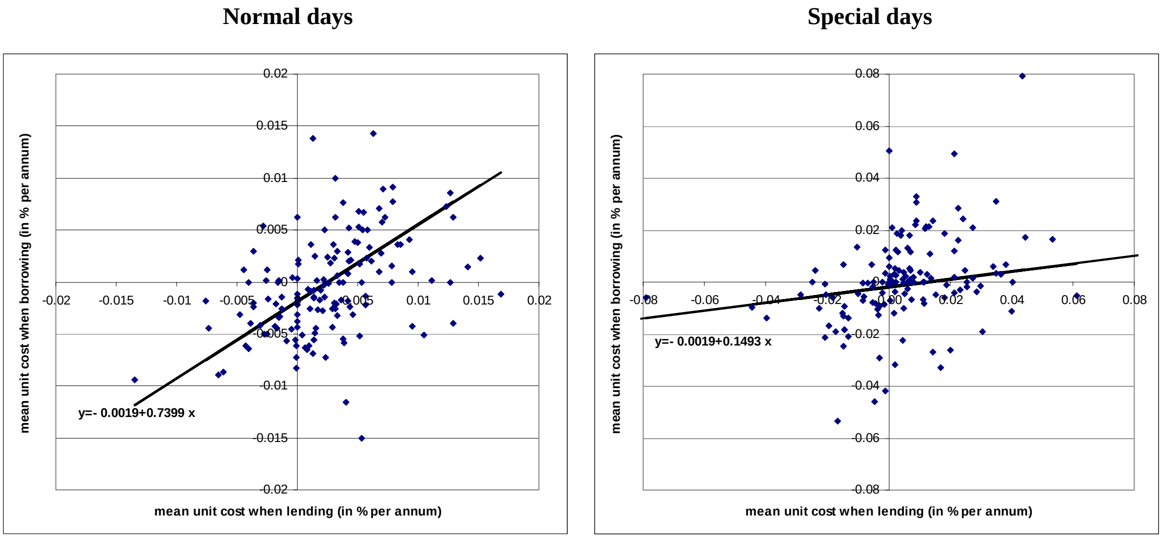
[17] See Würtz (2003) for a comprehensive analysis of the determinants of the EONIA rate.

[18] This threshold corresponds thus to 1 basis point of unit cost, since the daily interest for one day would amount to 0.01*(10^6)/36000 ≈ 0.28 EUR per EUR million transacted. In defining this threshold the weekend effect (on Fridays the cash is lent for three days and thus interest is multiplied by 3) has not been considered.

frictions computed using these two matrices of estimated unit friction costs, confirms that these bilateral unit frictions are stable within each sub-sample.

These aggregate frictions are computed in a straightforward way by multiplying the average estimated bilateral unit friction cost for bank A lending to bank B by the amount transacted and adding up the daily total. The estimated signed transaction costs reveal an interesting cross-section pattern, shown in **chart 8**, where each point in the scatterplot corresponds to a bank. On both sub-samples, a positive correlation between friction costs incurred by a bank when lending and when borrowing is present. However, the relationship is clearly stronger on normal days where market conditions are more stable. Hence whenever a bank A tends to lend at a *higher* rate, relative to the current market rate, it turns out that it also borrows at a rate *lower* than the market rate. The costs or profits would thus generally not depend on the side a bank is trading on, but on the bank itself. This is reassuring, since it indicates that unit frictions are well defined, reflecting bank characteristics stochastically orthogonal to all factors determining the general price level. On special days though, with a turbulent market and banks seeking more or less "desperately" to cover their short or long positions before TARGET closing, it seems natural that other factors, foremost the perceptions about aggregate liquidity situation, tend to dampen the effect of bank-specific factors on the prices paid. Thus being on the "right" side of the market, i.e. lending (borrowing) when there is an aggregate shortage (excess), would matter more than being a large player.

Chart 8: Individual bank average unit costs on each transacting side [19]



Normal days

Special days

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[19] The regression lines shown are not the usual least squares estimates. The method used consists of finding the least median of absolute residuals, instead of the least sum of square residuals. The robustness properties of this method are shown in Rousseeuw et al. (1987).

This matrix can be used for defining costs associated to each arc in a classical linear network flow cost minimisation problem. The general formulation of such a problem (Bertsekas, 1998) is as follows:

Let us assume that we have a set N of *nodes* and a set A of (ordered) pairs of distinct nodes from N called *arcs*. Being an ordered pair, the arc (i, j) is to be distinguished from the arc (j, i).[20] Suppose that a variable x_{ij} measures the quantity flowing through each arc (i, j). For instance, in the case of a hydraulic network, this variable would be water flow. In our case, the nodes will correspond to banks in the e-MID panel and the measured variable will simply be the amount lent by bank i to bank j during a day. The problem is to find, given a fixed unit transportation friction a_{ij} for each arc (i, j), a set of arc flows that minimises total transportation friction subject to given net inflows/outflows for each node and to upper and lower flow bounds for each arc. Expressed mathematically:

minimise $\sum_{(i,j)\in A} a_{ij} x_{ij}$

subject to the constraints

$$\sum_{\{j|(i,j)\in A\}} x_{ij} - \sum_{\{j|(j,i)\in A\}} x_{ji} = s_i, \forall i \in N$$

$$b_{ij} \le x_{ij} \le c_{ij}, \forall (i, j) \in A$$

Now let us consider a simple example of how to formulate our problem in the same terms:

Assume that the panel has only 4 banks, A, B, C and D and we observe on a given day these four banks have made the following transactions summarised in the actual flow matrix (fig. 3). Let us further assume that, over all days of the sample, the average friction costs computed[21] over all transactions involving each pair of banks are summarised in the matrix of average unit friction costs shown in fig. 4. From fig. 3, it results that the net flow for each bank, i.e, the change in the end-of-day reserve position with respect to the previous day, will be (in EUR million)[22]: $s_A = 200$, $s_B = -115$, $s_C = -35$, $s_D = -50$.

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[20] Such a set of nodes and arcs connecting nodes is generally known as a *directed* graph (Bertsekas, 1998).

[21] These average unit costs would be computed as a weighted average, with transacted volumes as weights.

[22] The net inflow for each bank is computed as the sum of the column minus the sum of the row corresponding to the bank.

Fig. 3: Actual transactions (in EUR million)

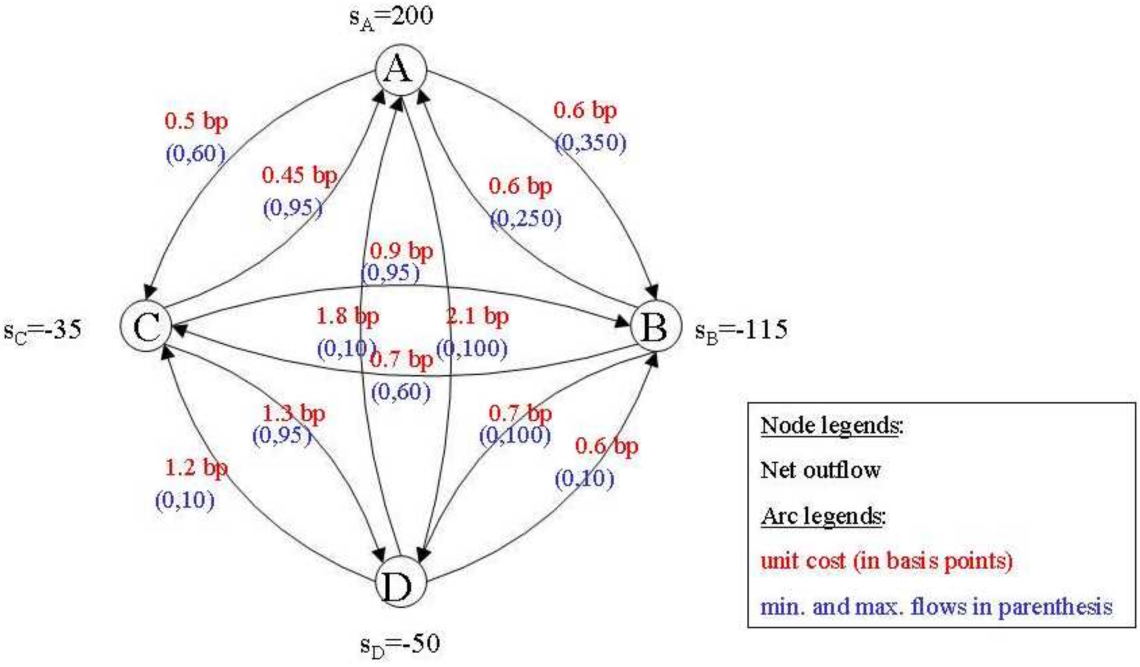
$$\begin{array}{cc} & \overbrace{\begin{array}{cccc} A & B & C & D \end{array}}^{\text{borrowing}} \\ \text{lending}\left\{\begin{array}{c} A \\ B \\ C \\ D \end{array}\right. & \begin{pmatrix} - & 100 & 50 & 50 \\ 0 & - & 10 & 0 \\ 0 & 25 & - & 0 \\ 0 & 0 & 0 & - \end{pmatrix} \end{array}$$

Fig. 4: Average unit costs (in basis points)

$$\begin{array}{cc} & \overbrace{\begin{array}{cccc} A & B & C & D \end{array}}^{\text{borrowing}} \\ \text{lending}\left\{\begin{array}{c} A \\ B \\ C \\ D \end{array}\right. & \begin{pmatrix} - & 0.6 & 0.5 & 2.1 \\ 0.6 & - & 0.7 & 0.7 \\ 0.45 & 0.9 & - & 1.3 \\ 1.8 & 0.6 & 1.2 & - \end{pmatrix} \end{array}$$

Now, let us imagine that these banks only cared about their end-of-day position, i.e. that all the job of the treasurers had been to make their end-of-day position match these net flows. In this case, the optimal flow of liquidity in the system, in the sense of minimising total friction costs, would be the result of the classical minimum network flow cost represented in **figure 5a**.

Figure 5a: Example of network transport optimisation.

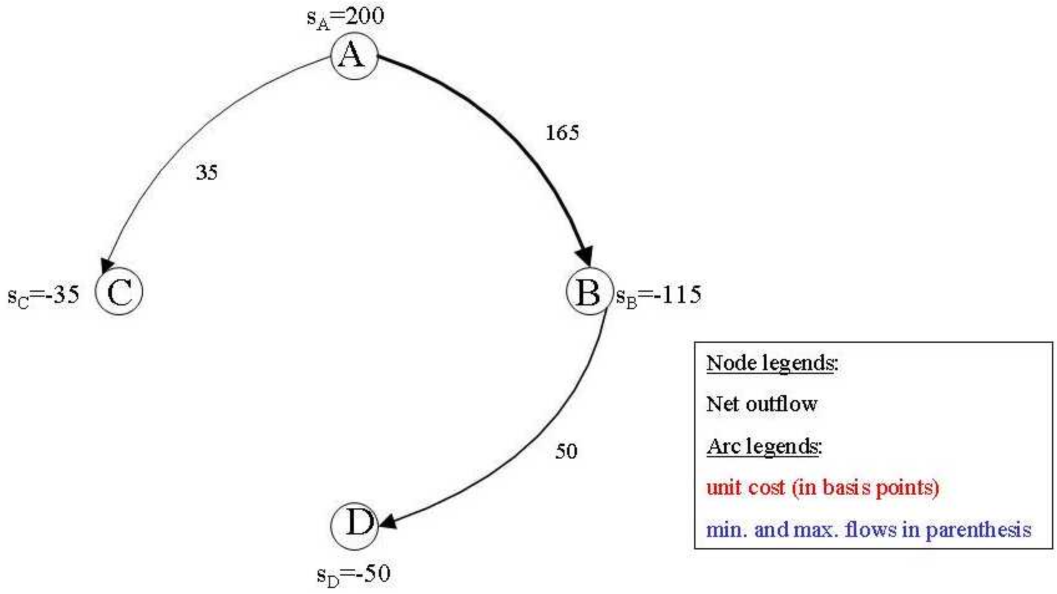


Note that the average unit friction costs serve as arc costs in our problem statement. What about the maximum and minimum admissible flow for each arc (i.e. the b_i's and c_i's in the problem notation)?. Obviously there are limits to the amount that a bank can prudently lend or borrow in one day to another bank and these limits will depend on their respective sizes. The approach we have followed is to set for an arc (i, j) always a minimum bound of zero (no bank is constrained to lend a positive amount) and to set as upper bound the minimum of these two:

1. the highest amount lent on any single day of the sample by bank i to any bank
2. the highest amount borrowed on any single day of the sample by bank j from any bank

In our example, we have assumed that the following maximum daily amounts lent and borrowed were observed for each bank: A (400,340), B (250,350), C (95,60) and D (10,100).
The solution to the example problem is given by

Figure 5b: Optimal solution to the example of network transport optimisation.

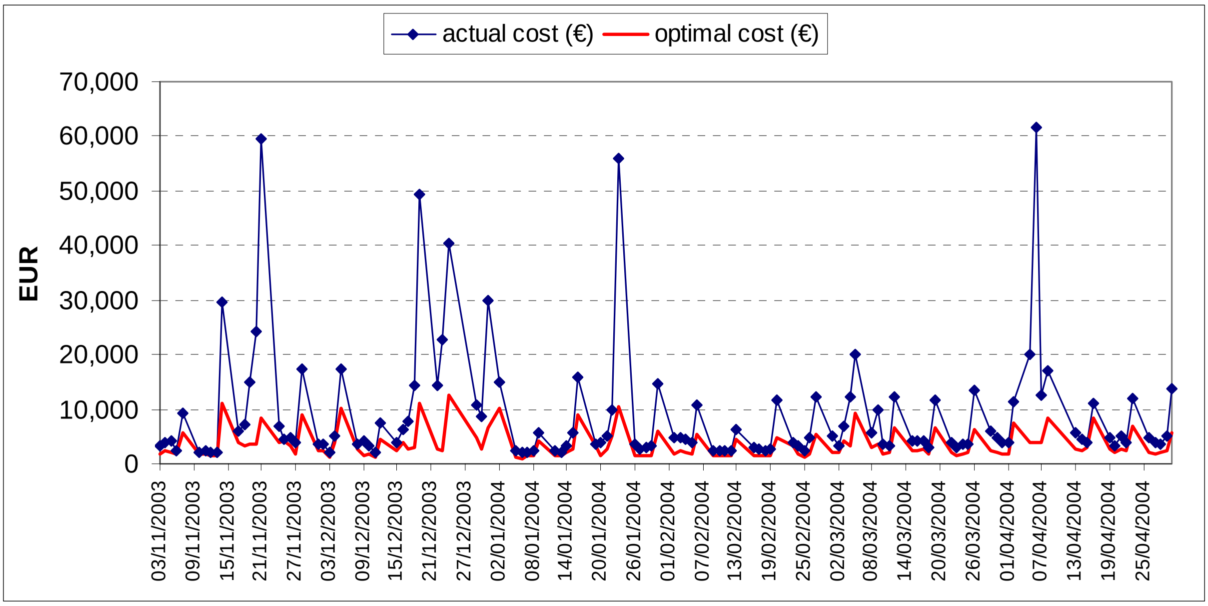


The real daily problem statements that we obtain from our sample are only different from the above example in quantitative terms, since the network is composed of 175 banks. Since the sample period was subdivided into two samples in order to reflect the different transportation costs of normal as against "special" days, we obtain a slightly different network structure for each of the two kinds of day. For some pairs of banks there are no trades in the sub-sample and therefore no friction cost estimate. In this case, no arc exists in our problem statement for such a pair. As a result, on any normal day the network will comprise 175 nodes and 4094 arcs, the number of distinct bank pairs for which at least one trade was observed on a normal day. On any "special" day, it will comprise 175 nodes and only 3603 arcs. The next subsection shows the solution to the stated optimisation problems.

4.2 The optimal transportation cost

The optimal solution to the daily friction cost minimisation problem was found using the so-called relaxation method (Bertsekas, 1998)[23]. **Chart 9** shows the optimal aggregate daily friction cost as compared to the actual one and the aggregate friction cost computed from the estimated arc costs. The most striking feature of the optimal daily friction series is its stability, since none of the sizeable increases occurring on end of maintenance period days or the other events mentioned appears to affect it in a comparable way. Aggregate friction costs increase on special days in a somewhat less than proportional way to the estimated unit friction costs on those days. On normal days, it appears that the optimal aggregate daily friction generally lies at around 40-70% of the observed one. Does this mean that important inefficiencies are present, mostly concentrated on special days? Are these inefficiencies unavoidable?.

Chart 9: Daily optimal trading costs vs. actual trading costs



A proper tentative answer to this question needs to take into account as well how the optimal solutions look like in terms of flows leading to such improvements in the friction costs. In the aggregate, the sum of all the optimal flows - the turnover - is higher than the corresponding sum of observed flows on every single day in the sample. Since by construction the net outcome is the same in both, a priori we can conclude that there is a higher volume of "floating" funds being traded in the optimal setting, i.e., funds that are borrowed and then redistributed in the system by some banks acting, to some extent, as brokers. Indeed, if we define the daily gross turnover of a given bank by the sum of total funds lent and borrowed on that day, we may compare it to the daily net flow (in absolute value). It is then clear, from **chart 10** showing the resulting (aggregate) ratio, that the optimal solution exhibits a higher degree of intermediation by some banks in the distribution of funds (lower ratio of net to gross flows). The amount of these "floating" funds, measured as the difference between gross and net aggregate turnover, is about three times higher in the optimal solution. A further interesting observation is that days with high volatility and spreads, such as end of maintenance periods, correspond to higher intermediation, mostly by a few Italian banks. However, these banks that are actually playing the role of redistributing liquidity are doing it at relatively high charged prices, so that this high degree of intermediation does not lead, as in the optimal solution, to an overall decrease in friction costs but, on the contrary, to the observed explosion. In fact, the banks that would be acting as turntables in the system, in the optimal solution, are different from those observed playing this role.

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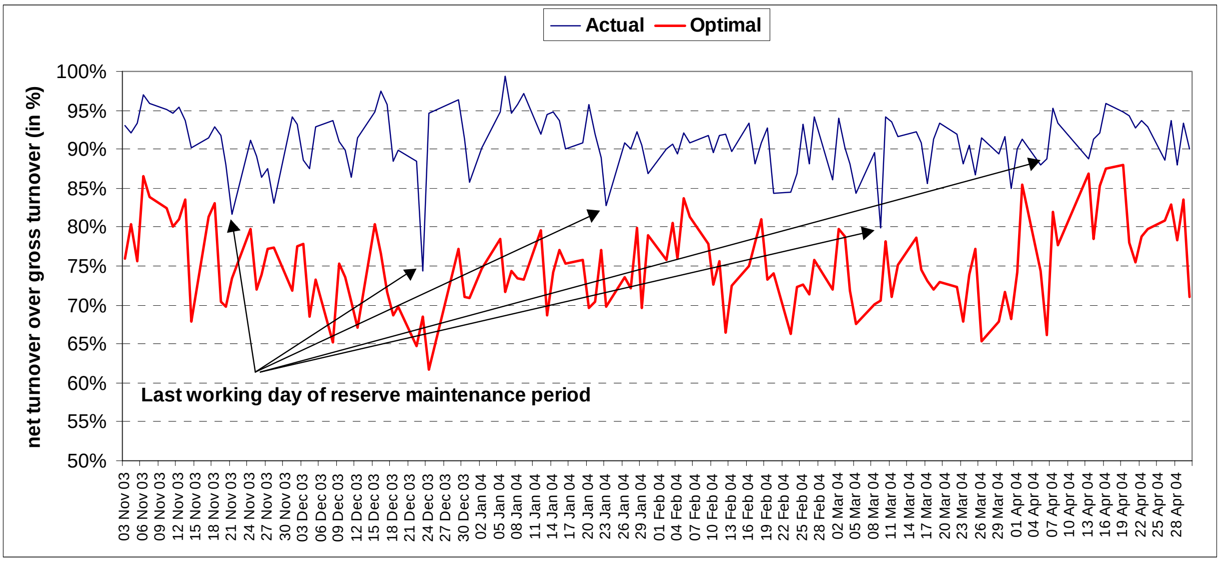
[23] The authors would like to thank the invaluable computational help provided by the publicly available algorithms located in the web site of NEOS server at http://www-neos.mcs.anl.gov/neos. Further documentation on these resources can be found in Czyzyk et al. (1998) and Gropp and J. Moré (1997).

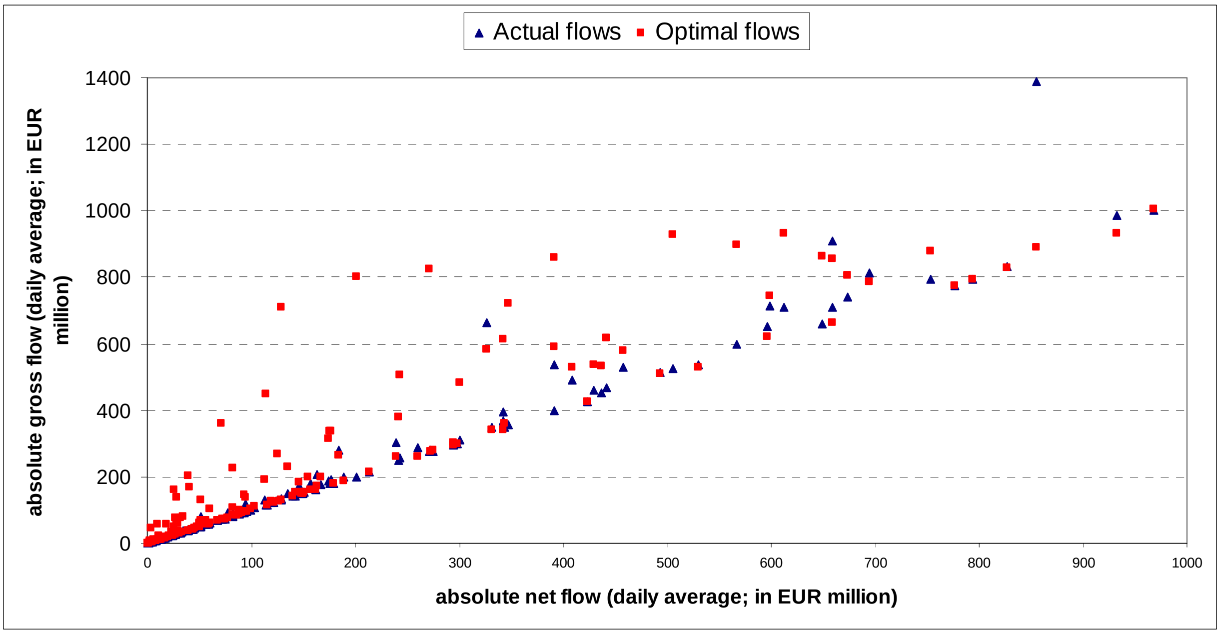
Their list is longer and led by foreign banks rather than Italian ones. **Chart 11** shows the absolute net and gross average flows for each bank. In the actual flows, most of the banks lie in the forty-five degree line, hence they only trade in the market in one direction, either lending or borrowing during the whole day. However, in the case of the optimal flows, a larger number of banks trade in both directions during the same day, re-distributing liquidity from different sources to different destinations. Most of these intermediaries would, in the optimal solution, still be among the largest participants, i.e. the optimal solution is not requiring smaller banks to trade unrealistic amounts.

Chart 10: Daily ratio between net and gross turnover



Note: Gross turnover is defined as the sum of all flows in the network. Net turnover is defined as the sum of the net daily flow over all banks.

Chart 11: Absolute individual banks' net and gross flows



We may thus summarise with the following three basic observations:

1. The optimal solution shows a higher degree of intermediation than the actual one, i.e. more banks are borrowing from some banks only to lend to some others on the same day, and this for higher amounts.
2. It is likely that this lack of re-distributing banks leads, on the last day of a maintenance period, to a higher impact on the overnight rate for a given aggregate liquidity shock, all other things equal.
3. Banks playing an active role as re-distributors of liquidity in the optimal solution are not the same as the banks playing this role in reality. In fact, those few banks actually intermediating are doing so because that trading is profitable, as can be seen from their price margins (estimated cost matrix), especially on "special" days with volatile market conditions (end of MPs, days with high uncertainty about liquidity conditions, after underbidding or large forecast errors).

Given the absolute size of the daily actual frictions, amounting to a daily average of EUR 5,895 for the whole e-MID system, it should be stressed that this market is nevertheless highly efficient, even though the daily average corresponding to our hypothetical optimal outcome would amount to EUR 2,352. However, the following tentative explanations can be put forward in an attempt to understand the reasons for this difference. These explanations are grounded on the function of this market and the way its participants make use of it, rather than theoretical models.

a) Lack of coordination: there is no central authority organising the flows, so in any case the very optimal solution is very unlikely to be found spontaneously by market participants. The problem indeed differs, it should be noted, from the problem of the determination of the fair price. One may intuitively understand how market forces are able to trigger a price discovery process. The intuition, encompassed in the "invisible hand" concept, relies on the idea of a negative feedback mechanism. Market participants have an interest in offsetting an excessively low buying price or an excessively high selling price by proposing a higher buying price or a lower selling price, thus enforcing price discovery. In the case of the optimal flow of transactions, this quite simple argument does not apply and no such simple discovery process can be imagined.

b) Uncertainty: each bank gains information about its liquidity shocks during the day and therefore infers only gradually what will be its final net need for adjustment of its end-of-day position. It is hence natural to think that banks trade whenever their private new information has arrived and thus have less chances to pick a low friction counterparty, but rather take the best instant quote. At any instant, a given friction cost prevails on the market for any given bid or ask size, and this friction cost, just as the spot price itself, is a "take it or leave it" condition. Waiting for it to diminish before performing the required transaction would expose to the obvious risk that the spot price adversely shifts in the meantime, especially in a volatile market as the one prevailing on what we have branded as "special" days. This is not a real option, given that the transaction friction cost is generally not sizeable in absolute terms. The fact that the actual flows of each bank are much more diversified in number of counterparties than the optimal flows would be evidence that banks are indeed not waiting to find a low unit friction counterparty. Those optimal flows, as one may have the intuition, are usually those where each bank would concentrate its trading with a more reduced number of banks, for higher amounts.

c) Lack of redistributing banks: the role of acting as a broker is scarcely attractive because the profits that can be obtained are not high enough to justify the entailed increase in the balance sheet size. Only on relatively tumultuous days, where aggregate imbalances and asymmetries in the information on aggregate liquidity conditions trigger a dry-up of the market[24], do some banks act as intermediaries, but then they do it at high premia. This negative correlation between market depth and activity of intermediaries seeking to take advantage of market power is further confirmed by the fact that intermediation somewhat increases on Fridays, apart from the more clear increases whenever volatility is high (special days).[25]

Out of this combination of effects, all of which surely contribute to explaining the discrepancy between the actual structure of flows and the optimal flows implied by the experiment conducted, we may discern, from a policy or public welfare perspective, what should be taken as an irremediable fact of life and what not.

The first factor is obviously a consequence of the unstructured character of the euro area money market. Such a system relies on the profit-seeking interest of some banks to act as brokers and hence will not be free of cost. It is not clear though whether a broker system with a reduced number of counterparties subject to the obligation to provide at all times market liquidity would lead to the sought friction reduction, not to mention issues related to credit risk if a reduced number of banks have to provide credit to the system. However, the high friction costs observed on what we have called “special” days are so highly correlated with end-of-maintenance-period volatility that the causality relation is easily suspected. The elimination or great reduction of the uncertainty surrounding liquidity conditions at the end of each maintenance period, which could be achieved either by the use of fine-tuning operations, the narrowing of the corridor defined by the standing facilities on the last day of the period or both, would certainly moderate friction costs.[26]

5. Conclusions

While the dynamics of the euro overnight rate have been the object of intensive analysis in recent years, the judgement on the cost-efficiency issues of this market has generally been limited to relevant

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[24] On the last day of a maintenance period, information on aggregate liquidity conditions becomes gradually translated in the overnight price. The process is smoother the smaller the imbalance. It is reasonable to assume that on such a day, most banks are seeking to trade in the same direction and that some market participants possess more information than others about the real aggregate liquidity conditions.

[25] Hartmann et al. (2000) point out as well that on Fridays there is a slightly higher volatility as a consequence of liquidity managers’ attempts to square positions before the weekend

[26] Note that the recent changes to the monetary policy implementation framework of the Bank Of England incorporate both measures, i.e, regular last-day fine-tuning and narrowing of the standing facility corridor. See www.bankofengland.co.uk/speeches/speech225.pdf

but somehow qualitative information. In particular, the important share of cross-border transactions in the total volume, the close and simultaneous co-movement of the overnight rate in the different countries composing the euro area and the fact that this rate generally behaves as predicted by rational models all indicate that no large market imperfections are reflected in the rate.

This paper has studied frictions in a part of the euro area interbank overnight market, the e-MID electronic platform, using a new, quantitative approach. Using a large sample of tick data containing individual trades and quotes identified through a bank code, we have looked at the prices paid and received by each bank and compared them to the instant market price. Together with the aggregate characteristics, such as intraday patterns of turnover, market spreads and rate volatility, these signed costs/profits reveal certain regularities, normally explainable by the heterogeneity of banks themselves, that fit well with previous analyses. Moreover, these instant frictions clearly dominate in size the speculative gains/losses resulting from the observed transactions when using the daily EONIA as a benchmark.

Using estimated unit costs, explained by these bank characteristics, we have taken a step further in the aim of assessing how large a share of these frictions could stem from individual intraday liquidity management constraints faced by treasurers, from the structure of the market, or from both. The approach taken has been to consider the observed net daily exchange of flows for each bank, i.e. the net change in its current account level, held in order to comply with reserve requirements, as fixed. Then, the set of "optimal" flows minimising the total cost is solved as a regular network transportation problem, for which solution algorithms exist.

The obtained set of optimal flows appears to lead to an important reduction in overall frictions, estimated at around 45% on normal days (excluding days with rate instability such as end of maintenance periods or large liquidity imbalances) and as much as 65% on hectic days in the market. This seems to indicate that treasurers enjoy a relative freedom during most of the maintenance period, being able either to simultaneously satisfy intraday obligations and achieve their end-of-day reserve target position or to focus mostly on intraday obligations and rely on averaging instead of really targeting a precise end-of-day position. At the end of the period, however, the binding constraint of reserve requirement fulfilment forces treasurers to incur higher frictions. However, overall frictions remain very low in absolute terms and are most likely considered by treasurers as a minor price to pay for a functioning market they can rely on to flexibly manage their cash payments. Costs entailed by an overnight deposit market not fulfilling this function would be incomparably higher.

However, looking in more detail at the obtained "optimal" flows, we observe that ideally the aggregated frictions would be reduced through the intervention of more large players in the market, which would act as re-distributors of liquidity, lending and borrowing on the same day, not just for their own liquidity needs. The fact that this does not happen, or rather that whenever some banks take such positions they obtain larger than usual profit margins, could indicate a less desirable feature on those days, namely lack of market liquidity.

Peaks in frictions are extremely correlated with important departures of the liquidity situation from neutrality and/or ends of maintenance period, leading not only to movements in the level and the volatility of the overnight rate, but also to increases in the spreads charged and received in the market. If, as can be expected, fewer banks are willing to participate in the market on those days, because they are risk-averse and fear information asymmetries, the result seems to be a relative lack of market liquidity and less smoothness in the flow of funds. This leads to a lower degree of market integration and to higher frictions.[27] From this perspective, the implementation of an adequate policy aiming at a reduction of the peaks in uncertainty about the marginal value of liquidity, observed on end-of-maintenance-period-days, would be a helpful response to improve market conditions and ensure an efficient, fair and smooth circulation of liquidity within the euro area banking system. In this vein, the changes to the Eurosystem's operational framework implemented in early 2004, aiming at stabilising the overnight rate and avoiding episodes of instability due to uncertainty about policy rate movements, should have contributed to a further improvement in the efficiency of the euro overnight market.

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[27] Note that sometimes, the EONIA rate on the last day of a maintenance period did not "match" with the net recourse to the standing facilities, indicating some kind of market imperfection or timing constraint. The largest such mismatch occurred recently, on 10 August, when EONIA was 16 basis points above the target (minimum bid) rate, although there was a net aggregate recourse to the deposit facility amounting to EUR 4 billion.

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Annex 1

Figure A: Projection of the distances among e-Mid panel banks to euclidean distances in the plane. Dot size indicates average daily gross trading volumes of each bank *(in EUR millions)*

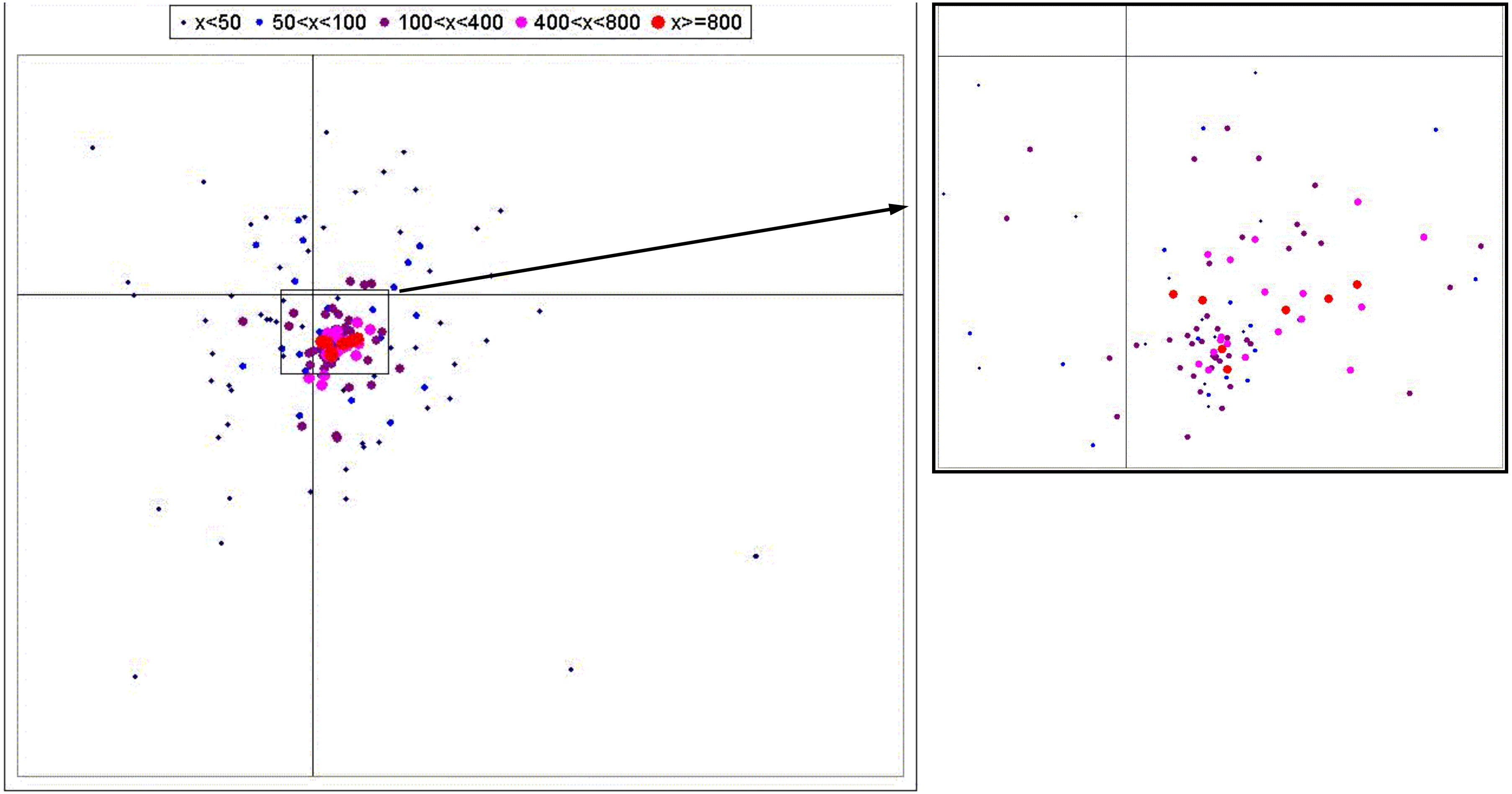
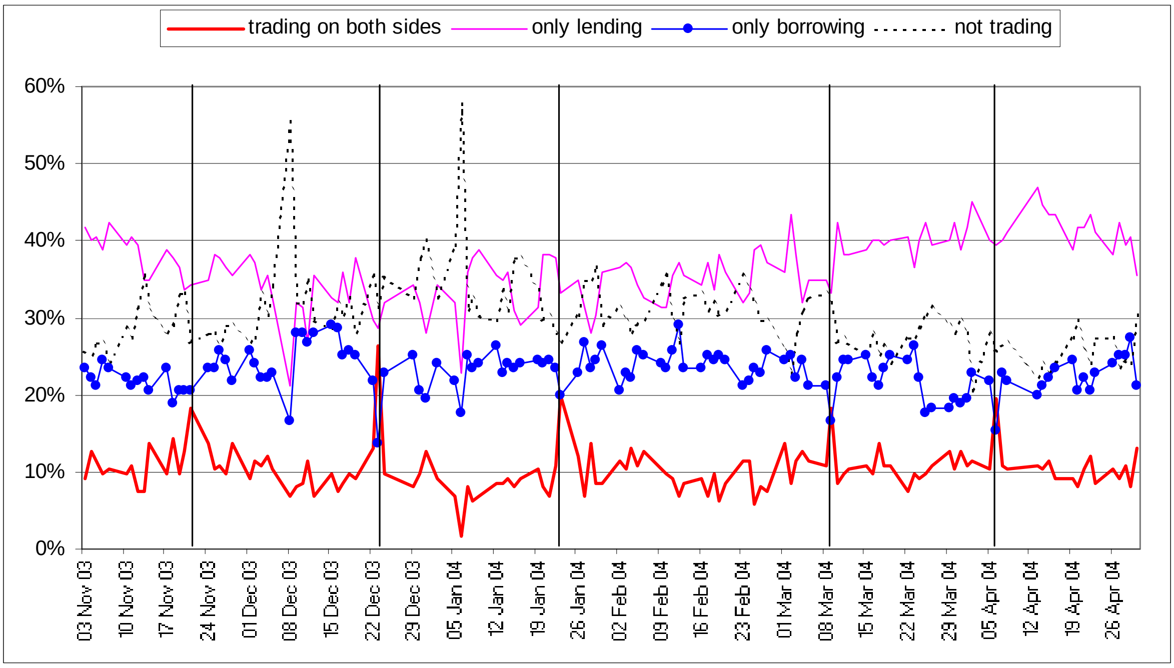


Figure B: Daily share of panel banks' trading on each side of the market, as a percentage of all banks

(vertical lines correspond to the last day of each maintenance period)



Annex 2

Several brokers are active in the overnight deposit market. It is worth to glance at the information contained in the quotations that they contribute on Reuters. We examine here the contributions of six of those brokers, for which we recorded quotations contributed on Reuters pages between the 24.May 2000 and the 20 Jul 2004. The list of those brokers is as follows

Name	City	Reuters page
Carl Kliemm GmbH	Frankfurt	KLIEMMM01
Geldhandels GmbH	Frankfurt	GEHA
Prebon Yamane	London	PYWMEURO
CIMD Agencia de Valores	Madrid	CIMD
Tradition Italia	Milan	TRIT
Tullet France	Paris	LIBERTYCASH1

where the “Reuters page” item indicates the code of the page on which the contributions were made when they were recorded in the data set, some of those codes may have ceased to be valid.

For each record, we define a reference price by taking the median of the mid prices of the brokers for which the contribution is recorded (not all the six are always present in the database. In about half of the cases, 3 of them are present in the database, in about 30% of the cases, 1 is missing, and in about 20% none is missing). Then, we compute the difference between mid prices of individual brokers and this reference price, that we call the spread to reference (str). The two following tables give the empirical probabilities of those spreads to reference for each of the six brokers, in the case of days which are not the last working day of a reserve maintenance period, as well that in the case of the last working days of a reserve maintenance period.

While those tables show a certain heterogeneity in the accuracy of the quotations of the 6 brokers, it remains clear that the accuracy is of an order of magnitude of around two basis points in the case of normal days.

All days except last days of a maintenance period

str	Broker 1	Broker 2	Broker 3	Broker 4	Broker 5	Broker 6
-0.05	0.39%	0.26%	0.28%	0.05%	0.16%	0.38%
-0.045	0.02%	0.02%	0.22%	0.01%	0.04%	0.09%
-0.04	0.03%	0.09%	0.08%	0.09%	0.03%	0.15%
-0.035	0.07%	0.14%	0.30%	0.05%	0.36%	0.78%
-0.03	0.21%	0.26%	0.12%	0.08%	0.17%	0.69%
-0.025	0.56%	0.54%	1.33%	0.41%	0.71%	0.71%
-0.02	0.59%	0.80%	0.41%	0.25%	0.69%	1.03%
-0.015	0.76%	0.96%	3.84%	0.65%	1.86%	0.73%
-0.01	5.55%	6.28%	1.28%	3.11%	7.50%	5.92%
-0.005	7.80%	10.50%	17.07%	10.64%	20.41%	7.57%
0	63.53%	65.61%	20.10%	51.69%	54.61%	52.85%
0.005	10.86%	7.96%	38.92%	19.31%	8.56%	11.19%
0.01	5.25%	3.41%	2.21%	7.28%	2.19%	10.24%
0.015	1.26%	0.54%	6.52%	1.33%	0.80%	1.77%
0.02	0.77%	0.58%	0.26%	0.97%	0.43%	1.94%
0.025	0.65%	0.33%	1.71%	0.77%	0.60%	0.75%
0.03	0.19%	0.08%	0.61%	0.57%	0.13%	0.68%
0.035	0.07%	0.03%	0.78%	0.13%	0.04%	0.32%
0.04	0.08%	0.06%	0.10%	0.11%	0.06%	0.23%
0.045	0.07%	0.03%	0.83%	0.07%	0.04%	0.26%
0.05	0.58%	0.34%	0.20%	0.18%	0.15%	0.45%

Last days of a maintenance period

str	Broker 1	Broker 2	Broker 3	Broker 4	Broker 5	Broker 6
-0.05	2.86%	3.41%	3.80%	1.67%	5.37%	2.57%
-0.045	0.17%	0.51%	1.24%	0.00%	0.18%	0.27%
-0.04	0.17%	0.25%	0.43%	0.42%	0.45%	1.51%
-0.035	0.71%	0.84%	1.83%	0.83%	1.00%	0.71%
-0.03	0.84%	1.81%	0.51%	0.21%	2.91%	0.62%
-0.025	5.09%	6.49%	4.69%	3.96%	5.19%	3.28%
-0.02	1.85%	3.41%	3.71%	2.08%	2.18%	2.13%
-0.015	1.60%	2.11%	2.82%	4.79%	1.64%	1.24%
-0.01	2.86%	4.97%	1.45%	4.38%	10.56%	5.23%
-0.005	3.83%	7.08%	6.14%	8.75%	7.10%	2.84%
0	48.28%	48.48%	26.28%	32.08%	37.67%	29.52%
0.005	5.72%	2.86%	8.92%	9.58%	5.37%	7.54%
0.01	4.08%	3.37%	2.69%	2.08%	4.37%	7.27%
0.015	2.90%	1.64%	4.65%	8.75%	1.55%	3.37%
0.02	3.28%	3.37%	1.79%	2.08%	1.91%	5.05%
0.025	4.50%	2.99%	4.39%	6.88%	2.91%	4.26%
0.03	0.63%	0.51%	4.95%	0.21%	1.91%	2.48%
0.035	0.50%	0.38%	1.11%	1.04%	0.18%	1.24%
0.04	0.59%	0.00%	0.26%	1.25%	0.36%	1.33%
0.045	0.71%	0.34%	2.01%	0.00%	0.27%	0.80%
0.05	3.57%	1.73%	2.77%	3.33%	1.82%	3.46%

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