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ESTIMATING THE MONEY MARKET MICROSTRUCTURE WITH NEGATIVE AND ZERO INTEREST RATES

by Edoardo Rainone* and Francesco Vacirca[#]

Abstract

Money market microstructure is fundamental to studying bank behaviour, to evaluating monetary policy and to assessing the financial stability of the system. Given the lack of granular data on interbank loans, Furfine (1999) proposed an algorithm to estimate the microstructure using data from the payment system. We propose an econometric methodology to assess and improve the quality of the money market microstructure estimated by the Furfine algorithm in the presence of zero and negative rates, exploiting information coming from market regularities. We first extend the standard Furfine algorithm to include negative rates and verify the presence of significant noise at a specific rate. Secondly, we propose an inferential procedure that enriches and corrects the standard algorithm based on the economic likelihood of loans. Market regularities observed in this decentralized market are used to increase the reliability of the estimated interbank network. Thirdly, the methodology is applied to TARGET2, the European wholesale payment system. The main impacts of recent monetary policy decisions on key interest rates are studied, comparing the standard algorithm with the new econometric procedure.

JEL Classification: E52, E40, C21, G21, D40.
Keywords: interbank markets, money, payment systems, trading networks, measurement error.

Contents

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1 Introduction

Knowledge of the interbank money market microstructure represents an important tool for monitoring and studying bank behaviour and for assessing monetary policy, both from a central bank and an academic perspective. In particular, it is helpful to evaluate the smoothness of the pass through mechanism and the financial stability of the system. These are the reasons why monetary policy makers, regulators, market operators and researchers closely look at money market indicators.

Several important papers used the interbank money market microstructure to study the financial and economic behaviour of banks. Among others, Ashcraft and Duffie (2007) showed how the intra-day allocation and pricing of overnight loans of federal funds reflect the decentralized inter-bank market in which these loans are traded. Afonso et al. (2011) examined the importance of liquidity hoarding and counterparty risk in the U.S. overnight interbank market during the financial crisis of 2008. Bech and Klee (2011) showed how successful the Federal Reserve was in raising the federal funds rate even in an environment with substantial reserve balances. Furfine (2003) examined the degree to which the failure of one bank would cause the subsequent collapse of other banks. Acharya and Merrouche (2012) studied the liquidity demand of large settlement banks in the UK and its effect on the money markets before and during the subprime crisis of 2007-08.

Given the lack of granular data about interbank loans, several approaches have been proposed to estimate the bilateral exposures in the money market. One body of literature drew inference from the bilateral exposures by starting with aggregate interbank assets and liabilities in bank balance sheet and applying information theory. Among others, Sheldon and Maurer (1998) and Helmut et al. (2013) applied the maximum entropy method, while Anand et al. (2014) used a minimal density approach. Another method for identifying the money market microstructure uses payment system data. Given that central bank money is exchanged in order to meet the reserve requirement and to settle payments, loans are usually settled in the payment system owned by the central bank in advanced economies.[1] Indeed, a loan is composed of two payments by definition, the payment corresponding to the setup of the loan, say from bank A to bank B, of an amount equal to p_t at day t and the reimbursement payment at day $t+k$ of an amount equal to $p_{t+k} = p_t(1+i)$ from bank B to bank A, where k is the duration of the loan and i the interest rate. Exploiting this information, Furfine (1999) proposed an algorithm that attempts to match payments from the same money market contract. The original algorithm was designed to identify overnight transactions within Fedwire payment system data, assuming a minimum contract value of \$ 1 million and an interest rate within a corridor of 100 basis points centered around the federal funds rate. Observe that almost all the papers mentioned above, which study the behaviour of banks within the interbank money market microstructure, used data generated by this algorithm. Several authors have applied Furfine's method to data from different payment systems and have proposed several improvements to increase the scope and the quality of the estimation. Demiralp et al. (2004) modified the algorithm to include loans of lower amounts and to limit the possible interest rates to

[1] Many types of transactions are settled within the payment system. Here is a short list: customer payments, securities systems payments, open market operations, treasury bond issues. This should give an idea of the importance of the payment system and its centrality to banks from a liquidity management perspective. Reserve requirements oblige banks to hold a certain average amount of central bank money in their accounts during a maintenance period. A maintenance period is a time interval during which the amount of central bank money is averaged.

1/32 of a percentage point or use integer values to replicate the convention of the US government securities market. This limitation aims to decrease the number of false transactions detected. Akram and Christophersen (2010) implemented an algorithm for the Norwegian market, whereas Hendry and Kamhi (2007) applied it to the Canadian Large Value Transfer System (LVTS) by excluding all matches between payments whose estimated interest rates did not correspond to rates expressed in units of half a basis point. Arciero et al. (2013) extended the search algorithm to maturities of up to one year and applied the algorithm to payments settled through TARGET2 using different corridors;[2] the results obtained were validated using EONIA panel data and loan data from the e-MID money market trade platform. Recently some works have focused on assessing the quality of original Furfine-based algorithms (see for instance Armantier and Copeland (2012) and Kovner and David (2013)).

All the main implementations of the Furfine algorithm implicitly assume that the key interest rates are strictly positive. To the best of our knowledge no work looks at the application of the algorithm when interest rates may be negative or equal to zero. This issue has gained relevancy as a result of recent decisions taken by several monetary policy authorities to decrease the lower bound of the interest rate corridor, first to zero and then to negative values (e.g. in the euro area and in countries such as Switzerland, Sweden and Denmark). In particular in the euro area, to provide incentives to banks to trade more following the interbank freeze triggered by the sovereign crises in 2011, the Governing Council of the European Central Bank set the overnight deposit (OD) rate equal to zero in June 2012, lowered it to -0.1% as from June 2014 and recently, from September 2014, to -0.2%.

The main goal of this paper is to extend the Furfine algorithm to correctly identify money market transactions exchanged at zero or negative rates.

As a first step, we adapt the Arciero et al. (2013) implementation of the algorithm to include negative rates or equal to zero and we evaluate its robustness. The analysis of the results shows that the microstructure obtained is unreliable: by applying a formal statistical test to the output of the algorithm, it is shown that the algorithm fails to identify zero-rate transactions. It turns out that the standard version of the Furfine algorithm is not able to detect loans traded at a zero rate with a good degree of reliability.

As a second step, to overcome the identified issue concerning zero rates, we propose an econometric methodology that takes advantage of the information on regularities that are observed in a *decentralized market*, where loans' rates are agreed bilaterally by the counterparties. This method robustly estimates the market microstructure even when rates may be equal to zero. Grounded in the economic theory of over-the-counter markets, see Afonso and Lagos (2012) and Babus and Kondor (2013) among others, and based on the empirical literature, see Ashcraft and Duffie (2007), Afonso et al. (2011) and Angelini et al. (2011) for example, we use information on market regularities observed in the bilateral rate formation process to robustly estimate market microstructure. The underlying idea is to use economic and econometric theory to correctly detect loans by exploiting the information on market regularities, to estimate the likelihood of observing a false loan and, finally, to correct the initial microstructure through additional steps. We show its practical benefits when applied to the zero interest rate. Nevertheless, the usefulness of the methodology is broader: if applied to the full range of observed interest rates, it can decrease the generalized likelihood of detecting

[2]TARGET2 is the European real-time gross settlement payment system (RTGS) and the platform where the reserve requirement is managed, payments are settled and central bank money can be traded by banks. For more information about TARGET2 see http://www.ecb.europa.eu/paym/t2/html/index.en.html.

false loans at every rate.

As a third step, we exploit the results obtained in order to describe the main impact of recent variations in the Eurosystem's key interest rates on the money market microstructure. When we compare the results of a standard implementation of the Furfine algorithm that includes negative rates with the filtered results of the proposed methodology, we see that the effects of introducing a negative OD rate is quite different when our methodology is used. The increase in the volume and the value of loans is less evident and the relative weight of negative rates is higher.

The rest of the paper is organized as follows. Section 2 describes the results of the standard implementation of the Furfine algorithm using TARGET2 data when interest rates may be negative or equal to zero. Section 3 outlines the econometric methodology proposed in the paper. Section 4 presents the results of the application of our methodology using TARGET2 data. Section 5 presents the robustness checks and Section 6 the conclusions.

2 Preliminary Evidence: The Furfine Algorithm with Negative and Zero Interest Rates

We start with the implementation of the Furfine algorithm described in Arciero et al. (2013). The main features of the algorithm proposed in that paper are: i) it is designed to identify money market transactions with maturities up to one year, ii) the implied interest rate is limited to a corridor between r_{min} and r_{max} and must be a multiple of half a basis point, and iii) in case of multiple matches, the algorithm includes a procedure for run-time selection of the most plausible match. In this work, the implementation characteristics include: the selection of a 200 basis point corridor width[3], between r_{min} and r_{max}, centred around the EONIA rate, the modification of the algorithm to include rates that are multiples of 0.1 basis points, thereby aligning it with the minimum rate tick used in euro money market (see, for instance, the e-MID platform rate tick); the application of the algorithm to ordering and beneficiary institution information drawn from payment system data, focusing on settled overnight transactions only.

To deal with the matter of negative rates, we removed the condition that, in the event the overnight deposit facility rate r_{OD} (OD rate) is lower than zero, the amount of the reimbursement transaction at day $t + k$, must be greater than the amount of the setup transaction at day t. That is, if the rate r_{OD} is greater than or equal to zero, the Furfine algorithm matches payments under the constraint that $p_t < p_{t+k}$, where p_t is the loan at time t and p_{t+k} is the repayment at time $t + k$, where k is the maturity. When $r_{OD} < 0$ the condition is removed and the amount of the reimbursement transaction, p_{t+k}, can be lower than, equal to or greater than the amount of the setup transaction, p_t, implicitly assuming that the contracted interest rate can be lower than, equal to or greater than 0 respectively.

In this section we report some of the aggregate results from the standard implementation of the algorithm, only removing the constraint, i.e. we assume it plausible to observe loans at zero or negative interest rates from June 2014, when the ECB Governing Council set the overnight deposit facility rate at -0.1%. From Figure 1 it appears that the daily average

[3] The same methodology described in the next sections was applied to the output of the algorithm using the other corridors presented in Arciero et al. (2013); the results obtained , not presented in this paper, show that the methodology is not impacted by the choice of corridor.

rate computed on estimated loans (FEONIA) is pretty close to the EONIA even after June 2014. If we look at panel (a) of Figure 2, which reports the daily number of overnight loans detected by the algorithm, it seems that the Eurosystem's decision increased market thickness. The same observation can be made for panel (b), where the daily value of those loans is reported.[4] Note that these results lead to the conclusion that the Eurosystem's decision favoured a significant increase in interbank loans. Nevertheless, we may think that the strong discontinuity observed in June 2014 may be due to the inclusion of zero and negative interest rates. In particular, it seems that daily volatility strongly increased too. Observe that high volatility could characterize financial crises (see Figure 2). Given that no crisis was observed in June 2014, this evidence may indicate the presence of noise introduced by false detection of loans.[5] If we focus on the time interval in which the OD is less than zero (from June 2014), we notice that many loans are agreed at negative rates, but the majority are settled at a zero rate (Figure 3). The graphical analysis of the empirical PDF and CDF of the rates shows an extremely high concentration of loans at zero rate (over 40% in both of the time intervals considered in Figure 3). This evidence supports the idea that some payments with the same value are paired by the algorithm even though they do not constitute a loan and are thus falsely labelled as money market transactions. The doubt is supported by the low degree of similarity between the CDFs (and PDFs) of FEONIA and EONIA (Figure 4). Apart from some discrepancies arising because they are computed using different samples, the two indices should be quite close to each other. These daily indicators are thus helpful in assessing the quality of the algorithm results. The possibility that ambiguous conclusions can be drawn about relevant central bank decisions means this issue must be addressed, using an accurate and formal approach.

3 The Econometric Methodology

Intuition. It therefore seems that the standard algorithm overestimates the number of loans at zero interest rate, but it is not clear a priori whether, and to what extent, this observation is correct. On the one hand, *(i)* it makes sense to lend money in the interbank market at a zero interest rate if the OD rate is less than zero. On the other hand, *(ii)* it is possible that pairs of payments that are not part of a loan agreement are imputed as loans. The difficulty lies in distinguishing the former case from the latter. It is an inferential issue, that stems from the fact that a loan can be observed and be true, as in the first case, or observed but instead be false, as in the second case.[6] The economic theory suggests the existence of regularities in a decentralized market, where agents bilaterally agree on the price of the exchanged asset, see Afonso and Lagos (2012) and Babus and Kondor (2013) among others. It may help to assess the incidence of false loans and to identify them. In these markets, rate dispersion depends

[4] The strong decrease observed in July 2012, the date on which the OD was set to zero, might derive from the missing zero interest rate in the set of reasonable rates. There is an economic rationale for not including it; lending money or not lending money are equivalent choices from July 2012 to June 2014. Since lending requires at least the effort to find a counterparty, it does not seem useful to include the zero interest rate from July 2012. We delve further into this issue in Section 5.

[5] In addition, note that it can generate false signals to analysts monitoring rate volatility.

[6] From a financial logic perspective, the distinction between a zero interest rate loan and a pair of payments for the same amount lies in the different natures of the trades. In particular, if a payment does not represent either the supply or the repayment of a loan, a different *economic aspect* apply to this transaction.

on the characteristics of the counterparties, the date and the maturity:

$$r_{bl,m,t,n} = f(b, l, t, m, \bar{\theta}, \epsilon),$$

where $r_{bl,m,t,n}$ is the rate of the n_{th} loan at time t with maturity m having b as a borrower and l as lender, $\bar{\theta}$ is a set of parameters and ϵ is a random component. Intuitively, we can exploit observed regularities and estimate the likelihood of false loans for each point in the rate space. Examples of such regularities are the following:

- the rate paid during a day in which the amount of central bank money in the market is low is going to be higher than one in which the amount of central bank money is high;
- a risky borrower is going to pay a higher rate than a solid one;
- a lender with a structural excess of liquidity in its account has a propensity for lending at a lower rate compared with a lender with a low liquidity surplus;
- the rate paid for a long maturity is going to be higher than that for a short maturity;
- the rate paid reflects the bargaining powers of counterparties.

All these examples hold on average and all other things being equal. We can use an econometric model to embed these regularities, infer false loans by using the estimates obtained and precisely detect loans that are most likely false.

Assumptions. In order to keep things simple, we assume linearity, normally distributed unobservables and standard conditions for $f(\cdot)$.

Assumption 1. *Let that the data generation process of the loan rate be the following*

$$r_{bl,m,t,n} = \begin{cases} 1 - P(r_{bl,m,t,n} = r^0) & r^0 \neq r_{bl,m,t,n} = \begin{cases} r_{bl,m,t,n} = \alpha_t + \beta_b + \gamma_l + \delta_m + \epsilon_{bl,m,t,n} \\ \epsilon_{bl,m,t,n} \sim N(0; \sigma_t) \end{cases} \\ P(r_{bl,m,t,n} = r^0) & r_{bl,m,t,n} = r^0 = \begin{cases} P^T & \begin{cases} r_{bl,m,t,n} = \alpha_t + \beta_b + \gamma_l + \delta_m + \epsilon_{bl,m,t,n} \\ \epsilon_{bl,m,t,n} \sim N(0; \sigma_t) \end{cases} \\ P^F & \begin{cases} r_{bl,m,t,n} = \alpha_t + \beta_b + \gamma_l + \delta_m + \epsilon_{bl,m,t,n} \\ \epsilon_{bl,m,t,n} = \underbrace{r^0 - \alpha_t - \beta_b - \gamma_l - \delta_m}_{\text{measurement error}} \end{cases} \end{cases} \end{cases} . \quad (1)$$

$$\sigma_t = s(|r_{ML,t} - r_{OD,t}|)$$

where $r_{bl,m,t,n}$ is the rate of the n_{th} loan at time t with maturity m with b as borrower and l as lender, α_t is the time fixed effect, β_b is the borrower fixed effect, γ_l is the lender fixed effect, δ_m is the maturity fixed effect and $\epsilon_{bl,m,t,n}$ is the normally distributed error. $r_{ML,t}$ is the marginal lending rate, $r_{OD,t}$ is the overnight deposit rate and $s(\cdot)$ is a function capturing the corridor width. P^T is the probability of observing a rate equal to r^0 when it is "true", while P^F is the probability of observing a rate equal to r^0 when it is "false".

It implies that if the loan is false, the measurement error takes an explicit form, as reported in model (1). Observe that $P(r_{bl,m,t,n} = r^0) = P^T + P^F$. We allow for heteroskedasticity and let the error variance depend on the corridor width at time t with a functional form $s(\cdot)$.[7]

Assumption 2. *The market rate is able to capture the daily liquidity conditions and it is independent to $\epsilon_{bl,m,t,n}$.*

Estimated parameter properties under false loans. Under Assumption 2 we let the market rate, like the EONIA for euro funds, capture the daily conditions and thus, we can consider the following matrix form for model (1)

$$R = E\alpha + B\bar{\beta} + L\bar{\gamma} + M\bar{\delta} + \Sigma = X\bar{\theta} + \Sigma,$$

where $\bar{\beta}$ is a vector of borrower fixed effects with size equal to the number of borrowers in the market, $\bar{\gamma}$ is a vector of lender fixed effects with size equal to the number of lenders in the market. $\bar{\delta}$ is a vector of maturities fixed effects. E is a vector with a value equal to the market rate, E_k if $t = k$, while B, L , M are matrices of zeros and ones that keep track of the loan borrower, lender and maturity and associate them with the respective parameters included in $\bar{\beta}$, $\bar{\gamma}$ and $\bar{\delta}$. Σ is a vector of errors. $X = [E, B, L, M]$ is the $n \times K$ matrix of regressors and $\bar{\theta}' = [\alpha, \bar{\beta}', \bar{\gamma}', \bar{\delta}']'$. Splitting the sample based on which loans are false and which are true, we obtain

$$\begin{bmatrix} R^T \\ R^F \end{bmatrix} = \begin{bmatrix} E^T \\ E^F \end{bmatrix} \alpha + \begin{bmatrix} B^T \\ B^F \end{bmatrix} \bar{\beta} + \begin{bmatrix} L^T \\ L^F \end{bmatrix} \bar{\gamma} + \begin{bmatrix} M^T \\ M^F \end{bmatrix} \bar{\delta} + \begin{bmatrix} \Sigma^T \\ \Sigma^F \end{bmatrix} = \begin{bmatrix} X^T \\ X^F \end{bmatrix} \bar{\theta} + \begin{bmatrix} \Sigma^T \\ \Sigma^F \end{bmatrix},$$

where the size of T elements is $N(1 - P^F)$, while the size of F elements is NP^F. Under Assumptions 1 - 2 where we have $X^{T\prime}\Sigma^T = 0_K$ and where 0_K is a $1 \times K$ vector of zeros, it turns out that

$$E(X'\Sigma) = f(P^F) = \begin{cases} 0 & P^F = 0 \\ -X^{F\prime}X^F\bar{\theta} & P^F = 1 \end{cases}.$$

In other words, when there are no false loans in the sample, the errors are not correlated with the regressors, while this correlation increases with the percentage of false loans. Consequently the following limits can be derived for the OLS estimates of the model parameters,[8]

$$\lim_{P^F \to 0} \hat{\alpha}_{OLS} = \alpha,$$

[7]We can allow σ_t to also depend on $r_{EONIA,t}$, the EONIA rate.

[8]Observe that if we assume that the covariance between the regressors is zero we also have:

$$E(E'\Sigma) = f(P^F) = \begin{cases} 0 & P^F = 0 \\ -E^{F\prime}E^F\alpha & P^F = 1 \end{cases},$$

$$E(B'\Sigma) = f(P^F) = \begin{cases} 0 & P^F = 0 \\ -B^{F\prime}B^F\bar{\beta} & P^F = 1 \end{cases},$$

$$E(L'\Sigma) = f(P^F) = \begin{cases} 0 & P^F = 0 \\ -L^{F\prime}L^F\bar{\gamma} & P^F = 1 \end{cases},$$

$$E(M'\Sigma) = f(P^F) = \begin{cases} 0 & P^F = 0 \\ -M^{F\prime}M^F\bar{\delta} & P^F = 1 \end{cases},$$

$$\lim_{P^F \to 0} \hat{\bar{\beta}}_{OLS} = \bar{\beta},$$

$$\lim_{P^F \to 0} \hat{\bar{\gamma}}_{OLS} = \bar{\gamma},$$

$$\lim_{P^F \to 0} \hat{\bar{\delta}}_{OLS} = \bar{\delta}.$$

Under Assumptions 1 and 2 the restricted sample on $r_{bl,m,t,n} \neq r_0$ does not contain false loans, while the unrestricted sample may. It follows that a set of formal tests for the significant presence of false rates equal to r^0 is

$$H_0 : \hat{\alpha}_{OLS,R} - \hat{\alpha}_{OLS,U} = 0,$$

$$H_0 : \hat{\bar{\beta}}_{OLS,R} - \hat{\bar{\beta}}_{OLS,U} = 0,$$

$$H_0 : \hat{\bar{\gamma}}_{OLS,R} - \hat{\bar{\gamma}}_{OLS,U} = 0,$$

$$H_0 : \hat{\bar{\delta}}_{OLS,R} - \hat{\bar{\delta}}_{OLS,U} = 0.$$

Where the subscript U defines the unrestricted sample, the subscript R defines the restricted subsample of $r_{bl,m,t,n} \neq r_0$. The test follows from the consistency of $\hat{\bar{\theta}}_R$ and the possible inconsistency of $\hat{\bar{\theta}}_U$ under Assumptions 1 and 2 (see the Appendix for more details). In other words, $\hat{\bar{\theta}}_R$ provides us with robust information about market regularities, while the divergence of $\hat{\bar{\theta}}_U$ signals the presence of false loans, that by definition do not follow such regularities. Let $D_{U,R} = \bar{\theta}_U - \bar{\theta}_R$ be the difference between the OLS estimators of the restricted and unrestricted sample. From the last equality of (5), in the Appendix, we can derive the expected value of the bias as a function of the probability of observing false rates:

$$\begin{aligned} E(D_{U,R}) &= E\left((nVC(X))^{-1}[n_F VC(X_F); n_T C(X_T, \Sigma^T)][-\bar{\theta}'; 1]'\right) \\ &= [P_F I_K; (1 - P_F)VC(X)^{-1}C(X, \Sigma)][-\bar{\theta}'; 1]' \\ &= ([O_K; o_K] + P_F[I_K; o_K])[-\bar{\theta}'; 1]', \end{aligned} \tag{2}$$

where $VC(X) = (X'X)/n$ and $VC(X_F) = (X_F'X_F)/n_F$ are the variance-covariance matrices computed on different samples, I_K is the identity matrix with dimension K, O_K and o_K are respectively a square matrix and a vector of zeros with dimension K. $C(X_T, \Sigma^T) = (X_T'\Sigma_T)/n_T$ is the sample covariance matrix between the error term and the covariates, while $C(X, \Sigma)$ is the covariance matrix of the respective random variables. From the last equality in (2) it turns out that a consistent estimator for P^F is

$$\hat{P^F} = \hat{\bar{\theta}}^{+} \hat{D}_{U,R}, \tag{3}$$

where $\hat{D}_{U,R}$ is a consistent estimator of the bias and $\hat{\bar{\theta}}^{+}$ is the Moore-Penrose pseudoinverse of a consistent estimator of the true parameters. Under Assumptions 1 and 2 both can be recovered using OLS estimates of $\bar{\theta}_U$ and $\bar{\theta}_R$. The intuition is as follows: the restricted model (R) gives consistent estimates of the model parameters ($\bar{\theta}$), providing the econometrician with a correct characterization of market regularities, while the estimates from the unrestricted model (U), departing from the true value as a function of the likelihood of observing false loans at a rate equal to r_0, make it possible to quantify the bias ($D_{U,R}$).

A test for false loans. Having estimates from the restricted and unrestricted models allows us to test whether the presence of false loans is significant for a specific rate r_0.

$$T = (\hat{\bar{\theta}}_U - \hat{\bar{\theta}}_R)' diag(1/\sqrt{\hat{\sigma}^2_{\bar{\theta}_U} + \hat{\sigma}^2_{\bar{\theta}_R}}), \tag{4}$$

where $\hat{\sigma}_{\bar{\theta}_U}$ and $\hat{\sigma}_{\bar{\theta}_R}$ are the $K \times 1$ vectors of the standard deviations of the estimated parameters respectively from the unrestricted and the restricted models and $diag(\cdot)$ transforms the vector into a diagonal matrix. The vector T gives K p-values, as a standard test for significant difference with $\theta^k_U = \theta^k_R, k = 1, \cdots K$, as the null hypotheses; the greater the distance from 0.5 in absolute value, the greater the likelihood that false loans at rate r_0 are present.

A correction procedure for the market microstructure. If the test signals a high likelihood of false loans, we can detect the loans that are the most likely to be false using the following simple procedure. Take the vector $\hat{\epsilon}^U$, which contains the residuals from the unrestricted model and has $\hat{\epsilon}^U_{bl,t,m,n}$ as a generic element and the time-varying estimates of its variance $\hat{\sigma}^U_t$. Then, compute the $(1 - \hat{P}_F)_{th}$ percentile of its empirical distribution, $\tau^{1-\hat{P}_F}_{\hat{\epsilon}^U}$. The loans most likely to be false are contained in this set:

$$F(r_0) := \{L_{bl,t,m,n} : (r_{bl,t,m,n} = r_0) \cap (\frac{\hat{\epsilon}^U_{bl,t,m,n}}{\hat{\sigma}^U_t} \geq \tau^{1-\hat{P}_F}_{\hat{\epsilon}^U}), \}$$

where $L_{bl,t,m,n}$ is the n_{th} loan at time t with maturity m having b as a borrower and l as lender. It is thus possible to clean our dataset of loans less likely to be true, identifying them precisely. In this way we can also study their characteristics ex-post in order to better identify the source of noise, using supplementary information if necessary.

4 Empirical Analysis

We implemented the procedure outlined in Section 3 for the set of loans detected by the standard Furfine algorithm applied to TARGET2 data.[9] The parameter estimates for the unrestricted and restricted (with $r_0 = 0$) models are reported in Table 1 columns (1)-(2). Most of the estimated coefficients differ significantly across these two subsamples. Furthermore some of the fixed effects are significant in the restricted sample while not so in the unrestricted, and viceversa. The hint is supported by the test proposed in equation (4) and reported in column (1) of Table 2. The relative p-values reported in column (2) show a quite significant difference between the two samples. In particular, the time coefficient α is very different, indicating that in the unrestricted sample, the dependence on the day in which the loan is agreed is lower. In other words, it means that, all things being equal, the number of estimated loans at a zero interest rate is almost independent of the average market rate, i.e. very likely in the days on which the average market rate is far from zero.

Our estimate of P_F, using estimand (3), is equal to 0.38, roughly 80% of the detected loans at zero interest rate (which in turn are 48% of the total). We delete this percentage of

[9] The econometric procedure is applied to the time interval starting from 11 June 2014. The reasons behind it are at least two. The first one is theoretical, there is no incentive to trade at zero interest rate when the OD is equal or greater than zero. The second one is empirical, we do not observe zero interest rate loans traded on the e-MID platform before this date.

loans from the initial sample, selecting them by following the correction procedure outlined in Section 3.

These steps lead us to a new sample, from which the loans most likely to be false loans have been deleted. Let us describe this sample. The volume (panel (a)) and the value (panel (b)) are reported in Figure 5. We can see that the discontinuity (in correspondence to the implementation of the negative OD rate on 11 June 2014) observed in the initial sample vanishes. In terms of policy relevant facts, it is worthwhile to note that this new sample draws different conclusions, as compared with the initial sample, regarding the effects of the Eurosystem's decision. The volume decreases from 11 June 2014, instead of increasing as in the initial sample. The increase in value does not seem to be as prominent as before, showing a substantial stationarity. It implies an increase in the average value of a loan. The new rate's empirical CDF and PDF do not signal the huge probability mass on zero (Figure 6). Furthermore, the frequency of negative interest rates significantly increases, moving from 16% to 20% during the maintenance periods in which the OD rate is equal to -0.1% and from 27% to 43% during the maintenance periods in which the OD rate is equal to -0.2%. Figure 7 shows the empirical CDF and PDF of the new FEONIA and the EONIA for both of the aforementioned maintenance periods. The similarity between these two indicators is significantly improved as compared with the initial sample, as the closeness of those functions highlights. To make the statement more robust we perform a number of similarity tests -the Kolmogorov-Smirnov test among others- using this sample and the one detected using the standard Furfine algorithm (Figure 4). The results are reported in Table 3. We clearly see that the p-values of the similarity tests are always closer to 0.5 when our additional step is performed and that the null hypothesis of belonging to the same distribution is almost never rejected.

5 Robustness Checks

To give us more confidence in the results obtained using the proposed econometric procedure, we implement, in this section, four robustness checks.

The first exercise consists in changing the reference interest rate (r_0 in the econometric procedure) from 0% to 0.01% and to -0.01%. Those rates are plausible, as zero is, but we empirically did not find an abnormal frequency of loans agreed at that rate. Furthermore, the related payments cannot be confounded with other liquidity transfers for the same value but of a different nature. The restricted model outlined in Section 3 is thus estimated with $r_0 = 0.01\%$ and $r_0 = -0.01\%$. Columns (3)-(4) of Table 1 reports the results, the estimated coefficients are very close to the ones from the unrestricted model in column (1), we also do not find any control to be significant in one specification and not in the other. Columns (3)-(4) and columns (5)-(6) of Table 2 show that we never reject the hypothesis of having the same coefficient for the restricted and the unrestricted sample. All p-values are extremely close to 0.5, which signals that there is no need to apply our procedure to these rates. The evidence indicates that the standard Furfine algorithm does a good job in matching loans with rates equal to 0.01% and -0.01% and that our econometric procedure is valuable especially for filtering out false loans at zero interest rate.

In the second exercise we apply our econometric procedure to a different sample. The latter is generated by assuming that zero interest rates may be observed even from 11 July 2012, the date on which the OD rate had been set to zero by the Eurosystem.[10] As we saw in Figure 2, the inclusion of zero rates seems to generate remarkable noise. The evidence is confirmed by Figure 8 where the standard Furfine algorithm is allowed to pick loans at zero rate from 11 July 2012; the additional noise between 11 July 2012 and 11 June 2014 is visible in both the panels. Data from the e-MID platform does not contain loans at zero rate in this time interval, suggesting that our econometric procedure should yield a subset of loans very similar to the baseline sample. In other words, it should reject almost every additional loan at zero rate detected by the algorithm in the time interval between 11 July 2012 and 11 June 2014. It is interesting to observe how the effects of monetary policy look quite different if we include zero rates from 11 July 2012. Looking at Figure 8 it seems that the number of loans increased after 11 July 2012 and decreased after 11 June 2014, exactly the opposite conclusions drawn in Figure 2. Results from our econometric procedure applied to this sample are reported in Figure 9, note that the volume and value of loans are almost coincident with those from the baseline sample (in Figure 5).

The third exercise consists in applying the econometric procedure to the set of loans agreed using the e-MID platform. The number of false loans should be very close to zero because all of these are actual loans. In order to more accurately asses the robustness of our procedure, we allow the standard Furfine algorithm to include zero rates from 11 July 2012 and from 11 June 2014. In Figure 10 the time series of the frequency of zero interest rates loans are reported for the original data and for the samples returned by the econometric procedure when zero rates are included from 11 July 2012 (filtered 1) and from 11 June 2014 (filtered 2). The three series are very close; this highlights the success of the procedure in holding the actual loans at a zero interest rate. Indeed, the number of deleted loans is negligible. In the fourth exercise we apply the procedure (with the same reference rate $r_0 = 0$) to the final sample we obtained in Section 4, which is already cleaned of loans that are most likely false. If the methodology is robust we should not reject the null hypothesis of an insignificant number of false loans at zero rate. The relative estimates, tests and p-values are reported in Table 4, and show that we never reject the hypothesis. Observe also that the ones in column (1) of Table 4 are thus the reliable estimates for the model parameters.

6 Concluding Remarks and Future Research

The Furfine algorithm is a useful tool for policy makers and researchers in monetary economics and central banking and therefore, its reliability is fundamental. Recently some central banks are allowing negative and zero interest rates, a notable example being the Eurosystem's decision of June 2014 to set the overnight deposit rate to -0.01%. In this paper we assess the robustness of the algorithm when rates are permitted to be negative or equal to zero.

Our first result is that the algorithm is not reliable in such a context; in particular, the level of noise for zero interest rate is huge. We formally prove this by proposing a statistical test for the presence of significant noise at a specific rate. It turns out that the microstructure generated by the algorithm is strongly biased. Specifically, many liquidity transfers having different economic natures are matched and erroneously labelled as loans.

[10] It is possible that loans were agreed at zero interest rate even from that date. This possibility is partially supported by the remarkable decreases shown in Figure 2 in correspondence to July 2012. Nevertheless, there are no direct costs for having an excessive amount of central bank money between July 2012 and June 2014.

As a second contribution, we propose an econometric methodology to robustly estimate the market microstructure even in the presence of strong noise, i.e. zero interest rates. Taking advantage of the recent theoretical and empirical literature on OTC markets, we built a procedure based on the regularities observed in this decentralized market. In practice, we enrich the algorithm with two additional steps, which respectively detect and treat the undesirable noise. These additional steps formally take into account the economic likelihood of loans. In other words, the procedure employs the information on market regularities, enriching the estimation with inputs from the observation of systematic patterns within the market.

Finally, the paper describes the main impact of recent monetary policy decisions regarding key interest rates. We use reliable data from the proposed procedure, and show how different they are with respect to the dataset produced by the standard algorithm. In particular, if we want to evaluate the consequences of a negative overnight deposit rate, the conclusions drawn are drastically different. The volume and value of loans are definitely lower and the frequency of loans at negative interest rates is absolutely higher as compared with the standard algorithm.

These discrepancies highlight the importance of making an appropriate inference when the money market microstructure is estimated and shed light on the key role that economic and econometric methods can play in this context.

In this paper, to keep things straight, we use a simple ex-post frequentist approach to correct the market microstructure for noise. A more effective and complex approach that estimates microstructure and market regularities jointly, using a Bayesian procedure, can be used. We are exploring this possibility and leave it for future research.

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Appendix

The OLS estimators for the restricted and unrestricted sample are

$$\begin{bmatrix} \hat{\alpha}_{OLS,R} \\ \hat{\bar{\beta}}_{OLS,R} \\ \hat{\bar{\gamma}}_{OLS,R} \\ \hat{\bar{\delta}}_{OLS,R} \end{bmatrix} = \left(\begin{bmatrix} E_R \\ B_R \\ L_R \\ M_R \end{bmatrix}' \begin{bmatrix} E_R \\ B_R \\ L_R \\ M_R \end{bmatrix} \right)^{-1} \begin{bmatrix} E_R \\ B_R \\ L_R \\ M_R \end{bmatrix}' R_R,$$

and

$$\begin{bmatrix} \hat{\alpha}_{OLS,U} \\ \hat{\bar{\beta}}_{OLS,U} \\ \hat{\bar{\gamma}}_{OLS,U} \\ \hat{\bar{\delta}}_{OLS,U} \end{bmatrix} = \left(\begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix}' \begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix} \right)^{-1} \begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix}' R,$$

with

$$\begin{bmatrix} R^A \\ R^R \end{bmatrix} = \alpha \begin{bmatrix} E^A \\ E^R \end{bmatrix} + \bar{\beta} \begin{bmatrix} B^A \\ B^R \end{bmatrix} + \bar{\gamma} \begin{bmatrix} L^A \\ L^R \end{bmatrix} + \bar{\delta} \begin{bmatrix} M^A \\ M^R \end{bmatrix} + \begin{bmatrix} \Sigma^A \\ \Sigma^R \end{bmatrix},$$

where the subscript U defines the unrestricted sample, the subscript R defines the restricted subsample of $r_{bl,m,t,n} = r_0$, while the subscript A identifies the rest of the sample. The size of R elements is $N[1-(P^F+P^T)]$, while the size of A elements is $N[P^F+P^T]$. If $P^F \neq 0$, because of the presence of false loans, only the estimates from the restricted sample are consistent, while the estimates from the unrestricted are biased:

$$E\left(\begin{bmatrix} \hat{\alpha}_{OLS,R} \\ \hat{\bar{\beta}}_{OLS,R} \\ \hat{\bar{\gamma}}_{OLS,R} \\ \hat{\bar{\delta}}_{OLS,R} \end{bmatrix} \right) = \begin{bmatrix} \alpha \\ \bar{\beta} \\ \bar{\gamma} \\ \bar{\delta} \end{bmatrix},$$

$$E\left(\begin{bmatrix} \hat{\alpha}_{OLS,U} \\ \hat{\bar{\beta}}_{OLS,U} \\ \hat{\bar{\gamma}}_{OLS,U} \\ \hat{\bar{\delta}}_{OLS,U} \end{bmatrix} \right) = \begin{bmatrix} \alpha \\ \bar{\beta} \\ \bar{\gamma} \\ \bar{\delta} \end{bmatrix} + \left(\begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix}' \begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix} \right)^{-1} \begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix}' \begin{bmatrix} \Sigma^F \\ \Sigma^T \end{bmatrix},$$

where

$$\begin{bmatrix} \Sigma^F \\ \Sigma^T \end{bmatrix} = \begin{bmatrix} [E^F, B^F, L^F, M^F]'[-\alpha, -\bar{\beta}, -\bar{\gamma}, -\bar{\delta}] + r^0 \iota^F \\ \Sigma^T \end{bmatrix}.$$

Let $r^0 = 0$, we then have

$$\begin{aligned} D_{U,R} &= \bar{\theta}_U - \bar{\theta}_R = \left(\begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix}' \begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix} \right)^{-1} \begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix}' \begin{bmatrix} [E^F, B^F, L^F, M^F]'[-\bar{\theta}] \\ \Sigma^T \end{bmatrix} \\ &= \left(\begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix}' \begin{bmatrix} E \\ B \\ L \\ M \end{bmatrix} \right)^{-1} \left\{ \begin{bmatrix} E^F \\ B^F \\ L^F \\ M^F \end{bmatrix}' \begin{bmatrix} E^F \\ B^F \\ L^F \\ M^F \end{bmatrix}; \begin{bmatrix} E^T \\ B^T \\ L^T \\ M^T \end{bmatrix}' \Sigma^T \right\} \left\{ \begin{bmatrix} -\bar{\theta} \\ 1 \end{bmatrix} \right\}. \end{aligned} \quad (5)$$

Tables

Table 1: Rate Equation - Parameter Estimates

Dependent Variable: loan rate	Baseline results		Robustness checks	
	Unrestricted model	Restricted model $r \neq 0$	Restricted model $r \neq 0.01$	Restricted model $r \neq -0.01$
	(1)	(2)	(3)	(4)
α	0.4319***	0.7124***	0.4348***	0.4317***
	(0.0052)	(0.0085)	(0.0054)	(0.0053)
βs	0.0094***	0.0248***	0.0089***	0.0096***
	(0.0014)	(0.0022)	(0.0015)	(0.0014)
	-0.0026	0.0186***	-0.0035	-0.0025
	(0.0028)	(0.0056)	(0.0029)	(0.0029)
	0.0044***	0.0602***	0.0048***	0.0044***
	(0.0015)	(0.0065)	(0.0016)	(0.0016)
	0.0213***	0.0313***	0.0222***	0.0215***
	(0.0032)	(0.0059)	(0.0034)	(0.0033)
	0.0143***	0.0442***	0.0146***	0.0145***
	(0.0012)	(0.0023)	(0.0013)	(0.0013)
	0.0381***	0.0667***	0.0431***	0.0382***
	(0.0019)	(0.0041)	(0.0021)	(0.0019)
	0.0043***	0.0265***	0.0045***	0.0045***
	(0.0012)	(0.0024)	(0.0013)	(0.0013)
	-0.0020*	0.0072***	-0.0016	-0.0020
	(0.0011)	(0.0027)	(0.0012)	(0.0012)
	0.0083***	0.0211***	0.0076***	0.0084***
	(0.0023)	(0.0039)	(0.0025)	(0.0023)
	0.0190***	0.0322***	0.0204***	0.0192***
	(0.0017)	(0.0034)	(0.0018)	(0.0017)
	-0.0019	0.0022	-0.0030	-0.0019
	(0.0024)	(0.0041)	(0.0026)	(0.0025)
	0.0005	0.0150***	0.0008	0.0007
	(0.0015)	(0.0027)	(0.0016)	(0.0016)
	0.0099***	-0.0073	0.0106***	0.0100***
	(0.0018)	(0.0061)	(0.0019)	(0.0019)
	0.0342***	0.0358***	0.0380***	0.0359***
	(0.0025)	(0.0037)	(0.0028)	(0.0026)
	-0.0234***	-0.0621***	-0.0200***	-0.0236***
	(0.0028)	(0.0049)	(0.0029)	(0.0029)
	0.0258***	0.0378***	0.0288***	0.0260***
	(0.0032)	(0.0060)	(0.0035)	(0.0033)
	0.0318***	0.1074***	0.0330***	0.0320***
	(0.0022)	(0.0066)	(0.0023)	(0.0022)
γs	-0.0145***	-0.0334***	-0.0154***	-0.0143***
	(0.0014)	(0.0022)	(0.0015)	(0.0014)
	-0.0208***	-0.0461***	-0.0214***	-0.0208***
	(0.0020)	(0.0031)	(0.0020)	(0.0020)
	-0.0083***	0.0120***	-0.0086***	-0.0083***
	(0.0016)	(0.0049)	(0.0016)	(0.0016)
	-0.0056	-0.0222***	-0.0058	-0.0055
	(0.0035)	(0.0061)	(0.0037)	(0.0035)
	-0.0232***	-0.0519***	-0.0245***	-0.0231***
	(0.0011)	(0.0019)	(0.0011)	(0.0011)
	0.0116***	0.0035	0.0134***	0.0120***
	(0.0018)	(0.0039)	(0.0020)	(0.0019)
	-0.0196***	-0.0451***	-0.0210***	-0.0196***
	(0.0013)	(0.0028)	(0.0014)	(0.0014)
	-0.0201***	-0.0466***	-0.0206***	-0.0201***
	(0.0012)	(0.0028)	(0.0012)	(0.0012)
	-0.0133***	-0.0231***	-0.0146***	-0.0133***
	(0.0026)	(0.0047)	(0.0028)	(0.0026)
	0.0078***	0.0056	0.0093***	0.0076***
	(0.0024)	(0.0041)	(0.0026)	(0.0025)
	-0.0097***	-0.0266***	-0.0099***	-0.0096***
	(0.0017)	(0.0033)	(0.0018)	(0.0017)
	-0.0078***	-0.0223***	-0.0085***	-0.0078***
	(0.0022)	(0.0036)	(0.0023)	(0.0022)
	-0.0288***	-0.0533***	-0.0295***	-0.0289***
	(0.0018)	(0.0034)	(0.0019)	(0.0018)
	-0.0091***	0.0121	-0.0097***	-0.0092***
	(0.0019)	(0.0077)	(0.0020)	(0.0019)
	0.2502***	0.2854***	0.2739***	0.2486***
	(0.0034)	(0.0049)	(0.0037)	(0.0035)
	0.0631***	0.1387***	0.0619***	0.0632***
	(0.0032)	(0.0059)	(0.0033)	(0.0032)
	0.0010	-0.0088	0.0011	0.0009
	(0.0031)	(0.0059)	(0.0033)	(0.0032)
	0.0391***	0.0378***	0.0400***	0.0390***
	(0.0028)	(0.0067)	(0.0029)	(0.0028)

Notes: * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Only fixed effects with more than 1% of observations are included in the model. βs and γs are country fixed effects for countries having a frequency higher than 0.01%.

Table 2: Test for false loans

Variable: loan rate

	Baseline results		Robustness checks			
	$r = 0$		$r = 0.01$		$r = -0.01$	
	$p(r) = 48\%$		$p(r) = 7\%$		$p(r) = 2\%$	
	T (1)	P (2)	T (3)	P (4)	T (5)	P (6)
α	-2.3956	0.0083	-0.0276	0.4890	0.0022	0.5009
β s	-0.2563	0.3989	0.0094	0.5037	-0.0039	0.4985
	-0.2322	0.4082	0.0123	0.5049	-0.0007	0.4997
	-0.6243	0.2662	-0.0067	0.4973	-0.0001	0.5000
	-0.1043	0.4585	-0.0113	0.4955	-0.0020	0.4992
	-0.5011	0.3081	-0.0055	0.4978	-0.0049	0.4981
	-0.3689	0.3561	-0.0786	0.4687	-0.0016	0.4994
	-0.3665	0.3570	-0.0031	0.4988	-0.0030	0.4988
	-0.1482	0.4411	-0.0076	0.4969	-0.0001	0.5000
	-0.1623	0.4355	0.0092	0.5037	-0.0019	0.4992
	-0.1848	0.4267	-0.0231	0.4908	-0.0033	0.4987
	-0.0513	0.4795	0.0148	0.5059	-0.0005	0.4998
	-0.2215	0.4123	-0.0054	0.4978	-0.0036	0.4985
	0.1921	0.5762	-0.0112	0.4955	-0.0016	0.4994
	-0.0202	0.4919	-0.0524	0.4791	-0.0247	0.4901
	0.4402	0.6701	-0.0449	0.4821	0.0028	0.5011
	-0.1254	0.4501	-0.0365	0.4854	-0.0028	0.4989
	-0.8054	0.2103	-0.0181	0.4928	-0.0023	0.4991
γ s	0.3174	0.6245	0.0172	0.5069	-0.0039	0.4984
	0.3564	0.6392	0.0094	0.5038	-0.0002	0.4999
	-0.2530	0.4001	0.0056	0.5023	0.0001	0.5000
	0.1694	0.5672	0.0015	0.5006	-0.0010	0.4996
	0.5323	0.7027	0.0292	0.5117	-0.0024	0.4991
	0.1074	0.5427	-0.0292	0.4883	-0.0062	0.4975
	0.3966	0.6542	0.0257	0.5103	0.0000	0.5000
	0.4198	0.6627	0.0111	0.5044	-0.0003	0.4999
	0.1148	0.5457	0.0181	0.5072	0.0007	0.5003
	0.0275	0.5110	-0.0217	0.4914	0.0018	0.5007
	0.2383	0.5942	0.0023	0.5009	-0.0016	0.4994
	0.1895	0.5751	0.0097	0.5039	0.0003	0.5001
	0.3384	0.6325	0.0107	0.5043	0.0020	0.5008
	-0.2167	0.4142	0.0096	0.5038	0.0009	0.5003
	-0.3862	0.3497	-0.2792	0.3900	0.0192	0.5077
	-0.7932	0.2138	0.0139	0.5055	-0.0020	0.4992
	0.1030	0.5410	-0.0021	0.4992	0.0014	0.5006
	0.0131	0.5052	-0.0119	0.4953	0.0016	0.5006

Notes: see Table 1. T is defined in equation 4.

Table 3: Tests of similarity between EONIA and FEONIA

Variables: EONIA and FEONIA samples

Time period	[11/6/2014 - 9/9/2014]				[9/9/2014 - 7/10/2014]			
FEONIA Sample	Standard algo		New procedure		Standard algo		New procedure	
Test	T	P	T	P	T	P	T	P
Kolmogorov-Smirnov	0.4242	7.748e-06	0.1818	0.2025	0.3500	0.1349	0.1524	0.2572
Ansari-Bradley	3.8962	9.7706e-05	2.2576	0.0239	-4.0079	6.1254e-05	-2.4914	0.0127
Wilcoxon	-3.0197	0.0025	-0.6576	0.5107	0.1758	0.8604	1.0144	0.3103
Kruskal-Wallis	9.1324	0.0025	0.4355	0.5093	0.0358	0.8498	1.0567	0.3039

Notes: T is the test statistic, P is the p-value. The Kolmogorov-Smirnov is a nonparametric hypothesis test that evaluates the difference between the CDF. The Ansari-Bradley test is a nonparametric alternative to the two-sample F-test of equal variances. The Wilcoxon rank sum test is equivalent to the Mann-Whitney U-test. The Mann-Whitney U-test is a nonparametric test for the equality of population medians of two independent samples. The Kruskal-Wallis test is a nonparametric version of classical one-way ANOVA, and an extension of the Wilcoxon rank sum test to more than two groups. It compares the medians of the groups.

Table 4: Clean sample

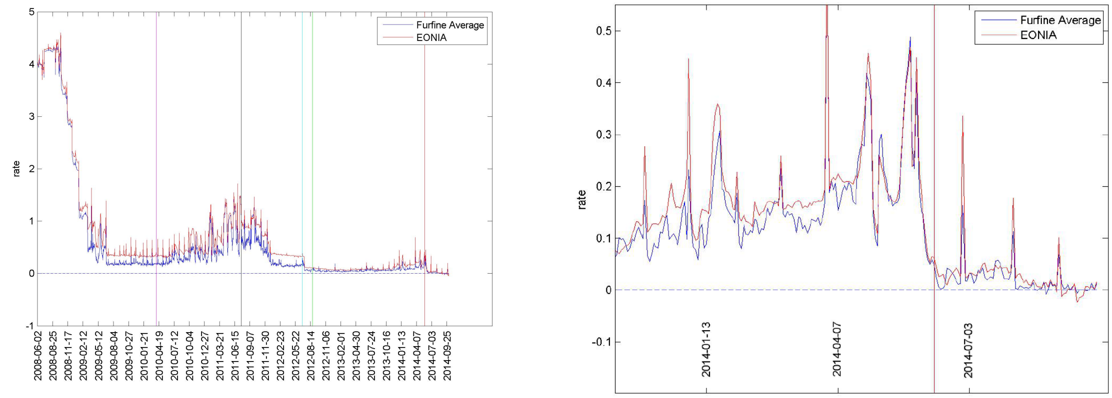
Dependent Variable: loan rate

	Estimates	Test	
		Z	P
	(1)	(2)	(3)
α	0.7143***	-0.0147	0.4941
	(0.0077)		
β s	0.0226***	0.0344	0.5137
	(0.0019)		
	0.0128***	0.0585	0.5233
	(0.0045)		
	0.0233***	0.3773	0.6470
	(0.0031)		
	0.0301***	0.0115	0.5046
	(0.0049)		
	0.0386***	0.0855	0.5341
	(0.0019)		
	0.0636***	0.0354	0.5141
	(0.0034)		
	0.0206***	0.0900	0.5358
	(0.0019)		
	0.0032	0.0590	0.5235
	(0.0020)		
	0.0192***	0.0223	0.5089
	(0.0032)		
	0.0316***	0.0075	0.5030
	(0.0026)		
	0.0011	0.0130	0.5052
	(0.0034)		
	0.0113***	0.0522	0.5208
	(0.0023)		
	0.0155***	-0.2347	0.4072
	(0.0032)		
	0.0327***	0.0365	0.5146
	(0.0034)		
	-0.0651***	0.0315	0.5126
	(0.0045)		
	0.0365***	0.0131	0.5052
	(0.0050)		
	0.0932***	0.1303	0.5518
	(0.0053)		
γ s	-0.0312***	-0.0350	0.4860
	(0.0018)		
	-0.0434***	-0.0360	0.4856
	(0.0026)		
	-0.0075***	0.2225	0.5880
	(0.0028)		
	-0.0210***	-0.0115	0.4954
	(0.0051)		
	-0.0477***	-0.0729	0.4709
	(0.0016)		
	0.0067**	-0.0373	0.4851
	(0.0034)		
	-0.0406***	-0.0633	0.4748
	(0.0022)		
	-0.0422***	-0.0636	0.4746
	(0.0020)		
	-0.0242***	0.0127	0.5051
	(0.0037)		
	0.0059*	-0.0035	0.4986
	(0.0035)		
	-0.0258***	-0.0113	0.4955
	(0.0026)		
	-0.0200***	-0.0279	0.4889
	(0.0030)		
	-0.0500***	-0.0419	0.4833
	(0.0030)		
	-0.0190***	0.2940	0.6156
	(0.0035)		
	0.2884***	-0.0316	0.4874
	(0.0044)		
	0.1417***	-0.0284	0.4887
	(0.0054)		
	-0.0074***	-0.0131	0.4948
	(0.0049)		
	0.0493***	-0.1031	0.4589
	(0.0058)		

Notes: see Table 1.

Figures

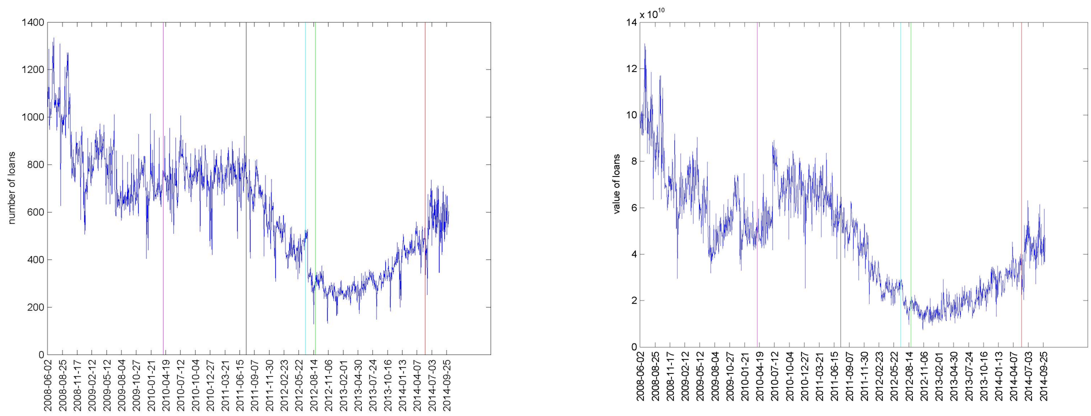
Figure 1: Time series of daily average rate detected by the Furfine algorithm and the EONIA rate. (19/05/2008 - 7/10/2014)



(a) Time series (b) Zoom

Notes: The violet vertical line traces the first sovereign debt crisis in April 2010, the black vertical line traces the second sovereign debt crisis in August 2011, the green line traces the ECB announcement of the Outright Monetary Transactions programme and the light blue line traces the signal rate change in July 2012 with the OD = 0%. The red lines traces the signal rate change in June 2014 with OD = -0.1%.

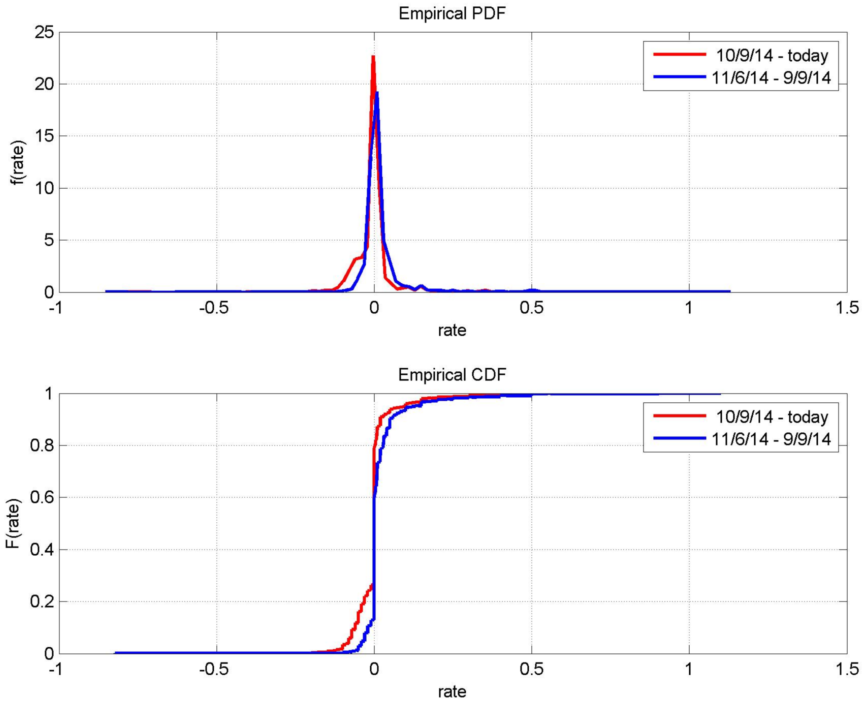
Figure 2: Time series of daily volume and value of loans detected by the Furfine algorithm. (19/05/2008 - 7/10/2014)



(a) Volume (b) Value

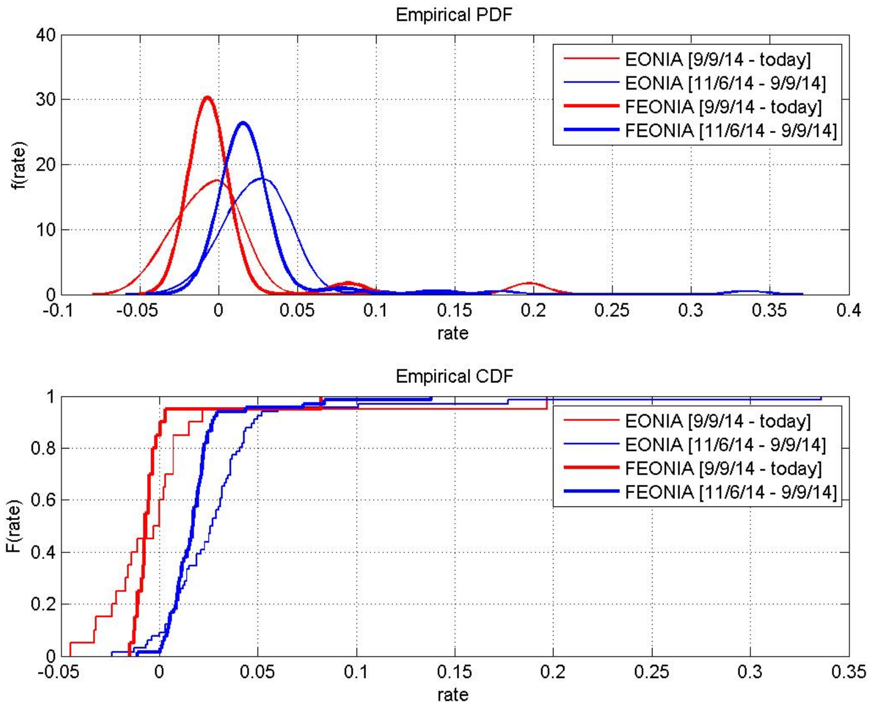
Notes: zero rates included by 11/06/2014, see Figure 1.

Figure 3: Empirical distribution functions of rates detected by the Furfine algorithm. (11/06/2014 - 7/10/2014)



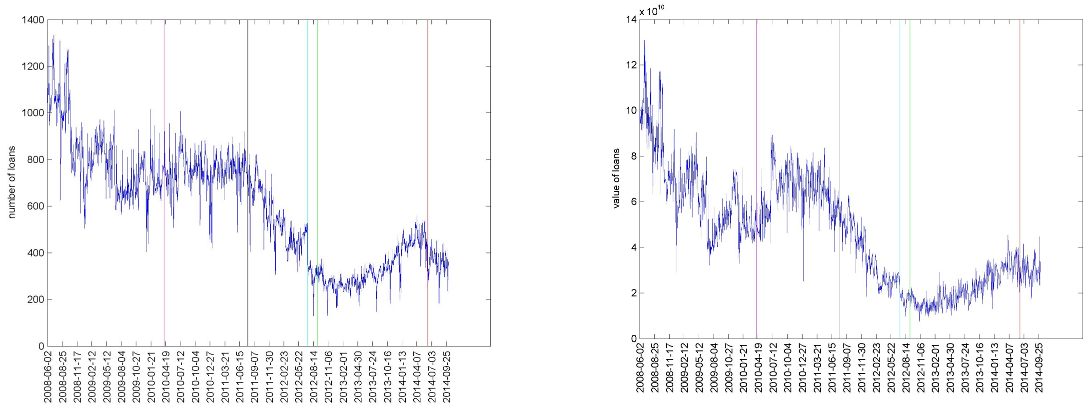
Notes: Blue curves refer to maintenance periods with OD = -0.1% and ML = +0.4%, red curves refer to maintenance periods with OD = -0.2% and ML = +0.3%.

Figure 4: Empirical distribution functions of FEONIA and EONIA. (11/06/2014 - 7/10/2014)



Notes: see Figure 3.

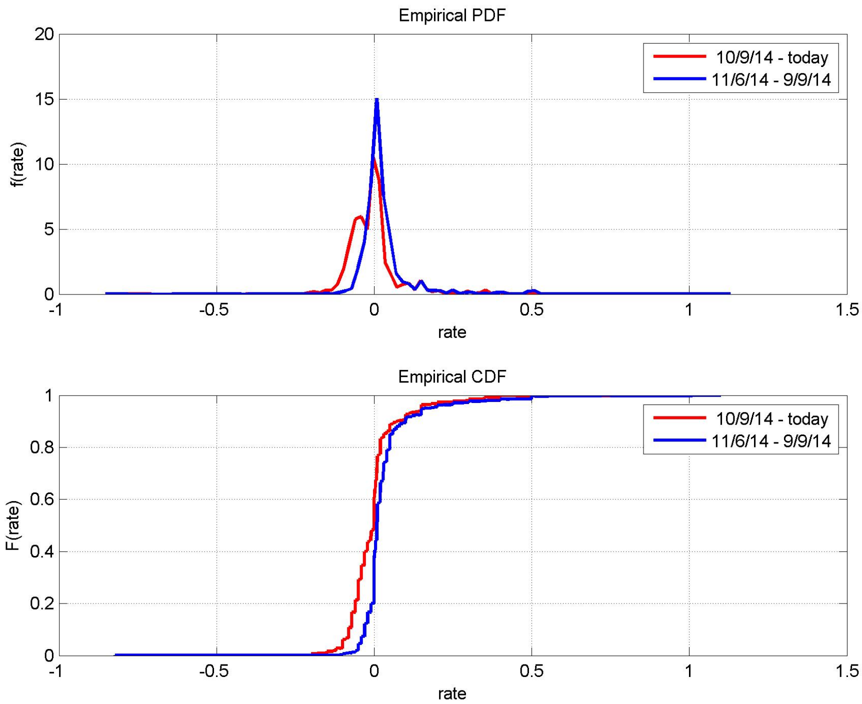
Figure 5: Time series of daily volume and value of loans returned by the econometric procedure. (19/05/2008 - 7/10/2014)



(a) Volume (b) Value

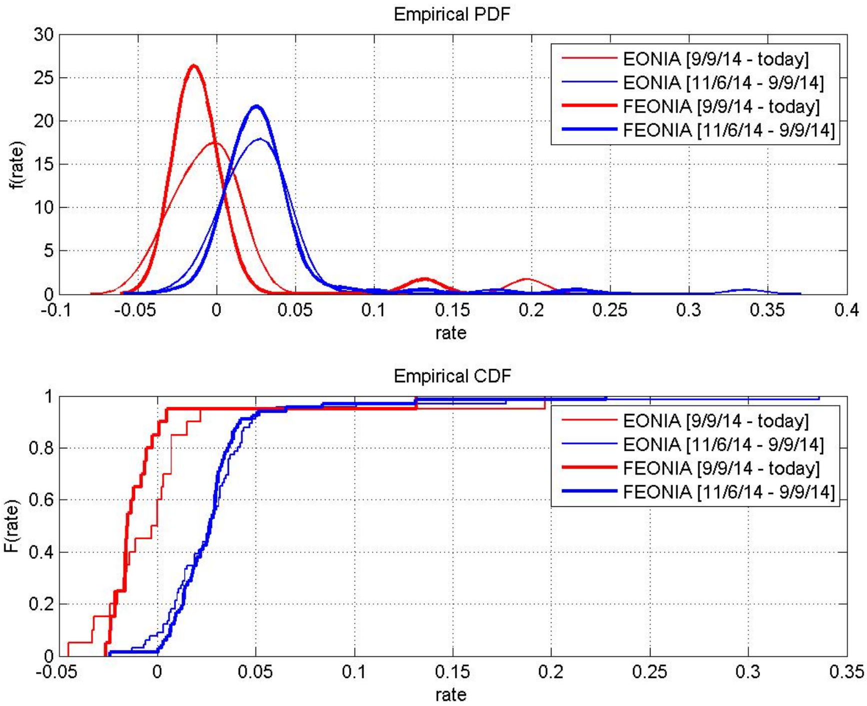
Notes: see Figure 1.

Figure 6: Empirical distribution functions of rates returned by the econometric procedure. (11/06/2014 - 7/10/2014)



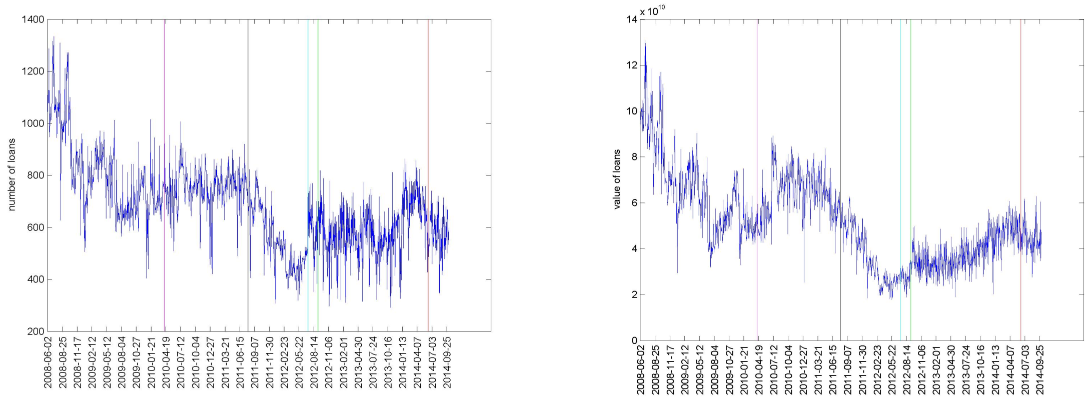
Notes: see Figure 3.

Figure 7: Empirical distribution functions of NEW FEONIA and EONIA. (11/06/2014 - 7/10/2014)



Notes: see Figure 3.

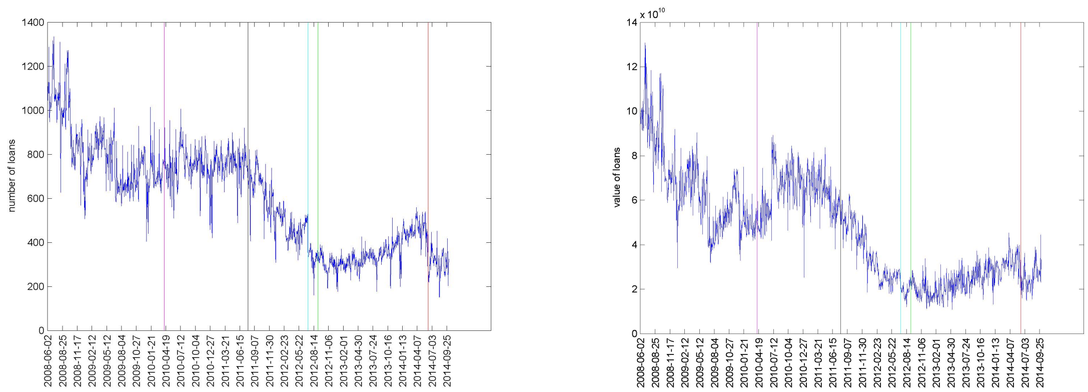
Figure 8: Robustness check - time series of daily volume and value of loans detected by the Furfine algorithm. (19/05/2008 - 7/10/2014)



(a) Volume (b) Value

Notes: see Figure 1.

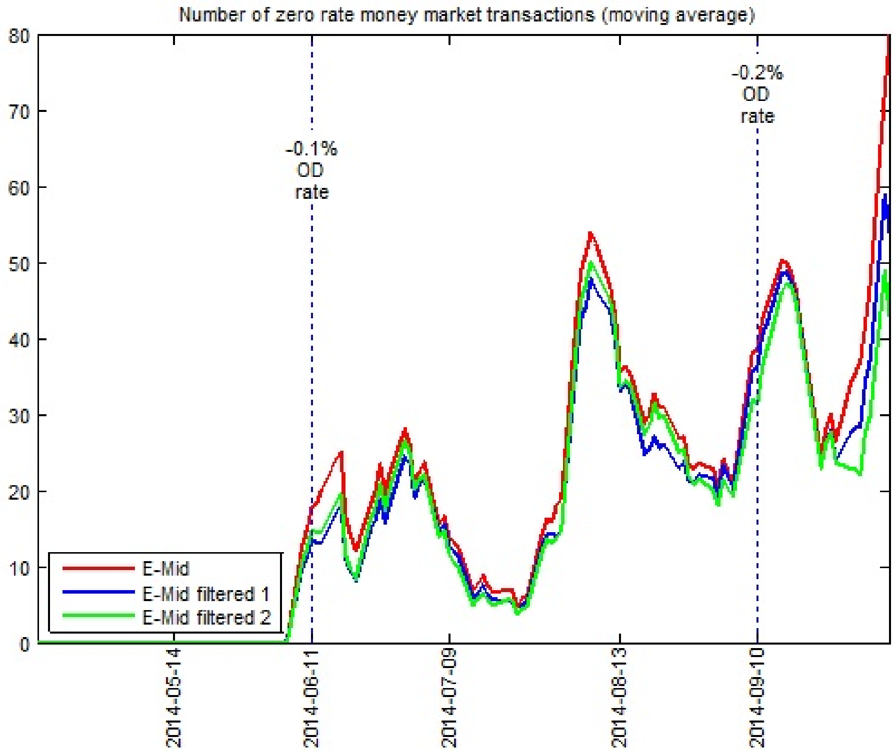
Figure 9: Robustness check - Time series of daily volume and value of loans returned by the econometric procedure. (19/05/2008 - 7/10/2014)



(a) Volume (b) Value

Notes: see Figure 1.

Figure 10: Robustness check - e-MID frequency of zero interest loans. (01/04/2014 - 7/10/2014)



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