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Probability of informed trading: an empirical application to the euro overnight market rate.[1]

Julien Idier[2]
Banque de France[3],
European Central Bank,
Centre d'Economie de la Sorbonne, Paris 1.

and

Stefano Nardelli
European Central Bank

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[2]Corresponding author: julien.idier@banque-france.fr. Banque de France, 41-1391, 31 rue croix petits champs, 75049 Paris cedex 01, tel: +331 42 92 37 19

Abstract:

This paper presents a microstructure model for the unsecured overnight euro money market, similar to that developed for stock markets by Easley and O 'Hara (1992). More specifically, this paper studies the role of heterogeneity in the population of banks participating on this market, and the influence of the institutional framework and market organizational aspects of the overnight deposit market. A first empirical assessment of the functioning of this market is based on the probability of informed trade which measures the ability of traders (banks) to interpret signals on the expected evolution of the overnight rate. This indicator is estimated on real-time data publicly available to market participants. Results show that between 2000 and 2004 a heterogeneous learning process of market mechanisms within participants could be observed. From 2005 onwards, however, heterogeneity in the learning process sharply decreased. Moreover, the empirical evidence show that the March 2004 changes in Eurosystem's operational framework have modified the informational patterns of order flow in the euro area money market : informed trades became even more predominant between the last main refinancing operation and the end of the reserves maintenance period than they were before March 2004.

Codes JEL: E58 G21

Keywords: Euro overnight market, PIN models, Microstructure, Monetary policy.

Résumé:

Ce papier présente un modèle de microstructure pour le marché non sécurisé au jour le jour de l'euro, similaire au modèle Easley et O'Hara (1992) développé pour les marchés boursiers. Précisément, le papier étudie le rôle de l'hétérogénéité de la population des banques participant au marché, l'influence du cadre institutionnel et l'organisation du marché de l'euro. Une première évaluation empirique du fonctionnement de ce marché est basée sur la probabilité d'agents informés. Celle-ci mesure la capacité des agents (banques) à interpréter les signaux sur l'évolution du taux au jour le jour. Cet indicateur est estimé sur des données en temps réel, disponibles publiquement, aux participants du marché. Les résultats montrent qu'entre 2000 et 2004 un processus d'apprentissage hétérogène des mécanismes de marché est observé entre les agents. A partir de 2005, néanmoins, cette hétérogénéité diminue très nettement. De plus, l'analyse empirique montre que la réforme du cadre opérationnel survenue en Mars 2004 a modifié l'aspect informationnel des flux d'ordres sur le marché monétaire de l'euro : les échanges informés sont devenus encore plus prédominants entre la dernière opération hebdomadaire de refinancement et la fin de la période de maintenance qu'ils n'étaient auparavant.

Mots clef: Marché au jour le jour de l'euro, Modèles d'agents informés, Microstructure, Politique monétaire.

Non technical summary:

The probability of informed agents models (thereafter PIN Model) have been never applied to money market albeit information is key for the central banks monetary policy. The subsequent paper is a first attempt for applying a simple PIN model to the euro overnight unsecured market based on Easley and O'Hara (1992).

An interesting aspect of this segment of the money market is that the primary source of its liquidity is the central bank, although most transactions actually take place among banks in what is normally indicated as "interbank market". Actually, banks can fulfil their liquidity needs (mainly composed of required reserves and autonomous factors) through two main channels: refinancing operations and the interbank market.

The first channel instruments are the weekly main refinancing operations (MROs), the long term refinancing operations (LTROs) and the fine tuning operations (FTOs). These operations are secured and banks must possess adequate collateral in proportion to the amount of liquidity received from the central bank. As a consequence, the existence of these provisions may actually be discriminatory as banks not having sufficient or low quality collateral are excluded. In other words, existing rules aimed at ensuring financial soundness may actually represent a barrier for some banks.

The second channel for obtaining liquidity is the interbank market. In this market, where a significant amount of transactions are unsecured, central bank's liquidity is distributed across banks through bilateral transactions. Liquidity in the interbank market is typically not centralized and contracts are mainly traded over the counter. Market reputation for a bank is thus important and population heterogeneity appears to be central in the analysis of market price dynamics.

The standard PIN model from Easley and O'Hara (1992) is thus transposed to the euro overnight unsecured market and estimated on a high frequency dataset that spans most of the history of the single currency money market (i.e. 2000-2006). It is notably analyzed the effects of the operational framework on market behaviour through the different reforms and especially during 2004.

Empirical results show that information mainly occurs during the very last days of maintenance periods. Due to the still short history of this market, a rolling estimation of the model is also presented in order to characterize the learning process among banks over time.

Between 2000 and 2004 a heterogeneous learning process of market mechanisms within participants could be observed. From 2005 onwards, however, heterogeneity in the learning process sharply decreased. This follows the March 2004 changes in Eurosystem's operational framework which have modified the informational patterns of order flow in the euro area money market since informed trades became even more predominant between the last main refinancing operation and the end of the reserves maintenance period than they were before.

To conclude it seems that even if market rules on liquidity provisions exclude a pool of banks from participating (due to collateral requirements), heterogeneity has been decreasing since 2004. This is linked to the March 2004 changes of the operational framework that improved market signals. Finally, by reducing both market tensions and opportunities for strategic trade, the increased frequency of FTOs at the end of reserves maintenance periods and the ECB's policy of allotting consistently liquidity above the benchmark amount since October 2005 have reduced the impact of information asymmetries.

Résumé non technique:

Les modèles de probabilité d'agents informés (noté modèle PIN ensuite) n'ont jamais été appliqués aux marchés monétaires bien que l'information soit centrale dans la mise en oeuvre de la politique monétaire par les banques centrales. Ce papier est une première application d'un modèle PIN (Easley et O'Hara (1992)) sur le marché non sécurisé au jour le jour de l'euro.

Un aspect intéressant de ce marché est que la banque centrale est la première source de liquidité bien que la majorité des transactions aient lieu sur ce qui est appelé le marché interbancaire. Les banques peuvent alors satisfaire leurs besoins de liquidité (principalement composés des réserves obligatoires et des facteurs autonomes) selon deux canaux : les opérations de refinancement et le marché interbancaire.

Les instruments du premier canal sont les opérations hebdomadaires de refinancement (MROs), les opérations de refinancement de long terme (LTROs) et les opérations de réglages fins (FTOs). Ces opérations nécessitent du collatéral que les banques doivent mobiliser en proportion du montant de liquidité demandé à la banque centrale. En conséquence, l'existence de ces provisions nécessaires peut être discriminatoire et exclure les banques ne pouvant présenter de telles garanties. En d'autres termes, la mise en place de ces règles qui garantissent la stabilité du système peut représenter une barrière au financement pour certaines banques.

Le second canal de refinancement est le marché interbancaire. Sur ce marché, pour lequel un nombre significatif de transactions ne nécessite pas de collatéral, la liquidité provenant de la banque centrale est échangée entre les banques de second rang de façon bilatérale. Cette liquidité n'est pas centralisée et les contrats sont négociés directement. Dans ce contexte, la réputation de marché se révèle importante pour les banques et l'hétérogénéité au sein de la population impacte alors les dynamiques de prix.

Le modèle standard PIN de Easley et O'Hara (1992) est transposé au marché non sécurisé au jour le jour de l'euro et estimé en utilisant une base de données haute fréquence qui retracent l'essentiel de l'histoire du marché de la monnaie unique européenne (2000-2006). Nous analysons particulièrement les effets du cadre opérationnel sur les comportements de marché au travers des différentes réformes et particulièrement celles survenues en 2004.

Les résultats empiriques montrent que l'information se manifeste sur le marché principalement lors des derniers jours de la période de maintenance. Etant donné l'historique relativement court de ce marché, une estimation glissante est également présentée pour caractériser les effets d'apprentissage parmi les banques au cours du temps.

Entre 2000 et 2004 un processus d'apprentissage hétérogène est observé. Néanmoins, à partir de 2005, cette hétérogénéité diminue. Ceci fait suite aux change-

ments du cadre opérationnel de l'Eurosystème qui ont modifié l'aspect informationnel des flux d'ordres sur ce marché avec des échanges informés plus concentrés entre la dernière MRO et la fin de la période de maintenance.

Pour conclure, il semble que même si les règles de marché concernant l'approvisionnement de liquidité exclut un certain nombre de banques en raison des règles de collatéral, cette hétérogénéité informationnelle est en train de diminuer. Finalement, en réduisant les tensions de marché et les opportunités stratégiques d'échange, l'augmentation de la fréquence des FTOs en fin de période de maintenance, ainsi que la politique de liquidité de la BCE (en allouant une quantité de liquidité supérieure au montant de référence depuis octobre 2005) ont réduit les asymétries d'information.

1. INTRODUCTION

A large part of empirical literature on market microstructure studies the stock and exchange rate markets. However, little attention has been dedicated to money markets. Plausible reasons are the scarcity or, at least, the inaccessibility of money market data, but more importantly the existence of a relatively complex set of rules put in place by central banks.

Central banks regulate and influence the functioning of the money market owing to the special role this market plays for the implementation of monetary policy. As a matter of fact, institutional rules of the money market have a strong influence both on the provision of liquidity - i.e. the asset traded on the market - and, to some extent, on the trading mechanisms between agents (essentially banks).

Unlike for other markets, a microstructure analysis of money markets requires a good knowledge of the operational framework that regulates trading among agents. In fact, the operational frameworks in place differ considerably depending on central banks' mandates and strategies and, more concretely, operational targets. As mentioned, money market is key in the euro area due to the fact that it constitutes the cornerstone for steering interest rates along the yield curve. Studying the money market from a microstructure perspective, therefore, may help to identify weaknesses or even biases. Adequate reforms might then be proposed to improve its efficiency.

The paper focuses on the euro overnight interbank market. An interesting aspect of this segment of the money market is that the primary source of its liquidity is the central bank, although most transactions actually take place among banks in what is normally indicated as "interbank market". In this sense, banks can actually fulfil their appetite for liquidity through two main channels: directly from the central bank through open market operations, or from bilateral transactions with other banks. The main instruments for the first channel consist in ECB's main refinancing operations (MRO). They take the form of weekly auctions where banks submit bids for liquidity, knowing that the quantity asked should be backed by adequate collateral. In the second channel, i.e. the interbank market, banks can fulfil their liquidity needs also through transactions for which no collateral is requested.

In the academic literature, many papers on the euro area money market focus on aspects of the auction process of the ECB. For example, Ewerhart et al. (2005) link the counterparts' bidding behaviour in MROs with the situation in the secondary market. In the former ECB fixed tender rate framework, they show how a liquid secondary market with a tightening of the quoted spread may lead to overbidding in MROs if the bid is greater than the tender rate; underbidding occurs if the ask is greater than the announced tender rate. Several papers investigate the influences of the 2004 changes to the operational framework on the bidding behaviour and study the consequences of these changes on the interbank market (Neyer (2004) on theoretical bidding behaviours in MROs, Durré and Nardelli (2006) or Jardet and Le Fol (2007) on the volatility of the EONIA). Neyer (2004) investigate the impact of heterogeneity in the banking sector, due to marginal cost of handling adequate collateral, on the MROs participation and on the interbank market. However, most of these papers address the heterogeneity in banks' behaviour from a theoretical perspective. Empirical applications are however still rather scarce.

This paper analyzes the effects of the market and trade behaviour on the interbank market at the transaction level from the perspective of empirical microstructure. The model deals with market uncertainty and with agents that do not have the same information sets so that price processes are imperfect signals. Within this strand of literature, variety of models has been proposed with focus on stock or exchange rate markets. One of the most known model is the sequential trade model of Glosten and Milgrom (1985). Based on this seminal model, Easley and O'Hara (1992) develop the probability of informed agents (PIN) model to compute a measure of information heterogeneity in populations of traders and study the impact on price formation, and market liquidity. This model is built on the pattern of buy and sell orders, which is interpreted as stemming from heterogenous information flows in the market.

The approach followed by Easley and others has inspired a relatively wide set of papers, most of which focus on equity markets. For instance, Easley Kiefer O'Hara and Paperman (1996) show that the PIN is lower for high volume traded stocks based on an estimate of a PIN model for the volume traded of a stock. In a similar manner, Easley Kiefer and O 'Hara (1997) use the PIN to test "cream skimming" between places in a fragmented market: in US local exchanges, trades are less likely to be informed based compared to main markets. From an organizational perspective, Grammig Schiereck and Thiessen (2001) relate the PIN measure to the trading rules of the equity market, showing that in floor markets (or non anonymous market) the PIN measure is higher. Recently, Easley Hvidkjaer and O'Hara (2005) use the PIN measure as a factor in the Fama-French model of asset pricing and find that PIN has an impact on returns. In general, the interest of such a measure lies in the fact that it crucially depends on market organization, populations of traders or market liquidity. The approach presented in the paper is an attempt to fill in the existing literature gap by using a PIN model to analyze the euro area overnight market microstructure (information flows, heterogeneity in population, market rules).

A key point addressed in this paper concerns the role of information in the mechanism of price formation in the overnight unsecured market and, in particular, the analysis of the link between heterogeneous information and interest rates. It is presented empirical evidence from data publicly available to market participants over a time horizon that spans most of the history of the single currency money market (i.e. 2000-2006). More specifically, a simple PIN model is estimated to identify the nature of market belief and the days when informed trades occur on the market. Moreover, some organizational aspects of the market (e.g. occurrence of MROs, periodicity of maintenance periods) are linked with order flows and the nature of days (informed or not). Finally, due to the still short history of this market, a rolling estimation of the model is also presented to characterize the learning process among banks over time.

The paper is structured as follows. Section 2 illustrates some features of the euro area money market organization, market participants and the evolution of the operational framework. Section 3 presents the econometric microstructure model used to analyze the overnight market and the information revealed in the order flow pattern. The trade classification used to classify orders on the borrowing side or on the lending side is also presented. Section 4 illustrates the distributions of borrowing and lending orders, which is a mixture of distributions. This fact is taken into account in the estimation of the PIN model and reveals that some days are likely to be information driven while other are not. Finally, section 5 presents the rolling estimated model and the evolution of learning process among participants. Due to a rupture in this process in 2004, the information pattern before and after 2004 of maintenance periods is analyzed. Section 6 concludes.

2. THE EURO MONEY MARKET STRUCTURE

The euro area money market is characterized by the existence of an important institutional player (the central bank), a set of rules imposed by this player because of its strategic objectives, and specific traders, namely banks. The amount of assets available in this market is supplied through open market operations regularly conducted by the central bank to meet demand and thereby ensuring an equilibrium interest rate compatible with its monetary policy objectives[4]. In the euro area, the size of operations and, thus, the amount of financial assets (liquidity) consists in two main elements: required reserves and autonomous factors. The size of required reserves is controlled and decided by the central bank, while autonomous factors include items that have an impact on the amount of liquidity but are not under the direct control of the central bank. These are banknotes in circulation, domestic and foreign assets possessed by national central banks, deposits of governments in national central banks and other assets.

Turning to the demand side, the appetite for liquidity is mainly determined by

[4] For more details on the operational framework principles, rules and available instruments see ECB (2006).

existing provisions on reserves which drive most transactions in the money market. Summing up, banks can fulfil their liquidity needs through two main channels: (1) participating to central bank's refinancing operations[5] and/or (2) bilateral transactions in the interbank market. The following section illustrates the main characteristics of these two channels.

2.1. Refinancing operations design

As far as the first channel is concerned, the main instrument used by the central banks to supply liquidity is represented by open market operations. The two main instruments are the already mentioned MROs and longer-term refinancing operations (LTROs). The frequency and the size of these operations is different: the bulk of liquidity (i.e. around 75%) is injected through weekly MROs, while the remaining quantity (i.e. around 25%) through monthly LTROs which have a maturity of three months. Banks can participate by submitting their bids, i.e. requesting a certain amount and offering a price (interest rate) for it that cannot be lower than the interest rate set by the monetary authority (the minimum bid rate). Depending on the total amount of liquidity decided by the central bank, bids are served starting from best price received (i.e. highest interest rates). At the marginal rate, i.e. the interest rate corresponding, liquidity is distributed *pro rata* to bidders based on the individual amounts requested. To be able to participate to central bank's auction, banks have to comply with requirements on their financial soundness. Moreover, banks must possess adequate collateral in proportion to the amount of liquidity received from the central bank[6]. From the perspective of participation to direct refinancing, the existence of these provisions may actually be discriminatory as banks not having sufficient or low quality collateral are excluded. In other words, existing rules aimed at ensuring financial soundness may actually represent a barrier for some banks.

Besides these two types of refinancing operations, a third type of operation has recently become rather frequent : fine-tuning operations (FTOs). FTOs take place generally at the end of reserve maintenance periods to resolve liquidity imbalances and to avoid further significant departures of the overnight rate from the minimum bid rate or an excessive level of volatility. Unlike the other two, FTOs can either supply or withdraw liquidity to the market depending on the sign of the imbalance.

[5] In the Eurosystem, banks can also get liquidity at any time by borrowing funds directly from the central bank. Interest rates applied to the marginal lending facility are also decided by the euro area monetary policy authority.

[6] Financial assets must fulfil some criteria to be eligible as collateral. Criteria for eligibility impose that credit rating of certain type of assets must be above a threshold decided by the central bank. These criteria have also an impact on the amount of collateral which is requested as a consequence of the "haircut" imposed by the central bank, which increases with the riskiness of the asset. The amount of collateral requested by the central bank is equal to the amount of liquidity received by a bank plus the interest rate plus the haircut.

Because of the need of acting rapidly, the list of banks eligible to participate is more restricted, and is normally limited from ten to fifteen large banks. Efficiency, therefore, creates another potential barrier for the participation to this special type of refinancing. In addition to operational rules, administrative costs may in some cases represent a disincentive, if not an obstacle, to participation in this primary channel of refinancing.

2.2. The interbank market

A secondary source of refinancing is represented by the interbank market. In this market, where a significant amount of transactions are unsecured, central bank's liquidity is distributed across banks through bilateral transactions. This way, all the banks - including those not possessing adequate collateral or not able to get liquidity in weekly auctions - may satisfy their liquidity needs. As stressed by Hartmann and Valla (2007), this market is characterized by both - and mainly- direct dealing (i.e. over-the-counter market, OTC) and electronic centralized platforms (for instance, eMid). Liquidity in the interbank market is typically not centralized and banks deal on this market in various ways. Being less regulated, interbank market is therefore less discriminatory; nonetheless, there may be situations in which more sophisticate agents are able to exert some market power either because they can access various refinancing sources, or they can exploit more efficiently the information on aggregate positions with regard to liquidity.

The euro money market has experienced a huge expansion since its creation in 1999[7]. This market is mainly organized around four main segments: unsecured market, secured market, OTC derivatives swaps and short-term securities. The two first two segments are particularly interesting. The unsecured market allows to trade lending and borrowing uncollateralised contracts. Since no collateral is requested for contracts, maturities are concentrated on the very short term to minimize default risk: in 2006, 96% of the contracts nominal value were less than one month, and 70% on the overnight as indicated in ECB (2007). By contrast, the secured market requires that contracts are backed by collateral. Since banks have a guarantee on the subscribed contracts, the maturity breakdown of this market is less concentrated on the very short-term maturity: only 13% are overnight maturities while "tomorrow/next to one month" of this market accounts for 77% of total transactions. Recently, electronic platforms have started taking on an increasing market share in the secured and unsecured trade. They account now for 17% on the unsecured market and 49% on the secured market. However it appears more difficult to implement an electronic platform on the unsecured market.

A key difference between secured and unsecured market is what can be defined

[7] For more details on the characteristics of the euro money market see ECB (2007).

as "reputation". Unsecured contracts are traded over the counter on a direct basis. Since counterparts do not have any guarantee (contracts are not collateralized), it is crucial to know whom a bank is trading with. The anonymity of electronic platforms does not allow this informal control procedure on contracts. This may explain the differences between the development of electronic platform on the secured and unsecured market. Therefore, even if analyzing market behaviour on an over the counter (OTC) market is more difficult , since price and data are partially observed, it is undoubtedly more accurate for capturing the incidence of a reputation concept.

Market reputation is important for the analysis of the impact of population heterogeneity on market price dynamics. Various factors may explain bank's reputation. The main one is the size of the bank: generally, big banks can trade more easily than small banks on the unsecured market[8].

A second factor may be the discrimination introduced between market participants by the ECB rules on participation to liquidity tenders. As illustrated before, the eligibility of banks is based on requirements on financial soudness that impose to possess adequate collateral. Since not all banks can participate to these operations, aggressiveness may arise on the secondary market from excluded market participants, or may give opportunities to a pool of banks to strategically trade the liquidity.

A third factor is the location of the bank. The euro money market is open to banks from the Eurosystem[9]. However, a country bias can still be observed in trading activities, in the sense that 25% of transactions are still made between banks within the same country, while only 55% are cross-border transactions. Considering that large market participants play the role of liquidity providers at a country level, there may be a form of discrimination in the countries that are traditionally less active in the weekly MROs.[10]

The empirical model presented in the next section considers information on the market and takes into account the fact that traders (banks in our case) do not perceive price signals in the same manner. This heterogeneity in behaviour and beliefs thus impacts on market dynamics. To simplify the view of heterogeneity in terms of the characteristics outlined above, two groups of banks is considered: the largest banks as informed bank, and the smallest banks as uninformed banks.

[8] This problem is observed in the established rules to trade on e-MiD, the most important electronic platform for the unsecured market. e-MiD's rules to access trading impose to have a net asset higher than 10 millions US dollar, which prevent smaller banks (with a possible unknown reputation problem, since trade are anonymous) from becoming market participants.

[9] The Eurosystem is composed of the ECB and the national central banks of countries sharing the euro as common currency.

[10] An example is represented by Portuguese banks, which never participates to weekly MROs.

2.3. The "2004" Eurosystem's operational framework

In this section, the functioning of the operational framework is presented with some details on the changes introduced in March 2004. Focusing on the history of the Eurosystem after 1999, the most notable changes were introduced to overcome some issues emerged in the mechanisms in place to supply liquidity and to ensure a smooth liquidity provision to banks. Two elements were decisive to motivate the changes: overbidding, i.e. the tendence of banks to submit bids of increasingly sizeable amount at the weekly tender to avoid (liquidity) rationing, and underbidding, i.e. a phenomenon which took place when bids did not entirely cover the liquidity amount which the central bank intended to allot.

To stop overbidding, fixed rate tenders - i.e. tenders in which banks only requested quantities since the price was decided by the central bank - were abandoned in June 2000. They were replaced by variable rate tenders, i.e. auctions where banks offer a price in addition to the demanded amount of liquidity. This change did actually succeed in stopping overbidding and, with few exceptions. The rates resulting from weekly tenders have turned to be well anchored to the minimum bid rate. In this sense, the change to a variable rate system was successful since it has never hindered the transmission mechanism although the ECB lose the direct control on prices (interest rates) paid for its liquidity. However, a new issue emerged: underbidding. Whenever the ECB failed to inject the liquidity necessary to the banking system, short-term money market interest rates reacted by rising markedly above the EONIA and increasing volatility. Before March 2004, underbidding took place 8 times and it was generally related to expectations on key ECB rate cuts.[11]

To overcome the occurrence of underbidding in weekly refinancing operations and, in this way, to stabilize money market rates, three major changes were introduced in the operational framework in March 2004:

1. The bulk of liquidity is supplied in only one operation and no longer in two outstanding operations. At the same time, the maturity of each main refinancing operation was shortened from two to one week.

2. Conditions on monetary policy interest rates are applied as of a new reserve maintenance period and no longer immediately after the decision is made.

3. The start and the end of reserve maintenance period is related to the date of the Governing Council meeting in which monetary policy decisions are made (i.e. normally on the first Thursday of each month), while before the change they always started on day 24 of each month and ended on day 23 of the following month.

[11] On three occasions, namely 6 November 2001, 3 March 2003 and 3 June 2003, underbidding preceded interest rate cuts. In all other cases, only expectations on policy rate cuts or other technical reasons explained it.

In this way, reserve maintenance period resulted better segmented and any interference of monetary policy decisions on liquidity management was removed and so were conditions for underbidding to take place.

These changes however have had some side effects which were addressed by other ad hoc measures. One effect is related to an expected increase of errors in autonomous factor forecasts due to the increase in the number of days between the last MRO and the end of the reserve maintenance period (normally five trading days after the changes, and on average three days before). To limit the impact on the expected higher uncertainty on autonomous factors' developments in the last days of the reserve maintenance period, it was decided to increase the information disclosed to the market before the weekly MRO. This change was also intended to reduce counterparties' uncertainty about the ECB liquidity management and to increase transparency vis-à-vis money markets. More precisely, the changes implied the publication of:

1. the benchmark allotment on the announcement day of the MRO;[12]
2. the updated benchmark allotment on the allotment day of the MRO (after making the decision on the amount of liquidity to inject);
3. the updated autonomous factor forecasts on the allotment day of the MRO after the allotment decision and
4. benchmark allotment and actual allotment amounts of the MRO

In practice, the ECB information disclosure moved from figure 1.1 to figure 1.2 in Appendix 1, which implied a substantive increase in the amount of information disclosed to market participants. In this way, at least in principle, ECB's decisions on allotment became fully transparent.[13]

A second measure was an increase in the frequency of fine-tuning operations conducted at the end of reserve maintenance periods to re-establish neutral liquidity conditions. From a microstructure perspective, these two events may explain more a discontinuity in the amount of informed trade as it will be shown in the empirical section of the paper. Unfortunately, due to the almost concomitant occurrence of these changes, it is difficult to analyze their effects separately on actual trade.

[12] The benchmark amount is broadly defined as the sum of (net) liquidity absorbing autonomous factors, reserve requirements and excess reserves.

[13] The new information complemented and completed what was disclosed in the Box "Benchmark allotment rule normally applied by the ECB in its main refinancing operations" published in the May 2002 ECB Monthly Bulletin. The box illustrated with some details the formula for the calculation of the benchmark.

3. THE MODEL

The seminal paper of Easley and O'Hara (1992), in this section, is applied to money market. The aim of this exercise is to assess the impact of these changes on the market behaviour of banks. Some features of the interbank market are only partially understood and still need further analysis. These features include the likely determinants of the widening of the spread between the minimum bid rate and the EONIA observed during a relatively long period after the changes were introduced to the operational framework.

3.1. Model Structure

The core of the analysis conducted in this paper is to apply to the money market a classical sequential trade model of an EO type. In order to apply this model and to capture the most relevant aspects of the overnight money market, some simplifications are requested. The transposition of the seminal model to the money market is developed below for some key aspects.

3.1.1. Assets

In the unsecured overnight market, assets are peculiar since they are contracts. Unlike in stock markets, what is negotiated is not the property of a share value of a firm with some fundamental factors, but rather a temporary cash transfer from one party to another. This transfer is negotiated at a certain interest rate, whose level determines the value of the contract and characterizes, at an aggregate level, trade patterns in the market. The value of the contract stems market needs, but also market information, the liquidity policy of the central bank or the heterogenous information.

Money contracts are assumed to be underwritten at a fair value. In traditional applications of the EO model, the true unobservable value is the fundamental value of a financial asset (usually stocks in equity markets or currencies in forex markets). It may be more contentious to define the true value of the overnight interest rate. However, this value should reflect the situation with respect to the aggregate liquidity in the money market.

3.1.2. Information on assets

On the role of information, two levels can be considered. First, a good knowledge of aggregate liquidity conditions in the money market gives an insight on central bank's expected supply. Second, most active banks may determine, or at least, influence demand because:

- the bigger the needs of liquidity are for a bank, the larger its share in global liquidity needs is;
- the more active a bank is, the better the tools it should have to perceive market information ;
- the more active a bank is, the more orders it centralizes.

As a consequence, the active role of a bank should enhance its knowledge about market needs and, thus, its information. A market signal can be defined as a piece of information that allows traders to update their beliefs in the true value of (overnight) liquidity, and to make the decision on wether to trade or to wait. If there is a signal, the type of the signal is assumed to be known by the pool of informed banks, and to remain constant during a given day. A signal can be classified as high or low. A "high signal" (H) means that contracts would be negotiated at a higher interest rate during the day, while a "low signal" (L) means that contracts would be negotiated at a lower rate. The model considers also days without signal (O).

3.1.3. The population of traders

The population is characterized by heterogeneity with respect to information. Traders are banks that can be classified as "informed", "uninformed" and "market makers". As in Neyer (2004), banks are motivated to trade mainly to comply with institutional rules (fulfillment of reserve requirements) and minimize the cost of handling liquidity.

Efficiently-informed banks meet two criteria. First, they have superior information and trade on the basis of this information. They represent the most active pool of banks: they acquire, understand and use market information. Second, they are supposed to have fulfilled their reserves requirements or to be not too far from their optimal inventory constraints. Actually, a bank may interpret a liquidity deficit on the market but may not be able to trade on this information since it can be itself in liquidity deficit. Unlike in the standard EO model interpretation, in this special case, trades opposite to the market signal might be rational, but are however considered as non informed trade.

Uninformed banks have no piece of information to trade. Trade is mainly motivated by inventory constraints, i.e. reserves requirements imposed by the central bank.

Finally, the market-maker pool is assumed to be mainly composed of banks fulfilling their liquidity needs directly from the central bank. These banks provide liquidity to the secondary market and are competitive. They set prices (quoted spreads) and the best quoted spread, i.e. the narrowest spread, is displayed publicly to the market.

3.2. A sequential trade model

As in the EO model, banks arrive to the interbank market sequentially and make their decisions on whether to trade or not. As in Neyer (2004), banks make their decisions mainly to fulfil their liquidity needs. Both reserves requirements and autonomous factors are influential to determine these needs but, while reserve requirements are known at the beginning of the reserve maintenance period and do not change after that, autonomous factors are subject to day-to-day shocks which change individual needs and motivate trade in the interbank market. Mainly due to the typical pattern in the fulfilment of reserves, the days between the last MRO and the end of the maintenance period appear crucial. During this period, information on liquidity is usually revealed to the market since banks do not have other choice than complying with reserves requirements. This fulfilment may be accomplished in two ways: by direct trading in the interbank market or by resorting to the existing central bank's standing facility (marginal lending). However, this latter is so costly - i.e. approximately 100 basis points above the minimum bid rate in the Eurosystem - that trading in the interbank market would normally be cheaper. As a consequence, it can be expected that the increased activity in the interbank market during this period would reveal the market participants' aggregate liquidity needs, and so imperfect information signals through price dynamics.

All the banks observe the trade process so that they may assign a probability on the type of order (i.e. coming from informed or uninformed banks) and, in case of informed trade, on the type of signal (high or low). As seen before, these signals are mainly driven by the aggregate liquidity situation which may only be witnessed by a pool of banks. The set of options for market agents can be summarized in the standard tree that represents the trade process.

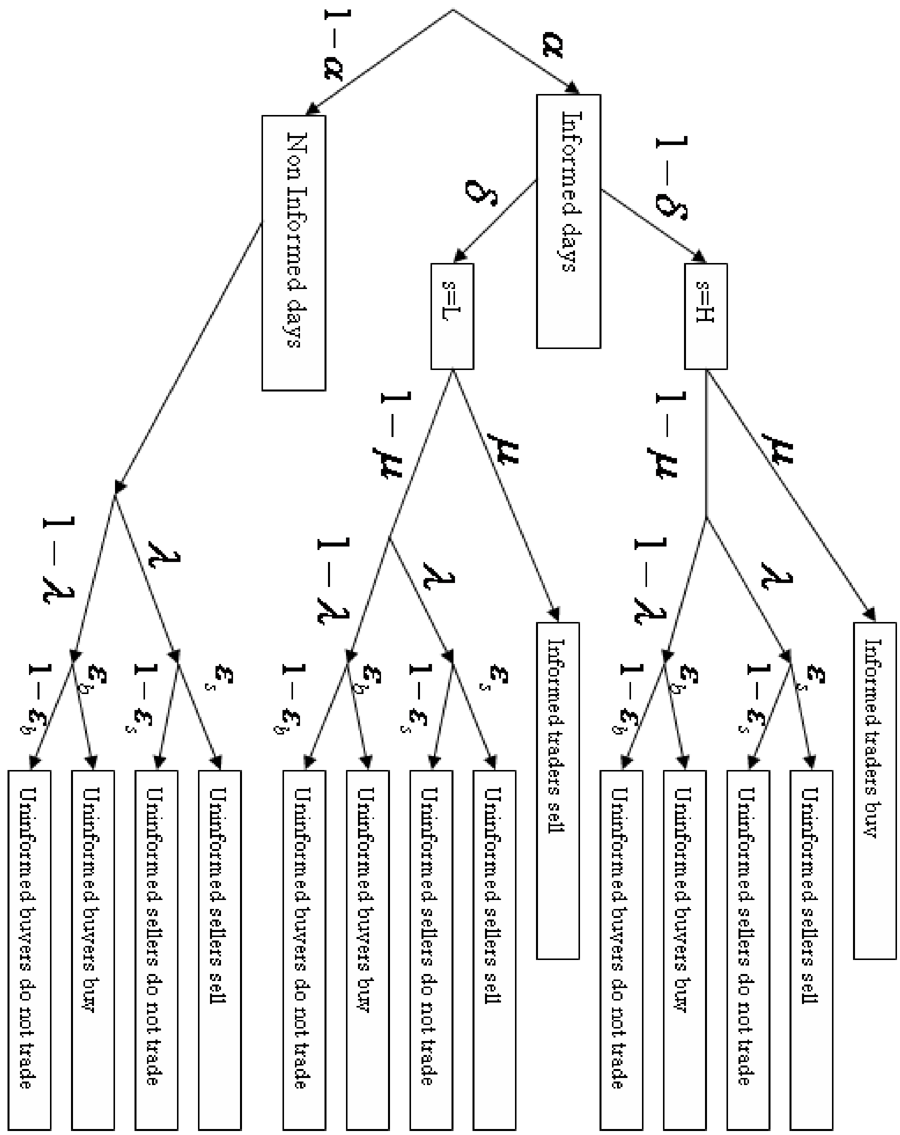

Figure 1: tree trade process

The information structure of this market is defined by a set of parameters P=$\{\alpha, \delta, \mu, \lambda, \varepsilon_s, \varepsilon_b\}$. The first parameter, α, represents the probability that information occurs on the market during a given day[14]. In days with a signal (informed days), this information is expected to be linked with the direction of the interest rates on the borrowing (buy orders) or on the lending side (sell orders) of the mar-

[14] Typically on financial markets, α is always quite high. Easley Kiefer and O 'Hara (1997) estimations on α for an asset traded on the AMEX was around 0.75, which means very few days without information.

ket. The coefficient δ measures the probability that information is perceived as driving the price lower than it actually is. Finally, the coefficients μ, λ, ε_s and ε_b are relative to the structure of the population of banks acting in the money market. The different probabilities assigned to the market orders are derived in the next section.

3.3. Informed trade vs uninformed trade

Assuming that sequential trade models represent adequately the trading mechanism in the money market, it is possible to calculate the probability of being in an informed day with a low or a high signal, or the probability to be in a day without signal.

Large banks give information to the market about the interest rates they practice either on the lending or on the borrowing sides. However, a bank, which plays the role of market maker, adapts its bid and ask prices to comply with its own inventory constraints.[15] This tends to influence the side of the order in terms of lending or borrowing contracts, but it does not qualify the nature of the order. The order can still be lending-initiated (or a sell order if the counterpart hits the bid price) or borrowing-initiated (or a buy price if the counterpart hits the ask price). Based on the tree in Figure 3, the probability to observe B borrowing orders, S lending orders and N no trades, conditional to the intensity of the signal during a given day, are respectively:

$$\begin{aligned}\Pr(B,S,N \quad | \quad s=H) = {} & (\mu+(1-\mu)\,\lambda\varepsilon_b)^B\cdot((1-\mu)\,\lambda\varepsilon_s)^S \\ & \cdot((1-\mu)\,\lambda\,(1-\varepsilon_s)+(1-\mu)\,\lambda\,(1-\varepsilon_b))^N\end{aligned} \tag{1}$$

$$\begin{aligned}\Pr(B,S,N \quad | \quad s=L) = {} & ((1-\mu)\,\lambda\varepsilon_b)^B\cdot(\mu+(1-\mu)\,\lambda\varepsilon_s)^S \\ & \cdot((1-\mu)\,\lambda\,(1-\varepsilon_s)+(1-\mu)\,\lambda\,(1-\varepsilon_b))^N\end{aligned} \tag{2}$$

$$\Pr(B,S,N \mid s=O) = \lambda^{B+S+N}[(\varepsilon_b)^B\cdot(\varepsilon_s)^S\cdot((1-\varepsilon_b)+(1-\varepsilon_s))^N]. \tag{3}$$

And, compounding these probabilities:

[15] The level of liquidity possessed by a bank in this context is assimiled to inventory constraints. It supposes it exists an optimal level of liquidity for banks to comply with reserve requirements and autonomous factors. The constraint represents the desire not to be too far from this optimal level.

$$\Pr\left[(B,S,N) \mid \alpha,\delta,\mu,\lambda,\varepsilon_b,\varepsilon_s\right] = \alpha(1-\delta)\Pr(B,S,N \mid s=H) + \alpha\delta\Pr(B,S,N \mid s=L) + (1-\alpha)\Pr(B,S,N \mid s=O). \quad (4)$$

Finally, considering a sequence of T days, and assuming that days are independent from each other[16], the following likelihood of observing B buys, S sells and N no trades can be computed as follows:

$$\Pr\left[(B_t,S_t,N_t)_{t=1}^{T} \mid \alpha,\delta,\mu,\lambda,\varepsilon_b,\varepsilon_s\right] = \prod_{t=1}^{T}\Pr\left[(B_t,S_t,N_t) \mid \alpha,\delta,\mu,\lambda,\varepsilon_b,\varepsilon_s\right] \quad (5)$$

where potentially different trade patterns (i.e. time varying B, S, N) in the time horizon on which the model is specified. For the actual estimation of these probabilities, it is necessary to know the number of borrowing, lending and no contracts which have been observed on each day.

Some restrictions are imposed to the set of parameters to streamline the model and to focus on the ability of banks to incorporate information. First, uninformed traders being sellers or buyers are supposed to have the same intensity, i.e. $\lambda = 0.5$. The second possible restriction is to consider that being a seller or a buyer have the same probability, i.e. $\varepsilon_s = \varepsilon_b = \varepsilon$. In this way, the set of parameters reduces to only four, i.e. $(\alpha, \delta, \mu, \varepsilon)$.

Based on the reduced form of the probabilities indicated above, the maximum likelihood function of the model is obtained for the EO model:

$$\begin{aligned} L(\alpha,\delta,\mu,\varepsilon) &= \Pr\left[(B_t,S_t,N_t)_{t=1}^{T} \mid \alpha,\delta,\mu,\varepsilon\right] && (6)\\ &= \prod_{t=1}^{T}\left[(1-\varepsilon)^N(1-\mu)^N A^{B+S}\right] && (7)\\ &\quad .[\alpha(1-\delta)\left(\frac{\mu}{A}+1\right)^B + \alpha\delta\left(\frac{\mu}{A}+1\right)^S + (1-\alpha)\left(\frac{1}{1-\mu}\right)^{B+S+N}] \end{aligned}$$

where $A = \frac{(1-\mu)\varepsilon}{2}$.

To estimate these parameters, it is necessary to derive the structure of the trade flows i.e. the number of buy (borrowing), sell (lending) and no trade orders on a given day. Section 4 presents standard estimation procedures using a classification of trades which has been adopted, given the only partial information on the available

[16] This usual simplification is obviously a shortcut that does not allow to analyze the effects of the averaging mechanisms of reserve requirements in the new operational framework. However, the paper is primarily focused on information disclosure aspects.

dataset on the overnight interbank market.

3.4. A qualification of the γ parameter

To understand how banks consider the institutional framework, how they use the information disclosed by the central bank and how this influences their behaviours, it is interesting to calculate from the model the probability that trade is informed for any given day, i.e. γ. This parameter represents the implicit risk that a bank is facing when trading with another bank, which is supposed to be better informed on the direction of the interest rate. This is obtained from the tree trade process as follows:

$$\gamma = \frac{\mu}{(1-\mu)\,\varepsilon + \mu}. \tag{8}$$

As in the classical EO model, this parameter measures the implicit risk for some banks to unintentionally create trade opportunities for other banks, because they are less informed than their counterparties.

From a time varying perspective, an increase in the parameter γ indicates a heterogenous learning process among banks. More concretely, it represents a situation where some banks have efficiently fulfilled their reserve requirements and know how to use information on the expected interest rate movements, while others do not know. By contrast, a decline in this parameter indicates decreasing opportunities to trade on this information. The learning process among banks would be homogeneous, with less trade opportunities on information, and thus less risk in trades.

4. DATA AND RESULTS

4.1. Data set and trade classification

Empirical studies based on market microstructure models normally make use of high frequency (HF) data. In datasets on equities and exchange rates markets, high-frequency data on transaction prices are generally available. As already described, the overnight unsecured market is mainly an OTC market, and thus it is difficult to obtain interest rates at which overnight contracts are actually traded. However, data providers, such as Reuters, display in real time best bid and ask quotes known to the market. This information is crucial since it gives an idea to all market participants about the prevailing levels of proposed rates.

The available dataset contains date, time and best bid/ask in the market at a 5-minutely frequency between 5 November 2000 and 15 December 2006. Actual transaction prices (interest rates) are not known[17], euro money markets are gener-

[17] Transaction prices are generally unavailable. An exception is the electronic platform eMid,

ally very liquid. In this way, quotes can be assumed to be highly representative of price movements with some approximations.

To analyze the order flow, it is necessary to identify buy orders, sell orders or no orders for each day included in the sample. To do so, standard techniques are usually applied[18]. Typically, if only transaction prices are available, a spread is constructed following Roll (1984) and then the price is compared with the midpoint of this spread to determine whether market orders are buy- or sell-initiated. This procedure cannot be applied in our case as prices are not available in our dataset but only spreads.

To overcome this limitation, the following solution is adopted. In the literature[19], quoted spreads are assumed to be characterized by three components: trading costs, information asymmetries and inventory constraints[20]. Due to the existence of reserve requirements, the inventory constraint component is predominant. As a consequence, the trade classification is based on the assumption that banks cannot be too far from their optimal inventory level. Thus, quoted spread movements should mainly reflect this fact.

Under this assumption, orders are classified based on variations in the ask or bid prices as follows:

- A common rise in the ask and bid (case 1 figure 2) price suggests that the price of the previous transaction was at the ask, and that dealers are now willing to sell the asset on the market at a higher price. On the bid side, we may consider either no revision or an increase, meaning that the dealer offers a best price to buy the asset to the market. This represents the dynamics following market "buy orders". In other words, this means that a borrowing unsecured overnight contract has been initiated on the market.
- A common decrease in the ask and bid price (case 2 figure 2) represents the opposite situation. Dealers are willing to sell the asset at a lower price to the market and worsen the bid price to limit the market sell orders. This can be interpreted as a market "sell order": a lending contract has been initiated.
- An increase in the ask and a decrease in the bid is interpreted depending on the relative amplitude of each bid and ask moves, as a buy order for bigger positive jumps in the ask (case 3) and sell order for bigger negative jumps in the bid (case 4).
- A decrease in the ask and an increase in the bid, by comparing absolute moves on each side, consider buy orders if the increase in the bid is bigger than the

in which volumes and prices of each transaction are recorded and avaible with some restrictions. Unfortunately such a platform only includes a limited set of large banks and, as such, it is not representative of the universe of transactions in the money market.

[18] See Lee and Ready (1991).

[19] See, for instance, Ho and Stoll (1997), George, Kaul and Nimalendran(1991) or Harris(2003).

[20] This is a simplified view since many other factors on this special money market may influence the quoted spread.

decrease of the ask (these cases are nor depicted in figure 2).

- Steady bid and ask prices, or symmetric revisions (case 5 and 6), characterize the absence of trade: this may only concern a change in market liquidity due to large volatility, or due to an increase in information asymmetry.

This classification is summarized in Figure 2.

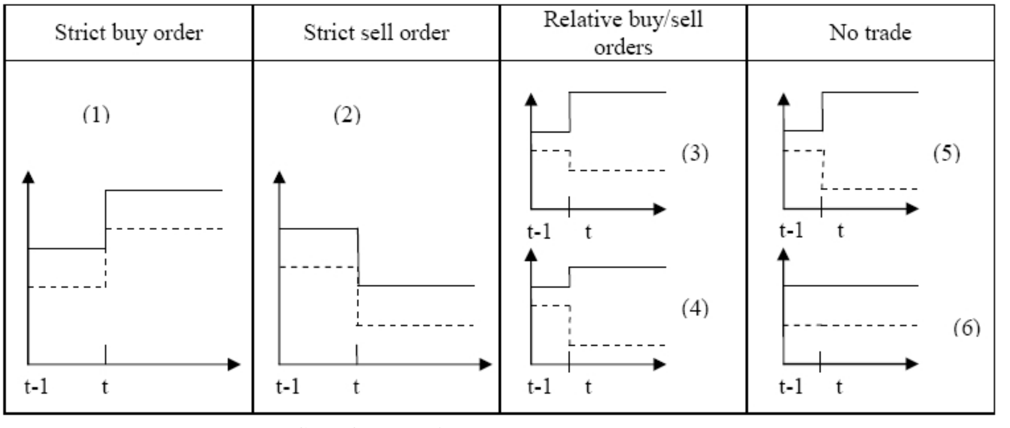

Figure 2: Classification of trades based on bid and ask variations

This classification is applied to the 165.717 quoted spreads available in the database. Daily sum of sell orders, buy orders and no trade orders are computed. Figures 3, 4 and 5 show the resulting distributions[21].

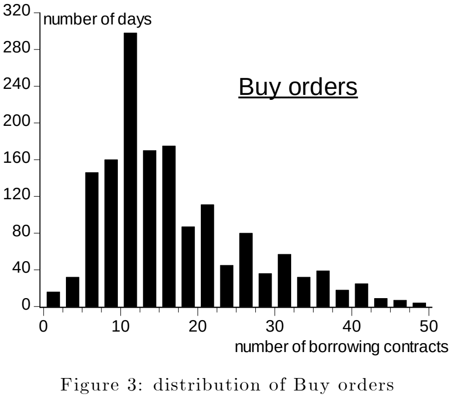

Figure 3: distribution of Buy orders

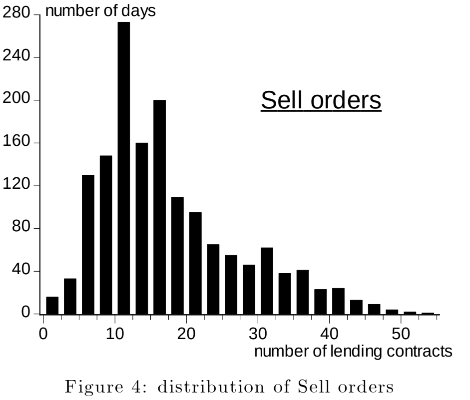

Figure 4: distribution of Sell orders

[21] On the entire sample for both buy and sell order 2/3 complied with pure moves (common increase or common decrease in the ask or bid quotes) and 1/3 with relative move (i.e. in opposite direction for the ask and bid quotes).

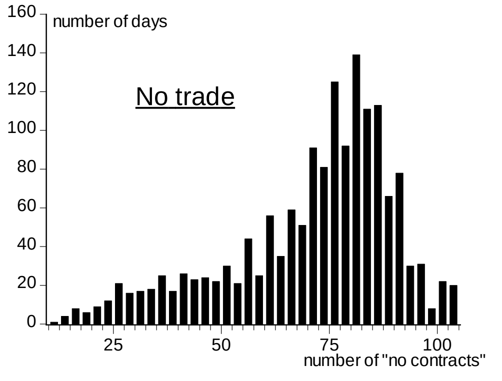

Figure 5: distribution of no trade orders

Results show that a trade takes place on average every 20 minutes in the market. All distributions are skewed and leptokurtotic, which may indicate that trade intensifies on particular days. This is clearly observed during the last week of maintenance period, but should be investigated further. The no-trade distribution confirms a similar pattern. At a first sight, a mixture of distributions stems to emerge from the bimodality of the distribution. The particular shape of these distributions can be captured by the α parameter of the model, which concretely represents this mixture of distributions between informed days (the most active ones) and uninformed days.

4.2. Results of the maximum likelihood estimation

Estimates for the four parameters introduced in Section 3 are obtained from maximizing the log-likelihood function on the full sample first. The estimation gives the following results:

	Parameter	Standard error	t-Prob
α	0.243	0.018	0.00
δ	0.622	0.031	0.00
μ	0.176	0.001	0.00
ε	0.287	0.001	0.00
Likelihood	-136741.6		

Table 1: MLE estimation, 29/11/2000-15/12/2006

First, the α=0.243 parameter indicate that on average 1/4 of the days are information driven. Considering a maintenance period length this correspond in mean at 4 or 5 informed days (a maintenance period is generally made of 17 to 22 days).

Second, on informed days, the signal is low (high) with probability δ $(1-\delta)$. A low signal is therefore observed with an estimated probability of 0.62, which means that banks believe that information-driven orders reveal excess liquidity supply on the market, rather than the opposite. In other words, orders are more likely to be sell-initiated (i.e. lending contracts during excess liquidity period on the market are relatively more frequent) than buy initiated. This result seems to confirm the fact that banks are more exposed to risk when the liquidity is scarce than when liquidity is abundant.

Third, μ=0.176 indicates that the proportion of trades made on the basis of this information is rather low. This suggests that banks tend to believe that observed orders are information-driven with a probability of only 17% : 1/5 of orders observed in the market are deemed to come from efficiently informed banks. For the money market, the interpretation of the μ parameter is more restrictive than in the standard PIN model, since it only takes into account the banks that are informed and which have efficiently fulfilled their reserve requirements.

Fourth, ε=0.287 indicates that the probability of liquidity trade is only around 30%. During informed day this parameter represents market liquidity stemming from uninformed banks, while, during uninformed days, it represents exactly market liquidity (since only uninformed traders are active on the market).

Based on these estimates, it is possible to derive numerically the parameter γ, i.e. the probability that a trade occurs and is initiated by an informed trader on event days. For the dataset used, $\gamma = 0.4$, which means that a bank involved in an overnight contract faces a 40% probability to be trading with a counterparty which is better informed on the direction of interest rates. This implies, for instance, that big banks may have superior information on the aggregate liquidity needs since they centralize the order flow coming from small banks.

4.3. Information pattern of maintenance periods

Based on the estimates for the full sample, it is possible to identify the days during which trading is informed and those when trading is uninformed. Since approximately α=1/4, trading is informed in about 380 days out of 1577.

A simple method to identify when exactly informed trading occurs, consists in selecting the most-active 380 days. To do that, days are ranked in a decreasing order with respect to the number of contracts and the 380 first days are selected and labelled as informed. This method allows to define a threshold for trades above which days are defined as informed. The threshold obtained in this way is 44, i.e. days with more than 44 contracts are considered as informed.

The next step is to associate informed days to their occurrence within a reserve maintenance period. Figure 6 shows the result in the form of fractions of informed days out of total days for each specific day within the maintenance period.