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PAIRWISE TRADING IN THE MONEY MARKET DURING THE EUROPEAN SOVEREIGN DEBT CRISIS

by Edoardo Rainone*

Abstract

This paper studies over-the-counter (OTC) trading in the unsecured interbank market for euro funds. The goal of our analysis is to identify the determinants of the probability of trading, the bilateral rate, and the quantity exchanged during the European sovereign debt crisis. We show how the specific features of this market bring to a non-standard estimation framework. We propose a dyadic econometric model with shadow rates to control for potentially endogenous matching with the counterparty, and construct a unique dataset containing banks' characteristics and bilateral trades to study trading patterns. The estimates provide mild evidence towards the existence of shadow rates. Active monitoring decreased market access to low equity and illiquid borrowers, while dispersion in rates and quantities was mainly driven by banks' nationality, especially at the peak of the crisis.

JEL Classification: E50, E40, C30, G01, G10, D40.
Keywords: interbank networks, payment systems, sample selection models, two-step estimation, over-the-counter market, money, dyadic model, financial crisis.

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1 Introduction[1]

Before the recent financial crises the unsecured money market was the most important channel to reallocate liquidity among the banks. During the crises the interbank markets were remarkably stressed. Given the importance of these OTC markets, the fact drew the attention of many policy makers and researchers.

A large number of theories have been proposed to explain the features of bilateral trades in OTC markets (see Afonso and Lagos, 2015; Bech and Monnet, 2016; Blasques et al., 2016; Duffie et al., 2005, among the others), but the empirical literature still lacks in providing econometric models and evidences to better understand these pairwise outcomes. While there are empirical studies investigating interbank markets after the 2008 crisis (Afonso et al., 2011; Angelini et al., 2011), few evidences about the European sovereign crisis are available in the literature.

In this paper we contribute in both these directions. Our main goal is to empirically study the evolution of bilateral trading outcomes in the unsecured interbank market for euro funds during the European sovereign debt crisis, a task never explored in the literature. More specifically, we want to understand how banks characteristics affect the probability to trade, bilateral rates and quantities. We are not aware of any study that analyzes formally and empirically this topic.[2] Evidences from our analysis can be used to assess European market fragmentation (de Andoain et al., 2014; Mayordomo et al., 2015), to explain rate dispersion (Gaspar et al., 2008) or to study supply concentration, preventing smooth and homogeneous pass-through of monetary policy.

To get to this point, the preliminary questions we have to answer are: how can we consistently estimate the effects of banks characteristics on such outcomes, namely the bilateral rate, the quantity and the probability of trading? Can we use a standard econometric model? Loan's rate and quantity are only observed when that specific pair of borrower and lender agree on a bilateral negotiation. Given the decentralized nature of the market, participants really pick up the phone and call each other to set up the loan and bargain prices (Afonso and Lagos, 2015).[3] In this sense, a matching model is a possible framework for studying the equilib-

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[2]Angelini et al. (2011) is the only study using pairwise data we are aware of. They analyzed the impact of the subprime crisis on the trades of the Italian platform e-MID. Frutos et al. (2016) describe the interbank market during the European sovereign crisis, not modeling bilateral outcomes nor studying the effect of bank characteristics and nationality.

[3]This feature characterizes also other type of decentralized markets.

rium formation of these relationships (Chiappori and Salanié, 2016; Fox, 2009; Graham, 2011; Sørensen, 2007). It implies that the trading patterns can follow rules that are difficult to be observed by the econometrician.[4] The endogenous matching process, generates a counterparty selection bias, and can be seen as a specification error in the spirit of Heckman (1979).[5] We show that the role played by money market-specific unobservable factors (such as monitoring and searching costs, see Afonso and Lagos, 2015; Blasques et al., 2016) and the presence of the central bank as a lender of last resort lead to a non-standard estimation framework that departs from a classic dyadic econometric model (Cameron and Miller, 2014; Kenny et al., 2006). To solve this issue we apply a control function approach to account for the selection bias. More precisely, the solution proposed in this paper is a new dyadic econometric model with shadow rates. The concept of shadow rates is used to model such selectivity issues and to capture the unique features of this market, as unobservable searching and monitoring costs (Blasques et al., 2016) or endogenous intermediation (Babus and Hu, 2017). In developing our econometric model, we discuss the potential bias resulting from not simultaneously modeling the matching process when bilateral rates and quantities are studied.

With the proposed econometric model at hand, we study the unsecured money market for euro funds during the European sovereign crisis, using a unique dataset containing the characteristics of banks operating worldwide and bilateral trades. To te best of our knowledge, this is the first attempt to jointly analyze the information from transaction-level data and characteristics of global banks operating in euro. We find a remarkable dispersion in rates and quantities driven by banks nationality and balance sheet composition, especially during the peaks of the crisis. More specifically, we witness an important role played by borrower characteristics. Balance sheet composition and nationality impact dramatically on the probability of borrowing money in general and especially at low rates. Most notably, bank's nationality, equity and size played a dominant role in determining access to the market and lower rates, which is coherent with a credit-risk story and an active monitoring by the lenders. Lender characteristics matter as well, especially in explaining the quantity of liquidity supplied in the market -which can be seen as liquidity hoarding- Heider et al. (2015). Interestingly, we find substantial time variation of these effects and differential magnitudes across countries during the crisis. Among the many new evidences collected, we found that Italian and Spanish borrowers paid increasingly higher spreads from the first phase of the sovereign crisis (April 2010) towards the second (August 2011). On the other side of the market, after the second phase of the crisis, banks from some of the most stressed countries (namely Italy, Spain and Greece) lent at extremely higher rates, because of the sudden scarcity of liquidity. After the first LTRO such spreads were cleared from the market by the huge amount of liquidity provided by the Eurosystem. A detailed description of the main findings is provided in Section 6.

The rest of the paper is organized as follows. Section 2 briefly connects this research with the related literature. Section 3 describes some aggregate evidence that motivates a pairwise analysis. Section 4 presents a conceptual economic framework for a decentralized unsecured money market. Section 5 outlines the proposed dyadic econometric model and the concept of

[4]Some of those patterns have been recently studied. Among the others, Affinito (2012) and Cocco et al. (2009) investigate the role of relationship lending, Rainone (2015) and Gabrieli and Georg (2014) study the role of the network structures.

[5]For example, if unobservable variables determine both the probability that two bank get in touch and the rate (quantity) they agree (exchange), then the estimated parameters of loans' outcomes -i.e. rate and quantity- can be biased as well. This generates a sample selection bias with the implication that simple OLS estimation of the loan rate and quantity functions is not consistent.

shadow rates. Section 6 describe the data, the specification and the results of the empirical analysis, Section 7 concludes.

2 Related Literature

In doing this exercise, we are bridging the literature on the role of liquidity hoarding and counterparty risk in interbank markets (as Afonso et al., 2011; Angelini et al., 2011; Heider et al., 2015, among the others) with the theoretical literature focused on explaining the features of OTC markets (like Afonso and Lagos, 2015; Bech and Monnet, 2016; Blasques et al., 2016; Duffie et al., 2005, among the others). Liquidity hoarding and counterparty credit risk have been identified as the main channels for idiosyncratic shocks propagation and systemic reduction of liquidity (Afonso et al., 2011; Angelini et al., 2011; Heider et al., 2015). When strong uncertainty on future own and others' liquidity condition occurs, banks can decide to hoard liquidity to prevent future shocks and may perceive some counterparties as excessively risky Heider et al. (2015). Caballero and Krishnamurthy (2008) used Knightian uncertainty (Knight, 2012) to explain market-wide capital immobility and liquidity hoarding. In their model agents focus on the worst case scenario and become self protective.[6] Among the others, Acharya and Skeie (2011) proposed a model for liquidity hoarding in which a reduction in quantities and an increase in prices is also driven by lenders' characteristics and not only by borrowers' ones.[7] They also highlight the lack in empirical works that jointly look at prices and quantities in the interbank market. Regarding the counterparty risk, as Afonso et al. (2011) pointed out, many theoretical models focused on adverse selection and inability of lenders to discern good from bad banks, Flannery (1996) is an example. On the other hand, some banks can be excluded from the market because they are seen as too risky from the others, see Furfine (2001) among the others.

3 Aggregate Evidence

As discussed above, great attention was paid to the variation of money market aggregate outcomes during the recent financial crises. Figure 1 reports the total number of bilateral trades, the total value of loans and the average rate in the unsecured money market for euro funds from may 2008 to the end of 2012.[8] The decrease of interbank trades and quantity exchanged from the subprime crisis is reported respectively in panel (a) and (b). The evolution of the market rate is depicted in panel (c). During the time span considered, large variations are observed in these plots, reflecting many episodes and events. Such macro picture can tell

[6]In Caballero and Krishnamurthy a lender of last resort can be beneficial to let the agents to free capital and waste less private liquidity. At the same time interventions must not be too frequent because of a moral hazard problem. They highlight that uncertainty is particularly strong when "new" shocks occur, thus no historical information is available to agents. The subprime crisis and the European sovereign crisis were new in this sense. Regarding the latter, country specific crises were observed in the past, but it was the first time in a context of a single currency union where the break-up scenario might have occurred.

[7]The rollover risk is the key component in their model and generates a lending banks' precautionary demand for liquidity. It theoretically turns out that lenders might be incentivized to rise rates even for relatively safe borrowers. This dynamic is particularly relevant for longer term maturities, it reverts the usual concept that rates are only driven by borrower's characteristics (risk).

[8]These statistics are computed on our sample, that is described in detail in Section 6.1.

us something about what happened and give us some interpretation key if matched with news and events timeline, but may still hide some underlying information at a more disaggregated level.

To get more insights, we can drill down to the market side and individual bank level. Figure 2 reports the quantiles of the same variables computed at the bank-level separately for borrowers and lenders. Light shades track the interdecile range, dark shades depict the interquartile interval and the median is traced with a bold line. From these figures we can learn more, and see for example that in addition to an aggregate shrinking number of trades after the second phase of the sovereign crisis, there was also a sharp decrease in the concentration of lenders (panel (a)) and borrowers (panel (b)), measured by the interdecile range. From panel (c) we can see an opposite evolution for the exchanged quantity. After the long term refinancing operations (LTROs) conducted by the Eurosystem, most of the liquidity was exchanged by few lenders, probably acting as disseminators. Moving to rates (panels (e) and (f)), we can notice a remarkable increase of dispersion and skeweness over time and especially after the two peaks of the European sovereign crisis (in April 2010 and August 2011). This evidence implies that some banks paid significantly higher rates than others during the crisis. Which banks paid more? What are the determinants driving such remarkable dispersion?

In a decentralized market, the mandatory step forward to answer theses questions and learn more is drilling further down to the pair-level in order to understand the most granular market dynamics. In Section 6 we provide such answers and show all the knowledge gained exploiting the bilateral nature of these trades. To do that consistently, we first introduce a conceptual framework that gathers together all the bilateral outcomes we that want to study, and then we construct a proper econometric model tailored for the money market peculiarities.

4 A Decentralized Market with Counterparty-risk Uncertainty and Risk-free Counterparty of Last Resort

4.1 Monitoring and Searching

Let us introduce a naive model of bilateral trading in a decentralized unsecured money market with counterparty credit risk, searching and monitoring. The aim of this section is just to give an heuristic view of the drivers that generate observables and unobservables variables in an empirical model of bilateral trade outcomes. See Duffie et al. (2005), Afonso and Lagos (2015), Bech and Monnet (2016) and Blasques et al. (2016) among the others for detailed and structured description of such models. In this environment banks lend money to each other depending on their liquidity needs. Pairs of banks match bilaterally in this decentralized market and searching for a counterparty is costly. Given that banks may default, they are incentivize to monitor others' solvency status.

Suppose that the central bank sets a interest rate corridor with p_{OD} and p_{ML} be respectively the overnight deposit and marginal lending rates. If we allow both the lender and the borrower to exert efforts to find counterparties and the lender to monitor the solvency status of the borrower, we have the following payoffs:

Borrower payoff

$$\pi_b = p_{ML} - (p_{lb} + s_{b,l}) \tag{1}$$

Lender payoff

$$\pi_l = i_{lb}(\hat{PD}_l(b)) - m_{l,b} - s_{l,b} - p_{OD} \tag{2}$$

where in equation (1) $s_{b,l}$ is the search cost paid by b to find l and p_{lb} is the rate paid by the borrower b to the lender l. In equation (2) i_{lb} is the expected profit for l on a loan to b, which differs from p_{lb} because b can default with probability $PD(b)$ and depends on the lender-specific estimate of such probability $\hat{PD}_l(b) = PD(b) + j(\sigma^l_\nu)$, where $\sigma_{\nu^l_b}$ is the variance of a lender-specific perception error ν^l_b about b solvency status and $j(\cdot)$ is a differentiable function. $m_{l,b}$ is the cost paid by l to monitor b. As in Blasques et al. (2016), let $\frac{\delta i_{lb}}{\delta \sigma_{\nu_b}{}^l} < 0$ and allow the lender to invest an amount $m_{l,b}$ in monitoring b's status with $\frac{\delta \sigma_{\nu_b}{}^l}{\delta m_{l,b}} < 0$. $s_{l,b}$ is the search cost paid by l to find b.

4.2 Bilateral Rate and Volume

Suppose that each bank i receives an exogenous liquidity shock ξ_i that may represent client's payments or cash withdrawals. Observe that both the monitoring cost $(m_{i,k})$ and the searching cost $(s_{i,k})$ can be allowed to depend on ξ_i. These initial liquidity conditions determine the demand and the supply of liquidity in the market. Let

$$\tilde{p}_{lb} = argmax\ f(\pi_l, \pi_b, \mu_l, \mu_b, w_{lb}) \tag{3}$$

$$\tilde{q}_{lb} = argmax\ h(\xi_l, \xi_b, y_{lb}) \tag{4}$$

be the Nash equilibrium interest rate and the liquidity exchanged in the bilateral trade between l and b, with the rate as a function of borrower and lender payoffs, their bargaining powers, μ_l and μ_b, and a set of observable and unobservable pair-specific characteristics, w_{lb}. The quantity exchanged is given by bilateral liquidity shocks and a set of observable and unobservable pair-specific characteristics, y_{lb}. $f(\cdot)$ and $h(\cdot)$ are differentiable functions, see Afonso and Lagos (2015) and Blasques et al. (2016) among the others for possible specifications of such functions.

In this paper we are interested in estimating the effect of observable characteristics, such as nationality and balance sheet composition, on these pairwise outcomes.

5 A Dyadic Econometric Model with Shadow Rates

Given that in such a market the price is not given, and it is formed at the pair-level, it can depend on counterparties characteristics, for example $\hat{PD}_l(b)$, $m_{l,b}$ or $s_{b,l}$. Suppose that the econometrician observes a set of realized loans in the market and she is interested in estimating how lender and borrower characteristics affect the observed bilateral rate

$$p_{lb} = l(x_l, x_b, q_{lb}, \beta, \alpha, \epsilon_{lb}), \tag{5}$$

where $l(.)$ is a differentiable function, β contains the unknown parameters of the exogenous variables, α captures systematic and macroeconomic risk, q_{lb} is the quantity exchanged,[9] ϵ_{lb} is the unobservable random component, x_b contains observable characteristics of the borrower that captures counterparty risk, while x_l includes observables characteristics of the lender that

[9]Observe that loan quantity is not meant to proxy counterparty risk.

represents her propensity to lend. Such empirical models could be used if we are interested in assessing market fragmentation, segregation or integration for instance.[10] For simplicity, suppose the rate is a linear function of its arguments

$$p_{lb} = \beta_0 + \beta_1 x_{lb} + \alpha q_{lb} + \epsilon_{lb}, \tag{6}$$

where $x_{lb} = h(x_l, x_b)$ is a pair-specific function of the relevant borrower and lender observable characteristics.

Without any prior knowledge of the data generation process induced by this decentralized market, equation (6) may look a standard dyadic model (Cameron and Miller, 2014; Kenny et al., 2006). Nevertheless, as described in Section 4, this rate is observed if both the lender and the borrower agree on the conditions of the loan conditional on the relevant rate bounds set by the central bank -i.e. if $\pi_l \geq 0 \cap \pi_b \geq 0$-. As we show below, the mixture of all these ingredients brings to a non-standard estimation framework that departs from classic dyadic models. To embed the specific features of pairwise trading in the unsecured money market into our econometric model, we use the concept of shadow rates. Before getting through the detail of the proposed method, let us give some economic intuition. Suppose a lender views two potential borrowers as having different counterparty risk (or monitoring costs). Then the lender could have different rates at which is willing to lend. Similarly, a borrower may view two lenders as more or less relationship lenders, willing to stick to the borrower through thick and thin. It may be willing to pay more to a more faithful lender.

Let bank j have two shadow rates one as lender and one as borrower, let us call them $p^*_{L,jk}$ and $p^*_{B,jk}$ respectively, they both depend on the counterpart k through its counterparty risk, searching and monitoring costs and a set of observable and unobservable variables. To ease the notation let us omit the index k. If the bank is engaging the contract as lender, it will agree on setting up the loan only if the rate is higher or equal to its lender shadow rate, -i.e. $p_{lb} \geq p^*_{L,j}$-, while, if the bank is acting as the borrower of the loan, it will agree only if the rate is lower or equal to its borrower shadow rate, -i.e. $p_{lb} \leq p^*_{B,j}$-. In this way, a loan between a lender l and a borrower b is observed if and only if $p^*_{B,b} \geq p_{lb} \geq p^*_{L,l}$, so that a loan and its rate are observed if $I(p_{lb} \geq p^*_{L,l})I(p^*_{B,b} \geq p_{lb}) = 1$. We assume that these shadow rates are functions of bank-specific and pair-specific characteristics:

$$p^*_{B,b} = l(k_b, z_{lb}, q_{lb}, \theta, u_{B,b}), \tag{7}$$

$$p^*_{L,l} = m(k_l, z_{lb}, q_{lb}, \gamma, u_{L,l}), \tag{8}$$

where $z_{lb} = g(z_l, z_b)$ is a pair-specific function of relevant borrower and lender characteristics, k_b and k_l are bank-specific characteristics, θ and γ are the parameters of those characteristics respectively in $l(\cdot)$ and $m(\cdot)$, $u_{B,b}$ and $u_{L,l}$ are bank specific unobservables.[11] Again for simplicity, suppose that those two functions are linear, so that

$$p^*_{B,b} = \theta_{0b} + \theta_1 z_{lb} + \theta_{2b} q_{lb} + \theta_3 k_b + u_{B,b}, \tag{9}$$

$$p^*_{L,l} = \gamma_{0l} + \gamma_1 z_{lb} + \gamma_{2l} q_{lb} + \gamma_3 k_l + u_{L,l}. \tag{10}$$

[10] This type of analysis is particularly relevant when the market includes participants from different countries, like the European money market.

[11] These unobservables can also vary with the counterpart, thus being pair-specific. Here we assume they do not in order to keep the notation simple.

The intercept and the quantity slope are allowed to be lender (borrower) specific. Note that the loan rate and both the shadow rates are pair specific, it means that a bank is allowed to vary its shadow rates depending on the counterpart's characteristics. This also allows us to capture persistence in banking relationships (see Affinito, 2012; Cocco et al., 2009). Observe that θ_{0b} can also capture b-specific unobservable variables such as reserves, payments volatility and market access (or absence).

To get an additional connection to the stylized model presented in Section 4, observe that $u_{B,b}$ contains searching costs ($s_{b,l}$) if they are not observable to the econometrician. On the other side, $u_{L,l}$ can include unobservable monitoring and searching costs ($m_{l,b}$ and $s_{l,b}$).

Each pair of banks is thus characterized by a plausible rate-quantity region, that is the intersection between the two areas respectively upper and lower-countered by (9) and (10), see Figure 3. For example, the lender L1 in panel (a) has a tighter acceptable area (the dark blue one) w.r.t. lender L2, when the borrower is B1. According to Section 4, this can be generated by higher monitoring costs for L1. Let us call $s_b^* = p_{B,b}^* - p_{lb}$, $s_l^* = p_{lb} - p_{L,l}^*$ and $s_l = I(s_l^* \geq 0)$, $s_b = I(s_b^* \geq 0)$, the loan is agreed if and only if $s_l s_b = I(s_l^* \geq 0)I(s_b^* \geq 0) = 1$. From equations (6), (9) and (10) the loan is observed at zero quantity if

$$\begin{cases} \theta_{0b} - \beta_0 + \theta_1 z_{lb} - \beta_1 x_{lb} + \theta_3 k_b \geq v_{B,b}, \\ \beta_0 - \gamma_{0l} - \gamma_1 z_{lb} + \beta_1 x_{lb} - \gamma_3 k_l \geq v_{L,l}, \end{cases} \quad (11)$$

where $v_{B,b} = \epsilon_{lb} - u_{B,b}$ and $v_{L,l} = u_{L,l} - \epsilon_{lb}$. Given that both are functions of p_{lb} but s_b is a function of the borrower shadow rate ($p_{B,b}^*$) while s_l is a function of the lender shadow rate ($p_{L,l}^*$), we can see them as two separate selection equations. Given their rate constraints, banks want to maximize the exchanged liquidity because searching for an additional counterpart is costly. The quantity of liquidity adjusts so that $p_{B,b}^* = p_{lb} = p_{L,l}^*$, then conditions (11) hold, the loan is observed and equations (6), (9) and (10) become a recursive system determining the quantity of money exchanged and the relative rate:

$$\begin{cases} q_{lb} = \zeta(\gamma_{0l} - \beta_0 + \gamma_1 z_{lb} - \beta_1 x_{lb} + \gamma_3 k_l) + \frac{u_{L,l} - \epsilon_{lb}}{(\alpha - \gamma_{2l})} \\ = \mu(-\theta_{0b} + \beta_0 - \theta_1 z_{lb} + \beta_1 x_{lb} - \theta_3 k_b) + \frac{\epsilon_{lb} - u_{B,b}}{(\theta_{2b} - \alpha)}, \\ \\ p_{lb} = \beta_0 + \beta_1 x_{lb} + \alpha q_{lb} + \epsilon_{lb}, \end{cases} \quad (12)$$

where $\mu = \frac{1}{(\theta_{2b} - \alpha)}$ and $\zeta = \frac{1}{(\alpha - \gamma_{2l})}$. Thus, the distributions of the disturbances of the system of equations (12) are conditional on inequalities (11). Since the same exogenous variables appear in conditions (11) and equations (12), the moments of these conditional distributions depend on the values of the exogenous variables. It turns out that the regressors in the system of equations (12) can be correlated with the disturbances and using ordinary least squares doesn't guarantee unbiased and consistent estimates of the parameters in the system of equations (12). However, parameters in (12) can be estimated controlling for the dependence between the disturbances, using the relationship between conditional and unconditional distributions.[12] The joint distribution of observed rates and quantities is

$$f(p_{lb}, q_{lb} | p_{B,b}^* \geq p_{lb} \geq p_{L,l}^*) = \frac{g(p_{lb}, q_{lb})}{P([p_{B,b}^* \geq p_{lb} \geq p_{L,l}^*])}. \quad (13)$$

[12] See Heckman (1974) for a detailed discussion.

where $g(p_{lb}, q_{lb})$ is the unconditional joint distribution of rates and quantities, $P([p^*_{B,b} \geq p_{lb} \geq p^*_{L,l}])$ is the probability to observe the loan -i.e. that loan rate is included in the shadow rates interval- and $f(\cdot)$ is the conditional distribution. It implies that the likelihood function of the entire sample (including observed and unobserved loans) is

$$\begin{aligned} L &= \prod_{lb \in O} f(p_{lb}, q_{lb} | p^*_{B,b} \geq p_{lb} \geq p^*_{L,l}) P([p^*_{B,b} \geq p_{lb} \geq p^*_{L,l}]) \\ &\times \prod_{lb \in U} P([p_{lb} \geq p^*_{B,b}, p_{lb} \leq p^*_{L,l}]) \\ &= \prod_{lb \in O} g(p_{lb}, q_{lb}) \times \prod_{lb \in U} P([p_{lb} \geq p^*_{B,b}, p_{lb} \leq p^*_{L,l}]). \end{aligned} \tag{14}$$

Where O and U indicate the observed and unobserved partitions respectively. Observe that here the likelihood is the product of a sequence of bilateral outcomes. Modeling all jointly would hamper the treatability of our framework and the computational feasibility of the likelihood. Nevertheless, if z_b, x_b and k_b do a good job in approximate counterparty risk and z_l, x_l and k_l capture the risk of lender's portfolio correctly, our bilateral shadow rates framework can control for integrated portfolio decisions. We are pretty confident that the wide set of controls described in Section 6.2, which includes balance sheet composition, nationality and banks' activity in the market, can treat this issue effectively. From the previous derivations we can summarize our empirical model with the following system

$$\begin{gathered} p_{lb} = p^*_{lb} s_l s_b, \\ p^*_{lb} = \beta_0 + \beta_1 x_{lb} + \alpha q_{lb} + \epsilon_{lb}, \\ s_l = I(s^*_l \geq 0), \\ s_b = I(s^*_b \geq 0), \\ s^*_l = \omega r_l + v_{L,l}, \\ s^*_b = \lambda r_b + v_{B,b}, \\ (\epsilon_{lb}, v_B, v_L) \sim f\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_\epsilon & \sigma_{\epsilon v_B} & \sigma_{\epsilon v_L} \\ \sigma_{\epsilon v_B} & \sigma_{v_B} & \sigma_{v_B v_L} \\ \sigma_{\epsilon v_L} & \sigma_{v_B v_L} & \sigma_{v_L} \end{bmatrix} \right), \end{gathered} \tag{15}$$

where $f(m, V)$ is a trivariate density function with mean m and variance-covariance matrix V, $\omega = [\beta_0, -\gamma_{0l}, -\gamma_1, \beta_1, \alpha, -\gamma_{2l}, -\gamma_3]$, $\kappa = [\theta_{0b}, -\beta_0, \theta_1, -\beta_1, \theta_{2b}, -\alpha, \theta_3]$, $r_l = [1, 1, z_{lb}, x_{lb}, q_{lb}, Lq_{lb}, k_l]^T$ and $r_b = [1, 1, z_{lb}, x_{lb}, q_{lb}, Bq_{lb}, k_b]^T$. From this system it is easy to see that

$$E[p_{lb} | s_b = 1, s_l = 1] \;=\; \beta_0 + \beta_1 x_{lb} + \alpha q_{lb} + E[\epsilon_{lb} | s_b = 1, s_l = 1], \tag{16}$$

where $E[\epsilon_{lb} | s_b = 1, s_l = 1]$ may be different from zero, generating the selectivity bias. Here and in the next section we focus on the rate equation, derivations for the quantity equation follow consequently. The model is close to selection models proposed in the labour market literature, see Ham (1982), Poirer (1980) and Dahl (2002) among the others.[13] While in labour market models usually agents are split in two sets (workers and firms) and have only

[13] A notable example of an empirical study using selection models in monetary economics is Fecht et al. (2011). A remarkable application of a double selection model in the labor literature is Accetturo and Infante (2013).

one match per time, in OTC markets agents can have multiple simultaneous matches (trades) with everybody.

Observe that if we have a panel and the unobservables do not vary *(i)* across time observations and *(ii)* pairs of banks, we can also use bank fixed effects to control for the endogeneous selection process. Nevertheless, the approach proposed here is preferable because it is effective even if conditions *(i)* and *(ii)* do not hold, which is possible in money markets.

At this point, it is worth to note that, if bilateral searching and monitoring efforts are not observable by the econometrician (that is usually the case) and ϵ_{lb} is correlated with them -i.e. with $s_{b,l}$, $s_{l,b}$ or $m_{l,b}$-, it implies that $\sigma_{\epsilon v_B} \neq 0$, $\sigma_{\epsilon v_L} \neq 0$ and $\sigma_{v_L v_B} \neq 0$. It is also possible that such costs are correlated with some of the observables characteristics included in the regression. This fact could impair OLS estimates of equation (6) because of selection on observables bias. Note that it could be the case if we want to estimates the effect of bank's size or nationality on rates and they are correlated with search and monitor activities. For instance, if there are monitoring or searching economies of scale the effect of banks' size can be biased. In addition, if searching costs vary by countries, nationality dummies may be biased as well. In Appendix A we describe three simple examples where selectivity bias could matter, the estimators used in the empirical analysis are detailed in Appendix B.

As we observe data on bilateral trades, a matching model is a possible framework for studying the equilibrium formation of these relationships.[14] In this literature, researchers use different methods to estimate matching model models (Fox, 2009). See Chiappori and Salanié (2016) and Graham (2011) for surveys on the econometrics of matching models. Among the others, Boyd et al. (2013) use the simulated method of moments, Ackerberg and Botticini (2002) and Akkus (2008) employ likelihood methods, Fox (2008) introduce a maximum score estimator, Dagsvik (2000) and Choo and Siow (2006) study games with logit methods, Sørensen (2007) explores the use of a matching model to parametrically selection correct an auxiliary outcome equation. As we want to model the outcome of a trade, but the outcome is only observed in the data for realized matches, we use the same approach of Sørensen (2007).

6 Empirical Analysis

Our final goal is to study the features of the unsecured money market for euro funds during the European sovereign debt crisis. In this section we apply the proposed dyadic econometric model to a unique dataset containing banks characteristics and bilateral trades to study how banks nationality and balance sheet composition affected rates, quantities and the probability of bilaterally trading.

6.1 Data

To answer our research question, we need three fundamental types of information: (i) bilateral trades, (ii) banks characteristics and (iii) banking groups structure.

Interbank bilateral trades are the main ingredient that we need, then information about counterparties allows us to model trading outcomes as a function of observable characteristics. Likewise knowing whether banks belong to the same group is fundamental in order to get unbiased estimates. Intragroup trades follow completely different logics, consequently the

[14] A matching model takes a set of payoffs or outputs for all possible matches and produces a set of matches where no couple would prefer to deviate and become matched, instead of their assigned matches.

same pair of banks, in terms of observable covariates, may be associated with unrealistic rates. Often intragroup rates are linked to extreme (close to the ceiling or to the floor) or average values that are totally inelastic to macro conditions or banks credit risk.

Unfortunately, for that period there is no institutional dataset containing such information. In this section we detail how we constructed the dataset.

To te best of our knowledge, this is the first study to collect and jointly analyze the information from transaction-level data and characteristics of global banking groups operating in euro.

Bilateral Trades. We need information about euro interbank money markets during the sovereign debt crisis. For that period, the most complete information available is from the application of the Furfine algorithm to TARGET2 (T2) data.[15] [16]

Alternative information on euro money market transactions could be found in: (i) reporting by the major banks in the euro area on their overnight lending rates and volumes (which make up the EONIA panel); (ii) data on individual exchanges on the Italian electronic trading platform e-MID; (iii) data on individual trades on the Spanish domestic market MID; and (iv) data on domestic and cross-border lending and borrowing for Greek banks. All of these datasets are not preferable to application of the Furfine algorithm to T2 data. EONIA panel data only refer to the aggregated daily overnight transactions of the major money-market actors in the euro area. e-MID data account for less than 20 percent of overall interbank transactions in the euro area and are, especially since mid-2011, mainly representative of Italian banks. Similarly, MID and Greek data mainly reflect the Spanish and Greek interbank markets.[17]

The majority of the interbank transactions are settled in T2, it allows banks to settle large value payments on their accounts in central bank money. The reserve requirement is managed on these accounts, so participating banks have to exchange money in T2 to meet the reserve requirement and make other payments. Furfine (1999) proposed an algorithm that matches the loan and its repayment, both settled on the RTGS payment system, identifying the market microstructure. Furfine's algorithm is used to detect loans from a set of payments. By definition a loan consists of two payments, the first equal to l and the second equal to $l(1+i)$, where i is the interest rate. The algorithm matches those two legs, see Furfine (1999) for details. See Armantier and Copeland (2012) for an assessment of the quality of Furfine-based algorithms on Fedwire data and Rempel (2016) for a refinement on the Canadian payment system. Arciero et al. (2016) applied this criterion to payments settled in T2, augmenting the maturity spectrum by up to one year and making several refinements to the algorithm. Rainone and Vacirca (2016) extended the algorithm when rates are zero or negative. Arciero et al. (2016) contains detailed information about the algorithm and its practical implementation in T2 for the period under analysis. Importantly, the Eurosystem implementation enhance the algorithm to reduce the uncertainty of the results. Moreover, the results have been validated against two external data sources: (i) individual EONIA panel contributions and (ii) e-MID

[15] Recently the Eurosystem started a project to get transaction-by-transaction data from a sample of EU reporting agents covering the secured, unsecured, foreign exchange swap and euro overnight index swap money market segments (called MMSR, money market statistical reporting). See https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/money_market/html/index.en.html.

[16] T2 is the European RTGS (Real Time Gross Settlement) payment system. For more information about TARGET2 see http://www.ecb.europa.eu/paym/t2/html/index.en.html.

[17] See Arciero et al. (2016) for more detail.

transaction-level data. The validation shows that the algorithm's performance is considerably reassuring, particularly in the overnight segment.[18] This is the reason why in this paper we focus only on this segment. In Appendix C we describe the potential issues of dealing with data from the Furfine algorithm and the necessary assumptions to make in order to get consistent estimates from the dyadic model outlined in Section 5.

Banking Groups Structure. To get unbiased estimates we need to correctly exclude intragroup loans. Such trades do not follow market rules and thus their inclusion generates distortion. Again, the challenge here is to get the most complete information available. Given that market participants are worldwide, there is no institutional database mapping the structure of these multinational banks.

Nevertheless, banks connect to payment systems using networks that enable them to send and receive financial transactions. SWIFT (Society for Worldwide Interbank Financial Telecommunication) is the provider of secure financial messaging services for T2 during the period under analysis. Consequently, banks operating in euro have to access such interbank network directly or indirectly. SWIFT provides users with a Bank Directory containing all the reference data to prepare, validate and process payments to other banks. This directory contains also the banking group structure. We exploit such source of information and exclude intragroup loans using the multinational group structure derived from the directory.[19]

Banks Characteristics. The most important observable banks characteristics that should influence trading outcomes are probably nationality and balance sheet composition. The first, is particularly important in the euro zone, as a currency union. Markets were still fragmented and sovereign risk was extremely heterogeneous during the period under analysis, then having market data with participants from many different countries is a key ingredient of our analysis. To exploit such a feature we need to precisely measure this characteristic and include it in the model. Another important information to include is the balance sheet size and composition. At the time of the sovereign debt crisis there were no official consolidated information collected at the Eurosystem level, and, given the presence of non European banks in the market, we would have been forced to search for additional data anyway. We thus have to rely on available information from public databases of banks worldwide. Our balance sheet data are taken from Bankscope.[20] An important advantage of this annual balance sheet dataset is that it allows us to control for a broader set of bank-specific variables. In addition, everybody can get this data, so lenders can also monitor their borrowers using such data source. Let us now detail the variables that we included in the model.

Total assets expressed in millions of euros captures the dimension of each bank. Balance sheet items are included as percentages of total assets. On the asset side *Loans*, *Fixed Assets* and *Non-Earning Assets* are included. *Other Earning Assets* are dropped because of collinearity. On the liability side, *Deposits and Short-term Funding*, *Other Interest Bearing Liabilities*, *Other Reserves* and *Equity* are included. *Loan Loss Reserves* and *Other (Non-Interest Bearing)* are dropped. Banks operating in the system are not necessarily from eurozone countries,

[18] This result is in sharp contrast with the recent paper by Armantier and Copeland (2012) assessing the quality of Furfine's algorithm implemented at the Federal Reserve Bank of New York against a data set of bilateral transactions between two large U.S. dealers.

[19] For this purpose the field Parent BIC code is considered to consolidate the group of accounts.

[20] The construction of this dataset was done in cooperation with Giovanni di Iasio, Marco Rocco and Francesco Vacirca.

even though the majority of market participants are from countries whose central bank is part of the Eurosystem. Country dummies are included for: Italy, France, Spain, Netherlands, Greece, Ireland, United Kingdom, Austria, Portugal, Luxembourg, Cyprus, Switzerland, Finland and Belgium. Germany is the reference category. Other European countries are grouped in one dummy as well as the US, Japan and other non-European countries. We consolidated banking groups according to the SWIFT Bank Directory, as outlined above. The nationality is thus taken from the head of the group. Descriptives statistics for three maintenance periods and variables detailed description are provided in Table 1.

6.2 Empirical Specification

To ease the computational burden we assume that θ_{2b} and γ_{2l} are equal to zero in this section.[21] Given the wide time span (from may 2008 to the end of 2012), the data is aggregated at the maintenance period level,[22] then we repeatedly estimate the parameters in equation (18) for each time interval. Observe that $b_{0,t}$ thus captures systematic and macroeconomic factors affecting time interval t. In the empirical application we use the following set of information. W.r.t. the variables defined in Section 5, we set $x_{bl,t} = [B_{l,t}, C_{l,t}, B_{b,t}, C_{b,t}, g_{lb,t-1}]$, $z_{bl,t} = [B_{l,t}, C_{l,t}, B_{b,t}, C_{b,t}]$, $k_{b,t} = [\bar{p}^B_{b,t-1}, q^B_{b,t-1}, n^B_{b,t-1}]$, $k_{l,t} = [\bar{p}^L_{l,t-1}, q^L_{l,t-1}, n^L_{l,t-1}]$. $B_{i,t}$ and $C_{i,t}$ contain respectively the information about the balance sheet structure and nationality of bank i at time t. $g_{ij,t}$ is equal to 1 if a loan with i as borrower and j as lender was observed at time t, it basically captures the persistence in the relationship between i and j, which may play a role in determine the rate of a loan (Affinito, 2012; Cocco et al., 2009). $\bar{p}^B_{i,t}$ and $\bar{p}^L_{i,t}$ are the average rates experienced respectively as borrower and as lender at time t by bank i, while $q^B_{i,t}$ and $q^L_{i,t}$ are the values exchanged respectively as borrower and as lender at time t by the bank i. $n^B_{i,t}$ and $n^L_{i,t}$ are the number of counterparties respectively as borrower and as lender at time t by the bank i. These last three variables can be powerful explanatory variables respectively for borrower and lender shadow rates and work as exclusion restrictions in the estimation process.[23] The presence of many financial crises during the time span considered provides frequent exogenous shocks to banks' shadow rates. For example, many lenders left the market suddenly. In our framework, it translates into considerable changes of the supply acceptable region (the blue areas in Figure 3) and the consequent exclusion of these banks from the market, no matter who the possible counterparts are. In the empirical section presented below, the robustness of such specification is also tested rather than directly imposed on the data.

6.3 Main Results

The description is organized as follows. Firstly, we focus on two maintenance periods to describe in detail the outcome of the empirical model and the estimation procedure. The

[21]In other words, we assume that the quantity slope is not borrower(lender)-specific. It is not a very restrictive assumption in this context, because it just implies that constraints in (9) and (10) only impose absolute upper (lower) bounds that are borrower(lender)-specific but not sensitive to the loan's quantity.

[22]The maintenance period is the reference time interval (roughly four or six weeks long) during which the amount of central bank money is averaged on the reserve accounts. It makes this time interval the best choice to aggregate data. Quantity are summed over the time interval, rates are averaged.

[23]In the case of collinearity problems (Leung and Yu, 1996), it follows that the strength of our estimation approach depends on the extent to which these variables impact on the selection process but not in the bilateral price formation.

main aim is to check whether shadow rates exist and can bias some parameter estimates, we thus compare the estimates obtained with and without controlling for the selectivity bias. Secondly, a time series analysis is used to describe the evolution of trading patterns over time. In the first part, tables are used to describe the results, while graphical tools are needed to track time evolution in the second part. The baseline results are referred to the parametric estimation when not specified.

6.3.1 Evidence of Shadow Rates

To describe in detail the estimation procedure, we focus on two maintenance periods going from 2010-01-20 to 2010-02-09 (MP1) and from 2009-02-11 to 2009-03-10 (MP2). The aim of this analysis is twofold. First, we want to provide a consistent characterization of the probability, the rate and the quantity exchanged through bilateral trades in the OTC market for euro funds. Second, we are interested in assessing the existence of shadow rates, to do that we compare the proposed econometric model with a standard dyadic regression where we do not take into account any endogeneity issue.

The results for the quantities are presented in Table 2 and 3, while those for the rates are represented in Table 5 and 4. The first two columns report the estimates from a simple dyadic regression, the second two estimates using our methodology, the last two report the T-stat difference and its p-value. In Appendix D we report the first steps, showing the results for the likelihood to trade as a borrower or lender -i.e. the selection equations-. This is the information that we use to control for the selectivity bias.

For quantities, Table 2 and 3 show that the selection correction terms (the Mills ratios) are significantly different from zero for both MP1 and MP2. Controlling for the selection mechanism considerably impacts on the coefficient of French borrowers in MP1 (Table 2) but not in MP2 (Table 3). In terms of economic implications, our methodology indicates that French banks borrowed on average 35 millions more than German banks, while no significant difference is detected by a standard dyadic regression. Furthermore, the effect of the amount of money previously borrowed switches from positive to a more rational negative sign.

Considering the rate function, also in Table 4 and 5 we can see that the parameters of lender and borrower Mills ratios are significantly different from zero. In Table 4 we witness substantial changes in the effects of the size of the borrower, which is underestimated by one third and more importantly the effects of the share of loans in the asset composition, which shifts from not significant to negatively impacting the loan's rate. Indeed, in Table 5, if we focus on the significant coefficients, we can notice that there are differences between the estimates with an without the selection correction. As an example, big banks are able to earn more as lenders, while they save more when acting as borrowers, taking advantage of a higher bargaining power, in line with the evidences found in the literature (see Angelini et al., 2011, among others). A simple regression underestimates the first effect and overestimates the second one, producing biased evidences.[24] In terms of estimated profitability, the average net interest margin is downward biased by almost 10% if selection bias is not taken into account.

As a whole, it seems that endogeneity does not strongly impact all the coefficients after controlling for the wide set variables included in this study. Nevertheless, some parameters are

[24]Another notable difference is between the coefficient of Greek, Portuguese and Cypriot borrowers, they are systematically overestimated by a simple regression. This difference points at tighter shadow rates when the borrower is from these countries. The selection bias comes from borrowers more prone to pay a higher rate. Such additional information would not be available without the proposed method.

not consistently estimated during some time periods. In the time series analysis that follows, we analyze more systematically and comprehensively the factors determining rates, quantities and trading link formation, always controlling for such potential bias.

6.3.2 Trading Patterns during the Sovereign Crisis

Here we want to study in detail the estimated coefficients and their variation during a long period which is strongly characterized by financial instability and uncertainty. The main aim is to understand how nationality and balance sheet composition influenced bilateral outcomes over time. With our econometric framework we can shed some light on the evolution of the aggregate time series presented in Section 3, and understand what are the banks characteristics that mainly drove such macro dynamics, such as the remarkable increase in rates dispersion and skewness depicted in panels (e) and (f) of Figure 2. Let us start with the likelihood to trade as a borrower or lender, Figures 4 - 6 describe these results. We then move to rates and quantities, presented in Figures 7 - 16. The results provide an unbiased characterization of the probability, the rate and the quantity exchanged of bilateral trades in the unsecured money market for euro funds from may 2008 to the end of 2012.

Trading Probability. Let us start with the characterization of the probability to bilaterally trade. Here we concentrate on the most interesting results, the rest can be found in Appendix E.

From Figure 4 we can see that the lender's balance sheet structure does not show a negative or positive persistent effect on the probability of trading, only the size matters (*Total assets*). Bigger banks are more likely to trade, which is consistent with a core-periphery structure (Craig and Von Peter, 2014; intVeld and van Lelyveld, 2014).

On the other hand, the borrower's balance sheet composition does matter in determining such probability and shows important variation through the time. Indeed, the borrower generates the risk behind the loan and then the probability of that trade. In particular, Figure 4 witnesses an increasing importance of *Equity* over the time span considered. The marginal effect of the weight of equity on the total assets of the borrower almost doubled (moving from 0.4 to 0.8). An inverse pattern is showed by the weight of *Loans* on total assets. The magnitude of the negative marginal effect steadily increased between the first and second peak of the crisis, signaling a higher difficulty of being financed by banks more exposed to illiquid assets. Both these evidences highlight the increasing selection of sound borrowers into the market by more worried lenders over time, and thus an active monitoring by the latter. After the LTROs, such selection of high-equity more-liquid borrowers disappeared, possibly because of the full allotment provided by the lender of last resort -i.e. the Eurosystem- (Garcia-de Andoain et al., 2016).[25] Appendix E reports the additional results on the effects of nationality.

Figure 5 and 6 show respectively the effect of lender and borrower's previous activity on the same side of the market. The number of past counterparties (in the right panel) positively affects the probability of trading for both the lender and the borrower.[26]

[25] Remarkably, borrowers with higher short-term funding and non-earning assets increased their presence in the market over time. On the other hand, an higher share of fixed assets provoked a lower probability of borrowing.

[26] Exchanged quantities (in the middle panel) have a more ambiguous effect, showing negative and positive effects, depending on the time the loan is agreed. Past rates (in the left panel) have more frequently a negative effect, this is especially true for the borrower.

Rates and quantities. Let us move to the second steps, the rate and quantity functions. From Figure 7 and 8 we can see that the coefficients of the Mills ratios are sometimes significantly different from zero, signaling that the selectivity bias can be an issue in several time periods.

For what concerns rates (Figure 9 - 11), country dummies show the most interesting evidences. Indeed they approximate borrower's counterparty risk at the country level.[27] Greek borrowers paid systematically higher rates after the subprime crisis and after the first phase of the sovereign crisis to then almost disappear from the market. Portuguese borrowers show a systematic positive spread in the period under analysis with an increasing trend, which stopped only after the LTROs in late 2011. Cypriot borrowers, when able to access the market, paid the highest interest rates especially after the subprime crisis. Italian and Spanish borrowers experienced an increasing spread from the first phase of the sovereign crisis towards the second. On the other side of the market, it is also interesting to notice that after the second phase of the crisis, lenders from some of the most stressed countries, namely Italy, Spain and Greece, extremely increased their rates, because of a remarkable increase in payment shocks during this period. More specifically, huge net outflows of central bank money occurred, as witnessed by the increase of TARGET2 balances (Figure 12). Most of these payments were related to securities trading reflecting the portfolio choices of investors (see Beck et al., 2016). In response to this higher uncertainty about payments, banks responded by becoming more reluctant to lend excess reserves when reserves were high and by becoming more aggressive in bidding for borrowed reserves when balances were low, a mechanism close to what happened during the 2007-08 financial crisis for the fed funds market (see Ashcraft et al., 2011). After the first LTRO such spreads were cleared from the market by the huge amount of liquidity provided by the Eurosystem. The balance sheet composition effects are less strong than nationality ones. Nevertheless, there are several periods in which balance sheet composition matters in determining the rate. Most interestingly, only bank size seems to have a systematic impact. Big banks seem to charge higher interest rates as lenders and pay lower rates as borrowers, that is coherent with bigger banks playing as intermediaries in the market.

Quantity time series also show interesting results. From Figure 13 we notice negative coefficients with U-shapes between the first and second peaks of the crisis for lender country dummies.

A significant negative coefficient here means that on average banks from that country lent less than the reference (German banks), which is coherent with a liquidity hoarding mechanism (see Acharya and Merrouche, 2012; Acharya and Skeie, 2011; Afonso et al., 2011; Heider et al., 2015, among others). From this figure it seems that banks started to hoard liquidity around the first peak of the crisis with a different timing and intensity depending on the nationality. With the second phase kicking in, it seems that all the banks started to hoard, thus clearing such country-time-level heterogeneity. In the same time interval we witness a inverse U-shape for Italian and French borrowers. It means that in this time interval Italian and French banks were not only lending less money but were also borrowing more money.[28]

[27] Country dummies can capture also redenomination risk.

[28] Balance sheet and borrower's country effects are reported in Appendix E.

6.4 Diagnostics

Mills Ratios Linearity. An issue that may arise when using the Mills ratios is that they can be linear functions of other covariates included in both the outcome equations and the first steps. Table 6 shows the explanatory power that the controls used in both rate and quantity equations have on the borrower and lender Mills ratios. Even though some regressors show a significant correlation with the ratios, overall the unexplained component is relevant as witnessed by the difference between the $\bar{R}^2$ and one. The lower panels of Figure 14 report the time series of the $\bar{R}^2$ computed after having regressed the two Mills ratios on the other regressors, both are almost always remarkably far from 1 and with different values, signaling that the linear dependence is not a big issue over this time span. Nevertheless, for the first four time periods the Mills ratios are perfectly explained by the other regressors (Figure 14). In addition to the Mills ratios coefficients (Figure 7 and 8), the issue affects only the first four estimates of the time-variant constant and their standard errors (see Figure 15), highlighting that the value assumed by the ratios is almost constant among the units for these time periods. This is because the Mills ratio is linear for some intervals of its arguments (see Leung and Yu (1996) and Puhani (2000)).

Functional Assumptions. Normality was assumed throughout the previous section. To test assumption's correctness, we use the semiparametric estimator outlined in Appendix B. The semiparametric method is able to capture non linear relationships w.r.t. a parametric estimator and does not depend on the Mills ratio's functional form. Table 7 and 8 compare the coefficients estimated using both the parametric and semiparametric methods during the MP1. On average they are very close, not highlighting a prominent departure from the normality assumption, thus the relative figures are not reported for the sake of brevity. Nevertheless, it is suggested to compute both these estimators to check this assumption and see whether some parameters are badly estimated under the distributional assumptions imposed to the data. Furthermore, the first four estimates of the time-variant constant and their standard errors are no longer badly computed, as shown in Figure 16 (comparing to panel (c) of Figure 15). This highlights the importance of considering both a parametric and semiparametric approach when selectivity issues are taken into account.

Exclusion Restrictions. As hinted in Section 6.2, the choice of variables that play as exclusion restrictions is fundamental to robustly identify the outcome equation's parameters. If these variables have an impact on the outcome and are correlated with some regressors at the same time, the correction terms may just capture this feature. It would imply that the Mills ratios only correct for the omission of observable variables included in the first step (shadow rates) but not included in the outcome equations (rates and quantities). If so, the inclusion of the correction terms would just be fictitiously informative. To check for such an issue, it is possible to test whether the inclusion of the Mills ratios changes the correlation between the residuals from the outcome equations and the exclusion restrictions. Table 9 reports the results of two regressions, with and without correction terms, for both rate and quantity equation and a test for a significant difference between the two. For all the exclusion restrictions there is no significant difference between the coefficients.

7 Concluding Remarks

In this paper we studied pairwise trading in the unsecured interbank market for euro funds during the European sovereign debt crisis. The goal of our analysis was to understand how banks characteristics affected the probability of trading, bilateral rates and quantities.

To embed the specific features of the OTC trading in the unsecured money market, we proposed a dyadic econometric model with shadow rates to simultaneously study trading probability, rates and quantities. In doing so, we discuss the potential bias emerging when the counterparties endogenously select each other into bilateral trades, for example when monitoring and searching efforts are endogenous. We propose a simple characterization of this counterparty selection bias as a specification error and present a consistent estimation methodology.

We built and used a unique dataset containing the characteristics of banks operating worldwide and bilateral trades in the unsecured interbank market for euro funds. We first found mild evidence regarding the existence of shadow rates after controlling for the wide set of controls included in this study, we then used our consistent estimator to study trade patterns during the European debt crisis.

As regards the formation of trading links, borrower's balance sheet composition matters in determining such probability and shows important variation through the time. We witness an increasing importance of equity over the time span considered. The marginal effect of the weight of equity on the total liabilities of the borrower almost doubled between the two peaks of the crisis. An inverse pattern is showed by the weight of loans on total assets. The magnitude of the negative marginal effect steadily increased between the first and second peak of the crisis, signaling a higher difficulty of being financed by banks more exposed to illiquid assets. Both evidences highlight the increasing selection of sound borrowers into the market by more worried lenders over time, and thus an active monitoring by the latter. After the implementation of the LTROs by the Eurosystem, such selection of high-equity and more-liquid borrowers disappeared, possibly because of the full allotment provided by the lender of last resort.

We find a substantial dispersion in rates and quantities driven by banks nationality and balance sheet, especially during the peak of the crisis, shedding light on new aspects featuring the unsecured money market for euro funds. Before the Eurosystem LTROs, we found that high market fragmentation and rate dispersion were mostly driven by borrowers characteristics, while liquidity rationing was largely explained by lenders characteristics. Among the many new evidences collected, we showed how borrower balance sheet composition and nationality impacted dramatically on the probability of borrowing money in general and especially at low rates, which is coherent with a credit-risk story and an active monitoring by lenders. Furthermore, we witnessed a differential liquidity hoarding activity across space and time between the two phases of the sovereign crisis mainly explained by lenders nationality. More Specifically, Italian and Spanish borrowers paid an increasing spread from the first phase of the sovereign crisis through the second one. On the other side of the market, it was also interesting to notice that after the second phase of the sovereign crisis, lenders from some of the most stressed countries, namely Italy, Spain and Greece, extremely increased their rates, because of the sudden market stress and the scarcity of liquidity providers.

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Tables

Table 1: Observed loans descriptives

Maintenance period		2009-03-11 - 2009-04-07				2010-11-10 - 2010-12-07				2011-09-14 - 2011-10-11			
Variable	Description	mean	std	min	max	mean	std	min	max	mean	std	min	max
Loan													
Rate	Interest rate paid	0.83	0.20	0.21	2.50	0.30	0.07	0.12	1.15	0.55	0.18	0.15	1.70
Quantity	Quantity exchanged (millions)	16.19	53.42	0.05	1033.16	16.06	45.13	0.07	664.29	19.50	98.50	0.05	3138.16
Lender													
A loan	Loans expressed as percentages of lender total assets	0.57	0.20	0.00	0.90	0.59	0.20	0.00	0.89	0.58	0.20	0.00	0.91
A fix as	Fixed assets expressed as percentages of lender total assets	0.01	0.01	0.00	0.14	0.01	0.01	0.00	0.09	0.01	0.01	0.00	0.09
A non ern	Non -earning assets expressed as percentages of lender total assets	0.07	0.07	0.00	0.96	0.07	0.06	0.00	0.96	0.07	0.08	0.00	0.96
L dep sh fun	Deposits and short-term funding expressed as percentages of lender total assets	0.62	0.17	0.00	0.99	0.62	0.16	0.00	0.98	0.62	0.17	0.00	0.98
L oth int bea	Other interest bearing liabilities expressed as percentages of lender total assets	0.25	0.17	0.00	0.87	0.25	0.15	0.00	0.85	0.25	0.16	0.00	0.85
L oth res	Other reserves expressed as percentages of lender total assets	0.01	0.01	0.00	0.13	0.01	0.00	0.00	0.04	0.01	0.01	0.00	0.20
L equ	Equity expressed as percentages of lender total assets	0.08	0.04	0.00	0.60	0.08	0.05	0.00	0.56	0.08	0.04	0.00	0.56
A tot asset	Total assets expressed in millions of euros	10.00	2.22	3.06	14.54	9.92	2.33	3.59	14.51	10.04	2.36	3.69	14.51
IT	Dummy variable taking value equal to 1 if the lender is from this country (or set of countries) and zero otherwise.	0.44	0.50	0.00	1.00	0.54	0.50	0.00	1.00	0.47	0.50	0.00	1.00
FR	””	0.05	0.21	0.00	1.00	0.04	0.21	0.00	1.00	0.04	0.20	0.00	1.00
ES	””	0.05	0.22	0.00	1.00	0.04	0.19	0.00	1.00	0.05	0.21	0.00	1.00
NL	””	0.03	0.16	0.00	1.00	0.02	0.13	0.00	1.00	0.03	0.16	0.00	1.00
GR	””	0.03	0.16	0.00	1.00	0.03	0.17	0.00	1.00	0.04	0.19	0.00	1.00
IE	””	0.02	0.13	0.00	1.00	0.01	0.08	0.00	1.00	0.00	0.07	0.00	1.00
UK	””	0.02	0.13	0.00	1.00	0.01	0.11	0.00	1.00	0.02	0.14	0.00	1.00
US/JAP/EX	””	0.03	0.16	0.00	1.00	0.02	0.13	0.00	1.00	0.03	0.17	0.00	1.00
AT	””	0.06	0.24	0.00	1.00	0.07	0.26	0.00	1.00	0.07	0.25	0.00	1.00
PT	””	0.04	0.19	0.00	1.00	0.03	0.17	0.00	1.00	0.04	0.19	0.00	1.00
LU	””	0.01	0.11	0.00	1.00	0.00	0.07	0.00	1.00	0.02	0.13	0.00	1.00
CY	””	0.01	0.11	0.00	1.00	0.01	0.07	0.00	1.00	0.00	0.07	0.00	1.00
CH	””	0.00	0.07	0.00	1.00	0.01	0.09	0.00	1.00	0.01	0.07	0.00	1.00
FI	””	0.00	0.06	0.00	1.00	0.00	0.04	0.00	1.00	0.00	0.04	0.00	1.00
EUEX	””	0.08	0.27	0.00	1.00	0.06	0.25	0.00	1.00	0.07	0.26	0.00	1.00
BE	””	0.00	0.06	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	1.00
Borrower													
A loan	Loans expressed as percentages of borrower total assets	0.57	0.19	0.00	0.91	0.60	0.19	0.00	0.87	0.57	0.20	0.00	0.87
A fix as	Fixed assets expressed as percentages of borrower total assets	0.01	0.02	0.00	0.09	0.01	0.01	0.00	0.09	0.01	0.02	0.00	0.09
A non ern	Non -earning assets expressed as percentages of borrower total assets	0.07	0.07	0.00	0.96	0.07	0.06	0.00	0.96	0.06	0.06	0.00	0.96
L dep sh fun	Deposits and short-term funding expressed as percentages of borrower total assets	0.57	0.17	0.00	0.93	0.59	0.16	0.00	0.94	0.60	0.15	0.00	0.94
L oth int bea	Otherinterest bearing liabilities expressed as percentages of borrower total assets	0.31	0.16	0.00	0.95	0.28	0.16	0.00	0.92	0.28	0.15	0.00	0.92
L oth res	Other reservers expressed as percentages of borrower total assets	0.01	0.01	0.00	0.08	0.01	0.00	0.00	0.03	0.01	0.00	0.00	0.08
L equ	Equity expressed as percentages of borrower total assets	0.07	0.03	0.00	0.29	0.07	0.03	0.00	0.27	0.07	0.03	0.00	0.27
A tot asset	Total assets expressed in millions of euros	11.28	1.97	3.06	14.54	10.74	1.98	3.99	14.51	10.94	2.15	5.23	14.51
IT	Dummy variable taking value equal to 1 if the borrower is from this country (or set of countries) and zero otherwise.	0.42	0.49	0.00	1.00	0.55	0.50	0.00	1.00	0.47	0.50	0.00	1.00
FR	””	0.06	0.23	0.00	1.00	0.03	0.16	0.00	1.00	0.08	0.27	0.00	1.00
ES	””	0.04	0.20	0.00	1.00	0.04	0.19	0.00	1.00	0.05	0.21	0.00	1.00
NL	””	0.01	0.09	0.00	1.00	0.01	0.11	0.00	1.00	0.01	0.12	0.00	1.00
GR	””	0.02	0.14	0.00	1.00	0.02	0.14	0.00	1.00	0.01	0.11	0.00	1.00
IE	””	0.02	0.13	0.00	1.00	0.01	0.09	0.00	1.00	0.00	0.07	0.00	1.00
UK	””	0.03	0.17	0.00	1.00	0.02	0.15	0.00	1.00	0.02	0.13	0.00	1.00
US/JAP/EX	””	0.05	0.21	0.00	1.00	0.04	0.19	0.00	1.00	0.04	0.19	0.00	1.00
AT	””	0.06	0.23	0.00	1.00	0.06	0.23	0.00	1.00	0.05	0.21	0.00	1.00
PT	””	0.02	0.13	0.00	1.00	0.02	0.15	0.00	1.00	0.02	0.13	0.00	1.00
LU	””	0.01	0.09	0.00	1.00	0.01	0.08	0.00	1.00	0.01	0.08	0.00	1.00
CY	””	0.01	0.11	0.00	1.00	0.01	0.12	0.00	1.00	0.01	0.10	0.00	1.00
CH	””	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FI	””	0.00	0.04	0.00	1.00	0.00	0.05	0.00	1.00	0.00	0.00	0.00	0.00
EUEX	””	0.06	0.23	0.00	1.00	0.03	0.18	0.00	1.00	0.03	0.17	0.00	1.00
BE	””	0.00	0.07	0.00	1.00	0.00	0.06	0.00	1.00	0.00	0.05	0.00	1.00
Pairs observed		1434				1613				1391			

Notes: Three representative maintenance periods are described. Other maintenance periods descriptives are not reported for the sake of brevity and are available upon request. Fixed assets are also known as tangible assets or property, plant, and equipment, they are illiquid assets and cannot easily be converted into cash. See Bankscope website for a more detailed description of the balance sheet data collection.

Table 2: Quantity equation MP1

Dependent Variable: bilateral quantity exchanged

	Simple regression		Selection correction		T-stat difference	
Mills Ratio Borrower			-115.0199***			
			(23.9951)			
Mills Ratio Lender			-85.5174 ***			
			(17.8718)			
	Lender	Borrower	Lender	Borrower	Lender	Borrower
A loan	6.3986	-6.1036	-0.8143	-14.1645 *	0.6512	0.6644
	(7.8825)	(8.6316)	(7.7816)	(8.5254)	[0.7425]	[0.7467]
A fix as	-205.9081	-214.8743	-144.4210	-27.0155	-0.2707	-0.7261
	(161.9778)	(183.5641)	(159.2448)	(182.3413)	[0.3933]	[0.2340]
A non ern	66.8535 **	-67.6508 **	73.2480 ***	-72.5851 **	-0.1600	0.1076
	(28.5485)	(32.7724)	(27.9638)	(32.0641)	[0.4365]	[0.5428]
L dep sh fun	34.8874	-44.4600	18.3525	-19.3109	0.4476	-0.6039
	(26.3047)	(29.4818)	(25.9386)	(29.4155)	[0.6727]	[0.2730]
L oth int bea	34.4045	-37.5091	30.1779	-23.8505	0.1122	-0.3289
	(26.9349)	(29.5910)	(26.3464)	(29.1361)	[0.5446]	[0.3711]
L oth res	-94.2805	-464.5184	-26.2109	-478.2933	-0.1601	0.0284
	(303.8844)	(346.9461)	(297.3783)	(339.3746)	[0.4364]	[0.5113]
L equ	26.2915	55.8195	15.5751	42.4104	0.1941	0.1410
	(39.4601)	(67.9548)	(38.6153)	(66.5232)	[0.5769]	[0.5561]
A tot asset	0.8051	0.2353	-1.7011 *	-1.8950 *	1.9349	1.3480
	(0.8898)	(1.1078)	(0.9412)	(1.1271)	[0.9734]	[0.9110]
IT	-5.3730	2.1513	-0.8136	10.9651 *	-0.5891	-0.9788
	(5.5120)	(6.3591)	(5.4327)	(6.3753)	[0.2780]	[0.1640]
FR	6.4208	9.6956	-7.8743	35.6712 ***	1.2724	-1.8280
	(7.8721)	(9.4197)	(8.0154)	(10.6393)	[0.8982]	[0.0339]
ES	7.3184	-9.9276	8.7138	-9.1562	-0.1092	-0.0625
	(9.1304)	(8.8161)	(8.9429)	(8.6224)	[0.4565]	[0.4751]
NL	0.1365	-20.6351	-7.6851	-15.2179	0.5706	-0.3066
	(9.7475)	(12.6118)	(9.6375)	(12.3784)	[0.7158]	[0.3796]
GR	10.7974	-10.2980	10.9168	-5.7408	-0.0050	-0.1782
	(17.1602)	(18.2703)	(16.7803)	(17.8894)	[0.4980]	[0.4293]
UK	9.5135	-8.0704	1.9895	-11.9184	0.4623	0.2885
	(11.5314)	(9.5098)	(11.4826)	(9.3498)	[0.6780]	[0.6135]
US/JAP/EX	-0.8014	9.2517	-0.5150	14.4930	-0.0193	-0.2810
	(10.5874)	(13.3213)	(10.3590)	(13.0572)	[0.4923]	[0.3894]
AT	-2.7670	-5.0445	1.7754	-0.4491	-0.5499	-0.4910
	(5.8758)	(6.6712)	(5.8060)	(6.5636)	[0.2913]	[0.3118]
PT	5.3247	-22.1638 **	7.1816	-14.7469	-0.1513	-0.5494
	(8.7659)	(9.5934)	(8.5896)	(9.4998)	[0.4399]	[0.2914]
CY		-27.2089		-18.2724		-0.3817
		(16.7152)		(16.3943)		[0.3514]
EUEX	-0.9160	-22.6624 ***	-1.4285	-16.1408 **	0.0535	-0.5929
	(6.8343)	(7.8358)	(6.7206)	(7.7185)	[0.5213]	[0.2767]
Rates at t-1	-2797.4123 *	1946.0673	-2922.3237 *	733.2042	0.0557	0.5280
	(1601.9363)	(1630.5859)	(1566.9273)	(1618.2008)	[0.5222]	[0.7012]
Value exchanged at t-1	0.0546 ***	0.0203 ***	0.0395 ***	-0.0261 **	2.5184	3.5207
	(0.0037)	(0.0066)	(0.0048)	(0.0114)	[0.9940]	[0.9998]
Number of counterparts at t-1	1.4814	-1.8501	0.9372	-1.2246	0.3077	-0.3441
	(1.2597)	(1.2955)	(1.2412)	(1.2749)	[0.6208]	[0.3654]
Connection at t-1	13.4627 ***		12.9965 ***		0.1194	
	(2.7910)		(2.7323)		[0.5475]	
Constant	10.0226		167.2367 ***		-2.5259	
	(41.4498)		(46.4306)		[0.0058]	
$\bar{R}^2$	0.3402		0.3692			
Time interval			2010-01-20 - 2010-02-09			
Maturity			1 to 3 days			
Observations			1067			

Notes: * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets, p-values in squared brackets. Estimates are from the linear model described in Section 5, the empirical specification is described in Section 6.2. Controls are described in Table 1, their effect are reported for borrowers and lenders in the respective columns. In the selection correction model the Mills ratios are added. "Number of counterparts at t-1" is the number of trading counterparties over the previous maintenance period as lender or borrower. "Value exchanged at t-1" is the average value of loans over the previous maintenance period as lender or borrower. "Rates at t-1" is the average rate over the previous maintenance period as lender or borrower. "Connection at t-1" is equal to 1 if the two banks exchanged money in the previous maintenance period. The T-stat differences are computed between the same coefficient estimated by simple regression and the selection correction procedure (H_0: equivalence of the two coefficients). Only country fixed effects with more than 1% of observations are included in the model. Estimates are from the parametric model.

Table 3: Quantity equation MP2

Dependent Variable: bilateral quantity exchanged

	Simple regression		Selection correction		T-stat difference	
Mills Ratio Borrower			-5.5061			
			(17.3867)			
Mills Ratio Lender			-16.9521			
			(158.2507)			
	Lender	Borrower	Lender	Borrower	Lender	Borrower
A loan	1.7606	6.6400	1.5393	5.2504	0.0117	0.0427
	(13.3267)	(16.2507)	(13.3544)	(28.2352)	[0.5047]	[0.5170]
A fix as	-149.1683	-432.8531	-147.1083	-417.7091	-0.0058	-0.0384
	(252.6273)	(276.8203)	(252.9713)	(280.8647)	[0.4977]	[0.4847]
A non ern	-94.0567 **	-27.6420	-93.3866 **	-21.9008	-0.0108	-0.0720
	(43.7994)	(54.8992)	(43.8824)	(57.7941)	[0.4957]	[0.4713]
L dep sh fun	-32.7732	7.4151	-32.2845	10.0088	-0.0086	-0.0356
	(40.3783)	(51.2354)	(40.4386)	(51.8562)	[0.4966]	[0.4858]
L oth int bea	-44.4192	-9.5320	-43.7578	-7.2354	-0.0109	-0.0323
	(43.0131)	(50.0215)	(43.0941)	(50.5855)	[0.4957]	[0.4871]
L oth res	-15.0961	-14.1784	-16.8335	-37.5391	0.0041	0.0324
	(303.1681)	(507.6146)	(303.4820)	(513.0739)	[0.5016]	[0.5129]
L equ	-157.6289 **	108.3875	-156.8065 **	105.2249	-0.0086	0.0196
	(67.6506)	(113.8246)	(67.7542)	(114.3171)	[0.4966]	[0.5078]
A tot asset	-3.1419 **	0.3531	-3.2202 **	0.0744	0.0385	0.0992
	(1.3967)	(1.6454)	(1.4797)	(2.2764)	[0.5154]	[0.5395]
IT	-3.6031	18.9753 **	-3.3973	19.6287 **	-0.0171	-0.0480
	(8.4757)	(9.4222)	(8.5394)	(9.8294)	[0.4932]	[0.4809]
FR	19.7853 *	31.1235 **	19.8211 *	30.4662 **	-0.0022	0.0378
	(11.7449)	(12.1966)	(11.7730)	(12.3621)	[0.4991]	[0.5151]
ES	2.2977	4.7209	2.2235	4.7715	0.0043	-0.0025
	(12.3112)	(13.9928)	(12.3322)	(14.1062)	[0.5017]	[0.4990]
NL	6.5555	5.5763	6.8656	5.7060	-0.0142	-0.0043
	(15.4091)	(21.4893)	(15.4726)	(21.6248)	[0.4943]	[0.4983]
GR	-14.4963	1.7322	-14.4807	1.5081	-0.0006	0.0096
	(17.4432)	(16.5155)	(17.4585)	(16.6484)	[0.4997]	[0.5038]
UK	-21.6804	14.8554	-21.4928	13.7790	-0.0095	0.0524
	(13.9617)	(14.3478)	(14.0123)	(14.7128)	[0.4962]	[0.5209]
US/JAP/EX	5.5621	-7.4766	5.5527	-6.3888	0.0004	-0.0354
	(17.5499)	(21.5685)	(17.5802)	(21.8964)	[0.5002]	[0.4859]
AT	13.3601	1.1660	13.2064	0.6481	0.0074	0.0346
	(14.6754)	(10.5086)	(14.7053)	(10.6555)	[0.5030]	[0.5138]
PT	0.2844	-2.6162	0.3742	-1.9588	-0.0065	-0.0236
	(9.7857)	(19.6470)	(9.8091)	(19.7927)	[0.4974]	[0.4906]
CY	3.5884	1.0048	3.5018	0.3234	0.0036	0.0238
	(16.9875)	(20.0984)	(17.0083)	(20.3666)	0.5014	[0.5095]
EUEX	3.1793	9.5185	3.3796	9.4619	-0.0159	0.0038
	(8.8992)	(10.4184)	(8.9523)	(10.5524)	[0.4937]	[0.5015]
Rates at t-1	1322.1041	-716.7974	1311.6763	-747.8046	0.0062	0.0320
	(1180.6889)	(680.7336)	(1182.0920)	(689.9159)	[0.5025]	[0.5128]
Value exchanged at t-1	0.0858 ***	0.0440 ***	0.0857 ***	0.0438 ***	0.0108	0.0168
	(0.0084)	(0.0074)	(0.0084)	(0.0075)	[0.5043]	[0.5067]
Number of counterparts at t-1	-5.8225	1.8141	-5.7800	1.7943	-0.0076	0.0061
	(3.9305)	(2.2935)	(3.9358)	(2.2977)	[0.4970]	[0.5024]
Connection at t-1	18.8324 ***		18.7308 ***		0.0168	
	(4.2594)		(4.2764)		[0.5067]	
Constant	63.3398		79.0490		-0.0927	
	(71.3843)		(153.6449)		[0.4631]	
$\bar{R}^2$	0.1920		0.1933			
Time interval			2009-02-11 - 2009-03-10			
Maturity			1 to 3 days			
Observations			1183			

Notes: See 2.

Table 4: Rate equation MP2

Dependent Variable: bilateral rate

	Simple regression		Selection correction		T-stat difference	
Mills Ratio Borrower			0.0398**			
			(0.0163)			
Mills Ratio Lender			0.0475***			
			(0.0182)			
	Lender	Borrower	Lender	Borrower	Lender	Borrower
A loan	0.0114	-0.0181	0.0100	-0.0936 **	0.0484	1.5798
	(0.0209)	(0.0243)	(0.0209)	(0.0411)	[0.5193]	[0.9428]
A fix as	-0.0528	0.4215	-0.0167	0.2554	-0.0620	0.2854
	(0.4118)	(0.4083)	(0.4111)	(0.4145)	[0.4753]	[0.6123]
A non ern	0.0342	0.2607 ***	0.0374	0.2745 ***	-0.0323	-0.1105
	(0.0706)	(0.0878)	(0.0705)	(0.0879)	[0.4871]	[0.4560]
L dep sh fun	0.0595	0.1794 **	0.0624	0.1629 **	-0.0307	0.1462
	(0.0658)	(0.0795)	(0.0657)	(0.0796)	[0.4878]	[0.5581]
L oth int bea	0.0017	0.2194 ***	0.0031	0.2098 ***	-0.0141	0.0847
	(0.0702)	(0.0802)	(0.0701)	(0.0802)	[0.4944]	[0.5337]
L oth res	0.7474	0.8611	0.7566	0.5835	-0.0133	0.2373
	(0.4916)	(0.8198)	(0.4906)	(0.8348)	[0.4947]	[0.5938]
L equ	0.0154	-0.0662	0.0203	-0.0591	-0.0315	-0.0270
	(0.1083)	(0.1849)	(0.1081)	(0.1848)	[0.4875]	[0.4892]
A tot asset	0.0139 ***	-0.0205 ***	0.0123 ***	-0.0271 ***	0.5373	1.5839
	(0.0021)	(0.0024)	(0.0022)	(0.0034)	[0.7044]	[0.9433]
IT	-0.0020	0.0263 *	-0.0001	0.0298 **	-0.1041	-0.1684
	(0.0132)	(0.0146)	(0.0131)	(0.0148)	[0.4586]	[0.4331]
FR	-0.0622 ***	0.0181	-0.0603 ***	0.0207	-0.0721	-0.0926
	(0.0190)	(0.0199)	(0.0190)	(0.0199)	[0.4713]	[0.4631]
ES	0.0189	0.0429 *	0.0200	0.0530 **	-0.0386	-0.3139
	(0.0198)	(0.0226)	(0.0198)	(0.0228)	[0.4846]	[0.3768]
NL	0.0426 *	0.2690 ***	0.0466 *	0.2793 ***	-0.1113	-0.2072
	(0.0253)	(0.0349)	(0.0253)	(0.0350)	[0.4557]	[0.4179]
GR	0.0298	0.1107 ***	0.0279	0.1203 ***	0.0466	-0.2512
	(0.0286)	(0.0268)	(0.0285)	(0.0270)	[0.5186]	[0.4008]
UK	-0.0114	0.0311	-0.0090	0.0330	-0.0731	-0.0564
	(0.0229)	(0.0233)	(0.0229)	(0.0233)	[0.4709]	[0.4775]
US/JAP/EX	-0.0676 **	0.0733 **	-0.0642 **	0.0779 **	-0.0847	-0.0965
	(0.0286)	(0.0338)	(0.0286)	(0.0338)	[0.4663]	[0.4616]
AT	-0.0519 **	0.0349 **	-0.0508 **	0.0394 **	-0.0313	-0.1860
	(0.0236)	(0.0170)	(0.0236)	(0.0171)	[0.4875]	[0.4262]
PT	-0.0222	0.1046 ***	-0.0214	0.1129 ***	-0.0398	-0.1813
	(0.0158)	(0.0320)	(0.0157)	(0.0322)	0.4841	[0.4281]
CY	-0.0149	0.2731 ***	-0.0159	0.2807 ***	0.0250	-0.1649
	(0.0278)	(0.0326)	(0.0277)	(0.0328)	[0.5100]	[0.4345]
EUEX	-0.0614 ***	0.0912 ***	-0.0580 ***	0.0979 ***	-0.1703	-0.2788
	(0.0143)	(0.0169)	(0.0143)	(0.0171)	[0.4324]	[0.3902]
Constant	0.9779 ***		1.4926 ***		-2.0431	
	(0.1112)		(0.2261)		[0.0206]	
Connection at t-1	0.0082		0.0049		0.3656	
	(0.0064)		(0.0066)		[0.6426]	
Quantity exchanged	-0.0000		-0.0000		0.0433	
	(0.0000)		(0.0000)		[0.5173]	
$\bar{R}^2$	0.3028		0.3572			
Time interval			2009-02-11 - 2009-03-10			
Maturity			1 to 3 days			
Observations			1183			

Notes: See 2.

Table 5: Rate equation MP1

Dependent Variable: bilateral rate						
	Simple regression		Selection correction		T-stat difference	
Mills Ratio Borrower			0.0398**			
			(0.0163)			
Mills Ratio Lender			0.0475***			
			(0.0182)			
	Lender	Borrower	Lender	Borrower	Lender	Borrower
A loan	0.0163	-0.0460 ***	0.0145	-0.0396 ***	0.0841	-0.0298
	(0.0133)	(0.0145)	(0.0136)	(0.0149)	[0.5335]	[0.4881]
A fix as	0.2910	0.9290 ***	0.3530	1.0132 ***	-0.2312	-0.4014
	(0.2739)	(0.2981)	(0.2753)	(0.3061)	[0.4086]	[0.3441]
A non ern	0.1006 **	-0.0532	0.1114 **	-0.0619	0.0468	-0.0175
	(0.0488)	(0.0554)	(0.0491)	(0.0570)	[0.5187]	[0.4930]
L dep sh fun	0.1067 **	0.0345	0.1316 ***	0.0327	-0.2102	-0.0476
	(0.0444)	(0.0487)	(0.0452)	(0.0526)	[0.4168]	[0.4810]
L oth int bea	0.0461	0.0573	0.0689	0.0556	-0.0939	-0.1052
	(0.0458)	(0.0491)	(0.0467)	(0.0535)	[0.4626]	[0.4581]
L oth res	-0.0826	-0.4602	0.1963	-0.6389	-0.1107	0.1622
	(0.5045)	(0.5828)	(0.5165)	(0.5985)	[0.4559]	[0.5644]
L equ	0.0258	0.3316 ***	0.0457	0.3033 **	-0.1446	0.0104
	(0.0667)	(0.1155)	(0.0677)	(0.1177)	[0.4425]	[0.5042]
A tot asset	0.0066 ***	-0.0052 ***	0.0080 ***	-0.0047 **	-1.2526	-1.1767
	(0.0015)	(0.0018)	(0.0016)	(0.0021)	[0.1053]	[0.1198]
IT	0.0096	0.0011	0.0162 *	-0.0032	-0.3541	0.7159
	(0.0089)	(0.0094)	(0.0094)	(0.0096)	[0.3617]	[0.7629]
FR	-0.0029	-0.0038	-0.0017	0.0020	-0.0252	0.2393
	(0.0131)	(0.0157)	(0.0141)	(0.0219)	[0.4900]	[0.5945]
ES	0.0138	-0.0061	0.0159	-0.0054	0.2196	0.2542
	(0.0156)	(0.0150)	(0.0157)	(0.0152)	[0.5869]	[0.6003]
NL	-0.0128	0.0061	-0.0124	0.0038	-0.1127	0.4059
	(0.0168)	(0.0219)	(0.0170)	(0.0221)	[0.4551]	[0.6576]
GR	-0.0411	0.0784 **	-0.0352	0.0749 **	-0.0169	0.2719
	(0.0296)	(0.0315)	(0.0297)	(0.0316)	[0.4933]	[0.6071]
UK	-0.0079	0.0079	-0.0226	0.0039	-0.0523	0.2362
	(0.0199)	(0.0160)	(0.0212)	(0.0165)	[0.4791]	[0.5933]
US/JAP/EX	-0.0311 *	-0.0294	-0.0345 *	-0.0345	0.2097	0.4740
	(0.0179)	(0.0230)	(0.0183)	(0.0232)	[0.5830]	[0.6822]
AT	-0.0089	-0.0150	-0.0064	-0.0138	0.0799	0.5175
	(0.0099)	(0.0113)	(0.0100)	(0.0114)	[0.5319]	[0.6975]
PT	0.0310 **	0.0566 ***	0.0360 **	0.0561 ***	-0.0056	0.4380
	(0.0145)	(0.0166)	(0.0146)	(0.0167)	[0.4978]	[0.6693]
CY		0.1003 ***		0.0973 ***		0.3012
		(0.0289)		(0.0289)		[0.6183]
EUEX	-0.0104	0.0110	-0.0114	0.0094	0.1273	0.3548
	(0.0116)	(0.0135)	(0.0119)	(0.0142)	[0.5506]	[0.6386]
Constant	0.1089		-0.0734		1.0777	
	(0.0744)		(0.0987)		[0.8593]	
Connection at t-1	-0.0081 *		-0.0076 *		-0.6167	
	(0.0045)		(0.0046)		[0.2688]	
Quantity exchanged	(0.0000		-0.0000		-0.7851	
	(0.0001)		(0.0001)		[0.2163]	
$\bar{R}^2$	0.2080		0.2172			
Time interval			2010-01-20 - 2010-02-09			
Maturity			1 to 3 days			
Observations			1067			

Notes: See 2.

Table 6: Diagnostics - Mills Ratio collinearity

Dependent Variable:

	Borrower Mills Ratio		Lender Mills Ratio	
	Lender	Borrower	Lender	Borrower
A loan	-0.0283	0.0753 ***	0.0570 **	-0.0759 ***
	(0.0253)	(0.0275)	(0.0227)	(0.0246)
A fix as	0.0790	-4.8675 ***	-1.9494 ***	0.5688
	(0.5199)	(0.5498)	(0.4661)	(0.4930)
A non ern	0.1833 **	0.1091	-0.0853	-0.1204
	(0.0932)	(0.1060)	(0.0836)	(0.0950)
L dep sh fun	-0.0233	-0.0123	-0.2581 ***	-0.0590
	(0.0844)	(0.0933)	(0.0757)	(0.0836)
L oth int bea	-0.0212	-0.0935	-0.1106	-0.0759
	(0.0876)	(0.0940)	(0.0785)	(0.0843)
L oth res	0.7661	5.4197 ***	-2.3072 ***	-1.7341 *
	(0.9622)	(1.1015)	(0.8627)	(0.9877)
L equ	-0.1447	-0.0873	-0.1664	0.1092
	(0.1274)	(0.2211)	(0.1142)	(0.1982)
A tot asset	-0.0128 ***	-0.0605 ***	-0.0419 ***	-0.0092 ***
	(0.0025)	(0.0030)	(0.0022)	(0.0027)
IT	-0.0156	0.1700 ***	-0.0800 ***	0.0526 ***
	(0.0167)	(0.0170)	(0.0150)	(0.0152)
FR	0.0218	0.1204 ***	-0.0281	0.0107
	(0.0251)	(0.0298)	(0.0225)	(0.0267)
ES	0.0469	0.1888 ***	0.0629 **	-0.0452 *
	(0.0297)	(0.0282)	(0.0267)	(0.0253)
NL	0.0246	0.3494 ***	-0.0769 ***	-0.0319
	(0.0320)	(0.0404)	(0.0287)	(0.0363)
GR	-0.0012	0.2253 ***	-0.0140	0.0664
	(0.0567)	(0.0599)	(0.0509)	(0.0537)
UK	0.0475	0.1783 ***	-0.0708 **	-0.0377
	(0.0379)	(0.0300)	(0.0340)	(0.0269)
US/JAP/EX	-0.0080	0.3487 ***	0.1185 ***	0.0287
	(0.0341)	(0.0427)	(0.0305)	(0.0383)
AT	-0.0240	0.1992 ***	0.0437 ***	0.0044
	(0.0189)	(0.0207)	(0.0169)	(0.0186)
PT	-0.0382	0.2582 ***	0.0296	-0.0021
	(0.0277)	(0.0308)	(0.0248)	(0.0276)
CY		0.2392 ***		0.0578
		(0.0547)		(0.0490)
EUEX	0.0298	0.1758 ***	0.0191	-0.0054
	(0.0221)	(0.0253)	(0.0198)	(0.0227)
Connection at $t-1$	-0.0423 ***		-0.0465 ***	
	(0.0084)		(0.0075)	
Constant	1.1330 ***		1.3370 ***	
	(0.1291)		(0.1158)	
$\bar{R}^2$	0.6559		0.4865	
Time interval	2010-01-20 - 2010-02-09			
Maturity	1 to 3 days			
Observations	1067			

Notes: See 2. Borrower and Lender Mills ratios are regressed on the controls listed to check potential collinearity of the ratios with the regressors.

Table 7: Diagnostics - Rate distributional assumptions

Dependent Variable: bilateral rate				
	Parametric		Semiparametric	
	Lender	Borrower	Lender	Borrower
A loan	0.0163	-0.0460 ***	0.0145	-0.0396 ***
	(0.0133)	(0.0145)	(0.0136)	(0.0149)
A fix as	0.2910	0.9290 ***	0.3530	1.0132 ***
	(0.2739)	(0.2981)	(0.2753)	(0.3061)
A non ern	0.1006 **	-0.0532	0.1114 **	-0.0619
	(0.0488)	(0.0554)	(0.0491)	(0.0570)
L dep sh fun	0.1067 **	0.0345	0.1316 ***	0.0327
	(0.0444)	(0.0487)	(0.0452)	(0.0526)
L oth int bea	0.0461	0.0573	0.0689	0.0556
	(0.0458)	(0.0491)	(0.0467)	(0.0535)
L oth res	-0.0826	-0.4602	0.1963	-0.6389
	(0.5045)	(0.5828)	(0.5165)	(0.5985)
L equ	0.0258	0.3316 ***	0.0457	0.3033 **
	(0.0667)	(0.1155)	(0.0677)	(0.1177)
A tot asset	0.0066 ***	-0.0052 ***	0.0080 ***	-0.0047 **
	(0.0015)	(0.0018)	(0.0016)	(0.0021)
IT	0.0096	0.0011	0.0162 *	-0.0032
	(0.0089)	(0.0094)	(0.0094)	(0.0096)
FR	-0.0029	-0.0038	-0.0017	0.0020
	(0.0131)	(0.0157)	(0.0141)	(0.0219)
ES	0.0138	-0.0061	0.0159	-0.0054
	(0.0156)	(0.0150)	(0.0157)	(0.0152)
NL	-0.0128	0.0061	-0.0124	0.0038
	(0.0168)	(0.0219)	(0.0170)	(0.0221)
GR	-0.0411	0.0784 **	-0.0352	0.0749 **
	(0.0296)	(0.0315)	(0.0297)	(0.0316)
UK	-0.0079	0.0079	-0.0226	0.0039
	(0.0199)	(0.0160)	(0.0212)	(0.0165)
US/JAP/EX	-0.0311 *	-0.0294	-0.0345 *	-0.0345
	(0.0179)	(0.0230)	(0.0183)	(0.0232)
AT	-0.0089	-0.0150	-0.0064	-0.0138
	(0.0099)	(0.0113)	(0.0100)	(0.0114)
PT	0.0310 **	0.0566 ***	0.0360 **	0.0561 ***
	(0.0145)	(0.0166)	(0.0146)	(0.0167)
CY		0.1003 ***		0.0973 ***
		(0.0289)		(0.0289)
EUEX	-0.0104	0.0110	-0.0114	0.0094
	(0.0116)	(0.0135)	(0.0119)	(0.0142)
Connection at $t-1$	-0.0081 *		-0.0076 *	
	(0.0045)		(0.0046)	
Quantity exchanged	0.0000		-0.0000	
	(0.0001)		(0.0001)	
Constant	0.1089		-0.0734	
	(0.0744)		(0.0987)	
Time interval	2010-01-20 - 2010-02-09			
Maturity	1 to 3 days			
Observations	1067			

Notes: See 2. Rate is modeled using the parametric and semiparametric techniques, the coefficients of the two alternative methods are reported. Only country fixed effects with more than 1% of observations are included in the model. A power of four was used to approximate the unknown function in the semiparametric model.

Table 8: Diagnostics - Quantity distributional assumptions

Dependent Variable: quantity exchanged

	Parametric		Semiparametric	
	Lender	Borrower	Lender	Borrower
A loan	-0.8143	-14.1645 *	4.2825	-16.6934 *
	(7.7816)	(8.5254)	(8.0464)	(9.1175)
A fix as	-144.4210	-27.0155	-169.1523	-22.5261
	(159.2448)	(182.3413)	(158.1029)	(183.1893)
A non ern	73.2480 ***	-72.5851 **	71.1222 **	-59.0340 *
	(27.9638)	(32.0641)	(28.0304)	(32.1148)
L dep sh fun	18.3525	-19.3109	27.2343	-3.3528
	(25.9386)	(29.4155)	(26.4520)	(29.7158)
L oth int bea	30.1779	-23.8505	42.0625	-12.4231
	(26.3464)	(29.1361)	(26.8888)	(29.4617)
L oth res	-26.2109	-478.2933	-49.8700	-489.8194
	(297.3783)	(339.3746)	(298.6204)	(338.6524)
L equ	15.5751	42.4104	34.9539	24.2006
	(38.6153)	(66.5232)	(38.8946)	(66.5888)
A tot asset	-1.7011 *	-1.8950 *	-0.9458	-2.6520 **
	(0.9412)	(1.1271)	(1.0443)	(1.2495)
IT	-0.8136	10.9651 *	0.3116	7.7030
	(5.4327)	(6.3753)	(5.6359)	(6.4850)
FR	-7.8743	35.6712 ***	-7.9446	37.7282 ***
	(8.0154)	(10.6393)	(8.1462)	(11.2568)
ES	8.7138	-9.1562	5.4231	-4.2421
	(8.9429)	(8.6224)	(8.9677)	(8.8740)
NL	-7.6851	-15.2179	-12.5694	-11.2910
	(9.6375)	(12.3784)	(9.7578)	(12.3228)
GR	10.9168	-5.7408	9.1887	-4.6172
	(16.7803)	(17.8894)	(16.7088)	(17.7893)
UK	1.9895	-11.9184	-7.4027	-11.0966
	(11.4826)	(9.3498)	(11.9258)	(9.6347)
US/JAP/EX	-0.5150	14.4930	-4.0424	13.2878
	(10.3590)	(13.0572)	(10.5510)	(13.0043)
AT	1.7754	-0.4491	1.4700	0.0962
	(5.8060)	(6.5636)	(5.8337)	(6.5400)
PT	7.1816	-14.7469	3.9825	-10.2616
	(8.5896)	(9.4998)	(8.6046)	(9.4808)
CY	-1.4285	-18.2724	-2.9129	-13.8566
	(6.7206)	(16.3943)	(6.7949)	(16.3476)
EUEX		-16.1408 **		-14.1677 *
		(7.7185)		(8.0200)
Rates at $t-1$	-2922.3237 *	733.2042	-1888.6205	318.4466
	(1566.9273)	(1618.2008)	(1586.4385)	(1616.0956)
Value exchanged at $t-1$	0.0395 ***	-0.0261 **	0.0539 ***	-0.0402 *
	(0.0048)	(0.0114)	(0.0065)	(0.0221)
Number of counterparts at $t-1$	0.9372	-1.2246	0.2687	-0.8201
	(1.2412)	(1.2749)	(1.2603)	(1.2818)
Connection at $t-1$	12.9965 ***		12.0219 ***	
	(2.7323)		(2.7653)	
Time interval	2010-01-20 - 2010-02-09			
Maturity	1 to 3 days			
Observations	1067			

Notes: See 2 and 7.

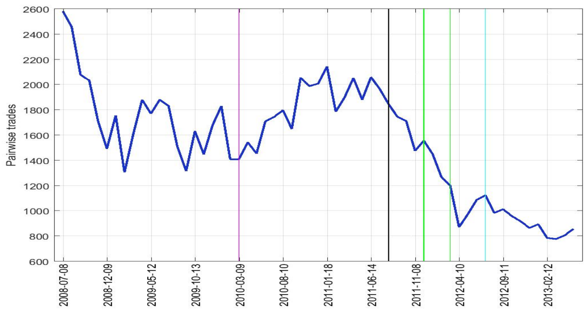
Table 9: Diagnostics - Exclusion restrictions

Dependent Variable: estimated residuals						
	Rate equation			Quantity equation		
	Simple regression	Selection correction	Δ	Simple regression	Selection correction	Δ
Borrower rates at $t-1$	4.6453 ***	4.3973 **	0.0710	-0.0000	0.0000	-0.0000
	(1.7471)	(1.7450)	(0.4717)	(1030.8095)	(1006.9246)	(0.5000)
Borrower value at $t-1$	-0.0000 ***	-0.0000 *	-0.4401	0.0000	0.0000	0.0000
	(0.0000)	(0.0000)	(0.3300)	(0.0040)	(0.0039)	(0.5000)
Borrower number of counterparts at $t-1$	-0.0034 **	-0.0032 **	-0.0820	0.0000	-0.0000	0.0000
	(0.0014)	(0.0014)	(0.4673)	(0.8129)	(0.7940)	(0.5000)
Lender rates at $t-1$	12.9894 ***	12.4827 ***	0.1156	-0.0000	-0.0000	-0.0000
	(2.1933)	(2.1905)	(0.4540)	(1294.0245)	(1264.0406)	(0.5000)
Lender value at $t-1$	-0.0000	0.0000	-0.2960	0.0000	0.0000	-0.0000
	(0.0000)	(0.0000)	(0.3837)	(0.0031)	(0.0030)	(0.5000)
Lender number of counterparts at $t-1$	-0.0107 ***	-0.0101 ***	-0.1677	0.0000	0.0000	0.0000
	(0.0017)	(0.0017)	(0.4334)	(1.0158)	(0.9923)	(0.5000)
Time interval	2010-01-20 - 2010-02-09					
Maturity	1 to 3 days					
Observations	1067					

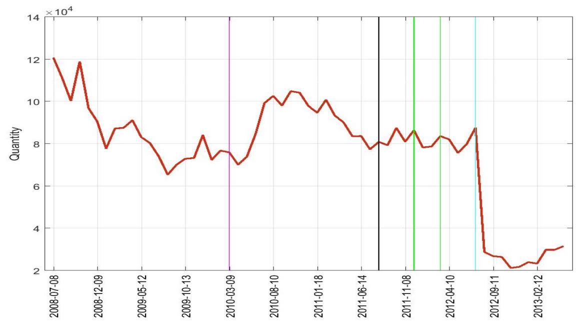
Notes: See 2. The residuals are from the parametric model and respectively from the rate and quantity equations for both the simple regression and the selection correction model. The residuals are regressed on the excluded variables, reported in the first column. The Δ columns report the difference between the coefficients when the correction is applied and when it is not and its standard deviation.

Figures

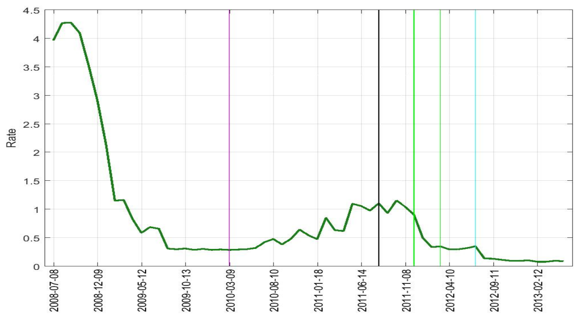
Figure 1: Aggregate evidence - Number of links, quantity exchanged and rate.



(a) Number of bilateral trades



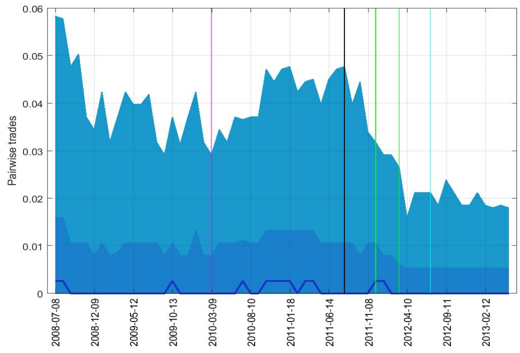
(b) Total quantity exchanged



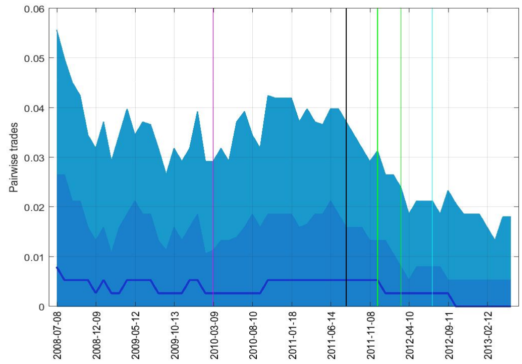
(c) Average rate

Notes: Each data point represents a maintenance period (the starting date is reported on the X axis). Panel (a) reports the number of trades reported in each maintenance period. Panel (b) reports the quantity exchanged in millions of euro. Panel (c) plots the weighted (by volume) average rate agreed in each period. Violet vertical line traces the first peak of the sovereign debt crisis (April 2010), the black vertical line traces the second peak of the sovereign debt crisis (August 2011), the green lines trace the dates of the two Eurosystem LTROs and the light blue line traces when the overnight deposit rate was set to zero in July 2012.

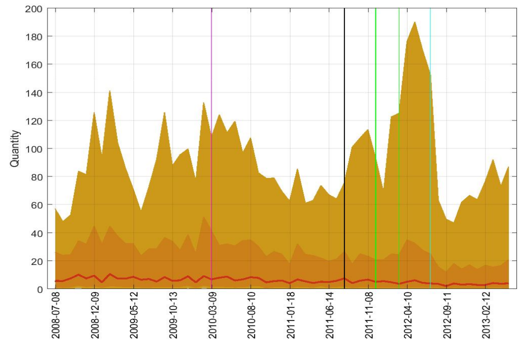
Figure 2: Market side evidence - Number of links, quantity exchanged and rate.



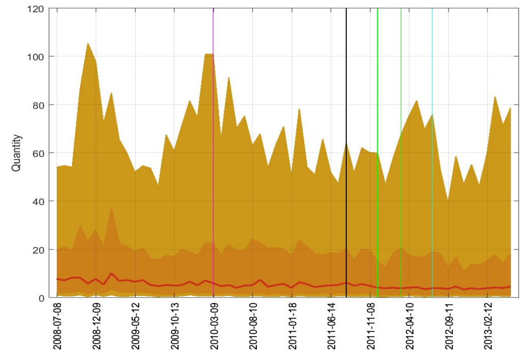
(a) Lenders bilateral trades



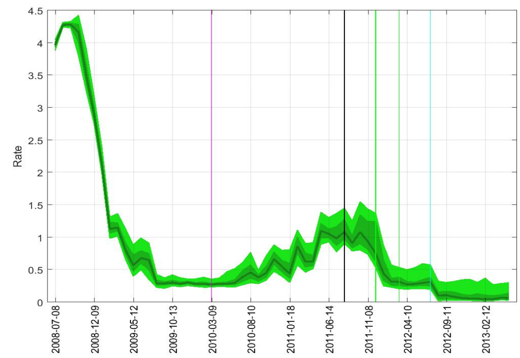
(b) Borrowers bilateral trades



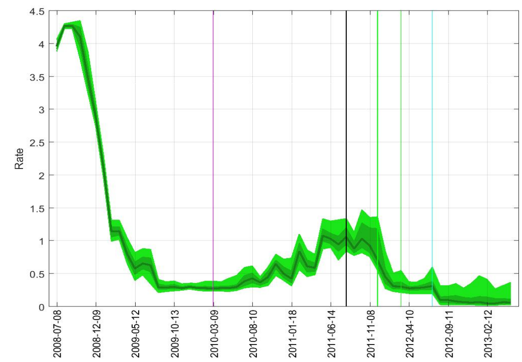
(c) Lenders quantity exchanged



(d) Borrowers quantity exchanged



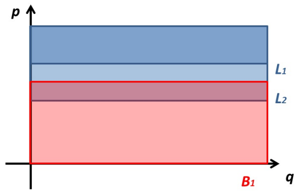
(e) Lenders average rate



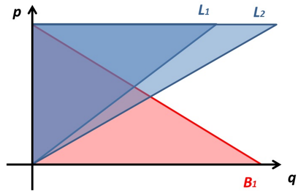
(f) Borrowers average rate

Notes: See Figure 1. Light shades track the interdecile range, dark shades depict the interquartile interval and the median is traced with a bold line. Panel (a) and (b) report the number of trades for each bank relative to the possible matches with other market participants, 0.01 means that a lender (borrower) trades with one borrower (lender) on 100 possible market participants. Panel (b) and (d) report the average number of millions of euro per transaction for each bank. In Panel (e) and (f) rates are averaged over the maintenance period for each market participant.

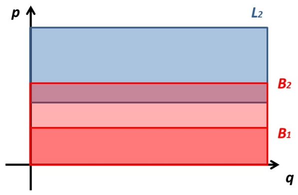
Figure 3: Lender and borrower shadow rates



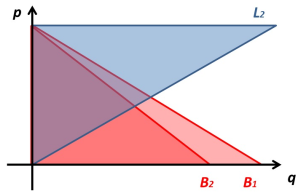
(a) Supply intercept



(b) Supply slope



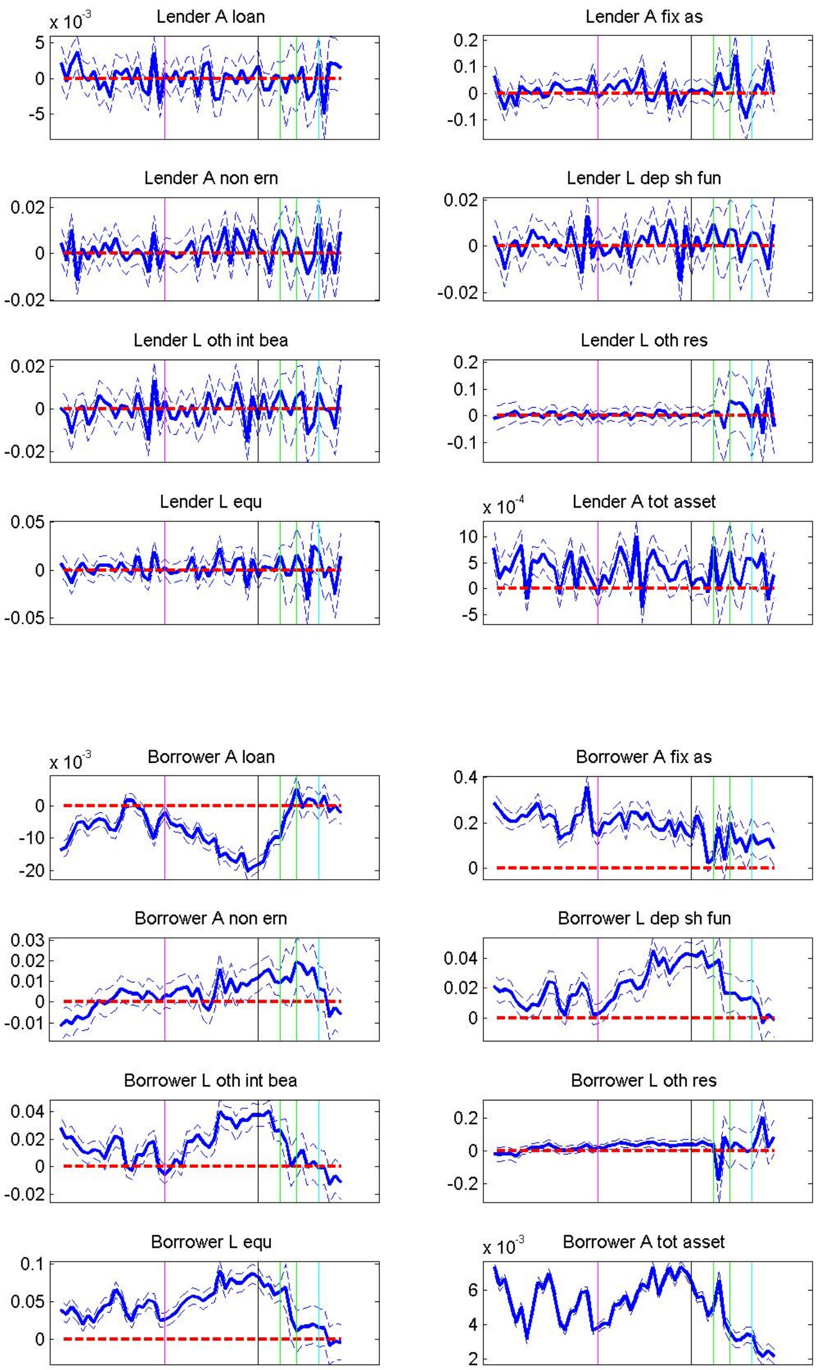
(c) Demand intercept



(d) Demand slope

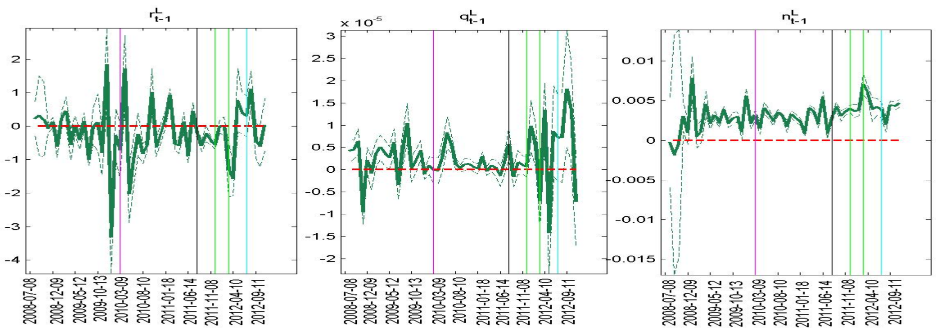
Notes: Blue areas refer to lenders, red areas refer to borrowers. Panel (a) depicts two different lenders (L_1 and L_2) with different γ_0, panel (b) represents two different lenders (L_1 and L_2) with different γ_2, the red area refers to a borrower (B_1). Panel (c) depicts two different borrowers (B_1 and B_2) with different θ_0, panel (d) represents two different borrowers (B_1 and B_2) with different θ_2, the blue area refers to a lender (L_2).

Figure 4: Probability to trade - Lender and borrower's balance sheet effects.



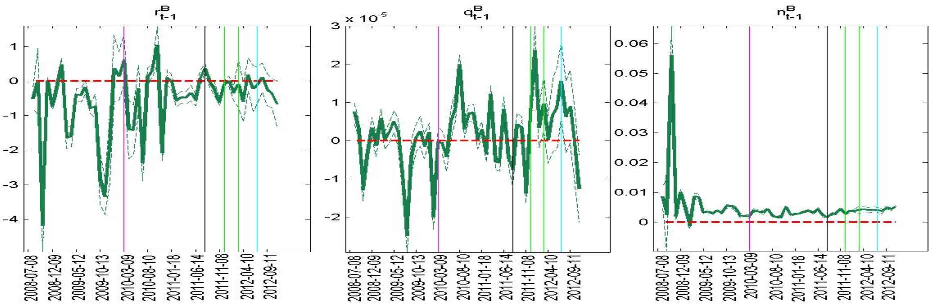
Notes: See Figure 1. The X axis is the time line, each data point represents a maintenance period as in Figure 1, dates are not reported for convenience. The title of the subplot reports the name of the covariate for which the effect is measured. The bold lines represent repeated cross-section OLS estimates of a linear probability model, the dashed lines represent 95 percent confidence intervals (Probit estimates produce the same patterns and are available upon request). The dependent is a binary variable taking value equal to 1 if a trade occurred between the pair of banks. The controls (z and k) listed in Section 6.2 are on the RHS. The model is estimated including all the covariates. The bold dashed red line tracks the zero axis.

Figure 5: Probability to trade - Lender's previous activity effects.



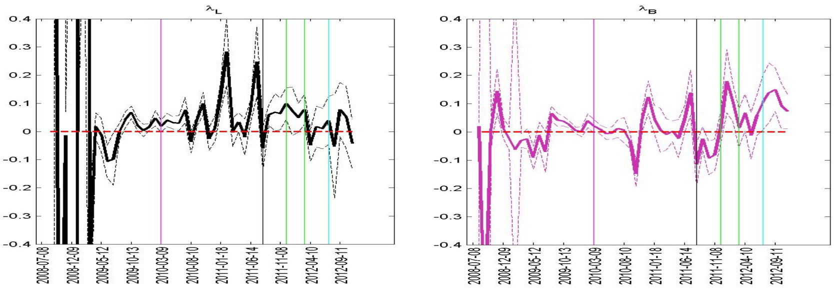
Notes: See Figure 1 and Figure 4. r_{t-1} is the average rate during the previous maintenance period. q_{t-1} is the quantity exchanged and n_{t-1} is the number of counterparties.

Figure 6: Probability to trade - Borrower's previous activity effects.



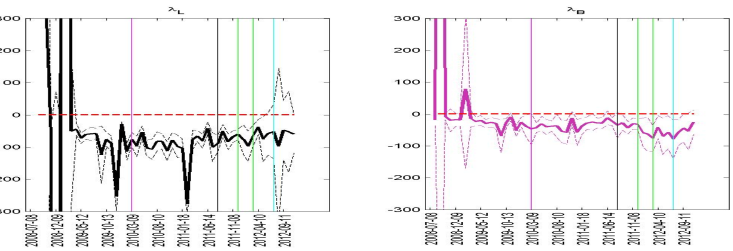
Notes: See Figure 1, Figure 4 and Figure 5.

Figure 7: Rate equation - Mills ratios coefficients.



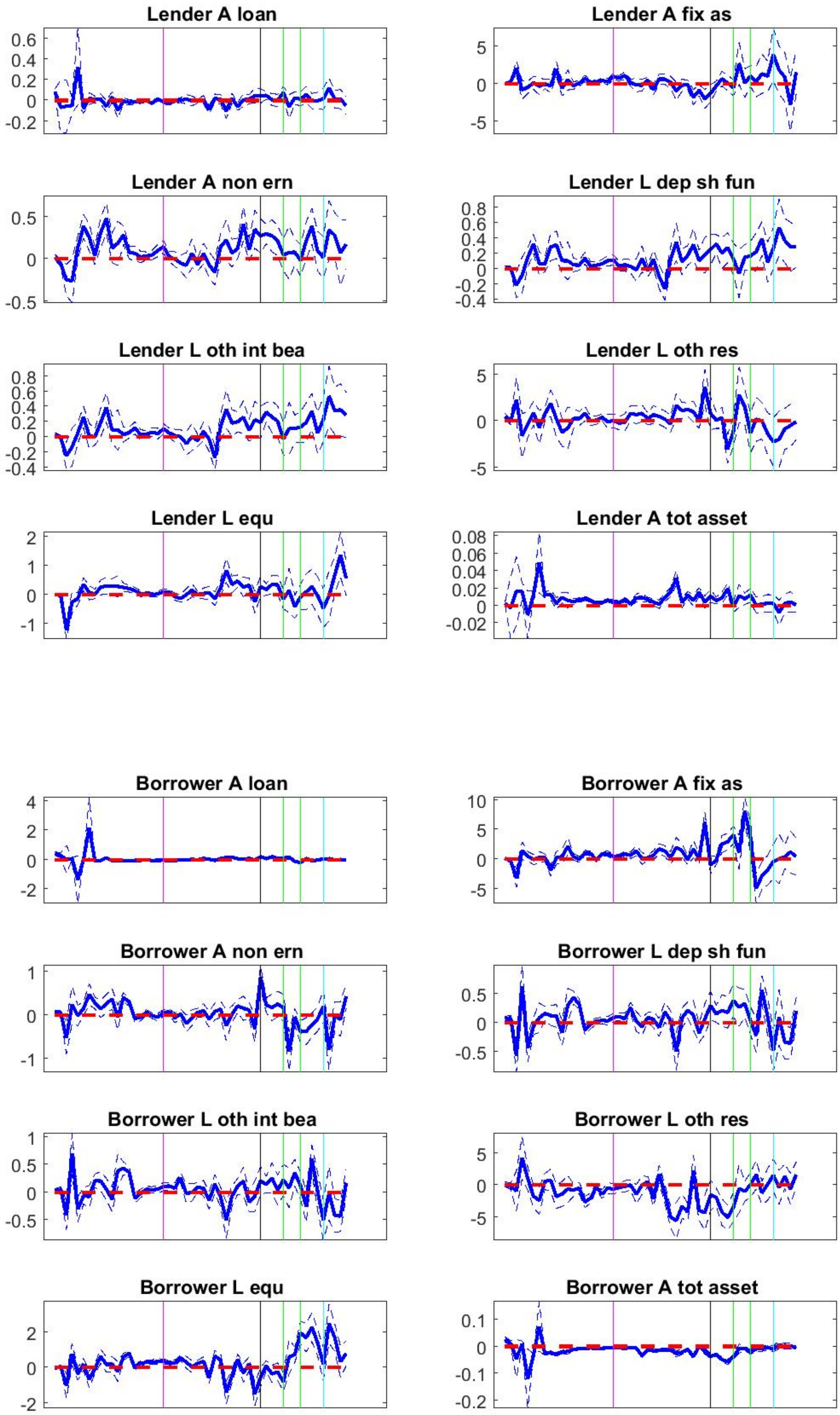
Notes: See Figure 1 and Figure 4. The black line represent the coefficient of the lender Mills ratio λ_L, the violet line represent the coefficient of the borrower Mills ratio λ_B.

Figure 8: Quantity equation - Mills ratios coefficients.



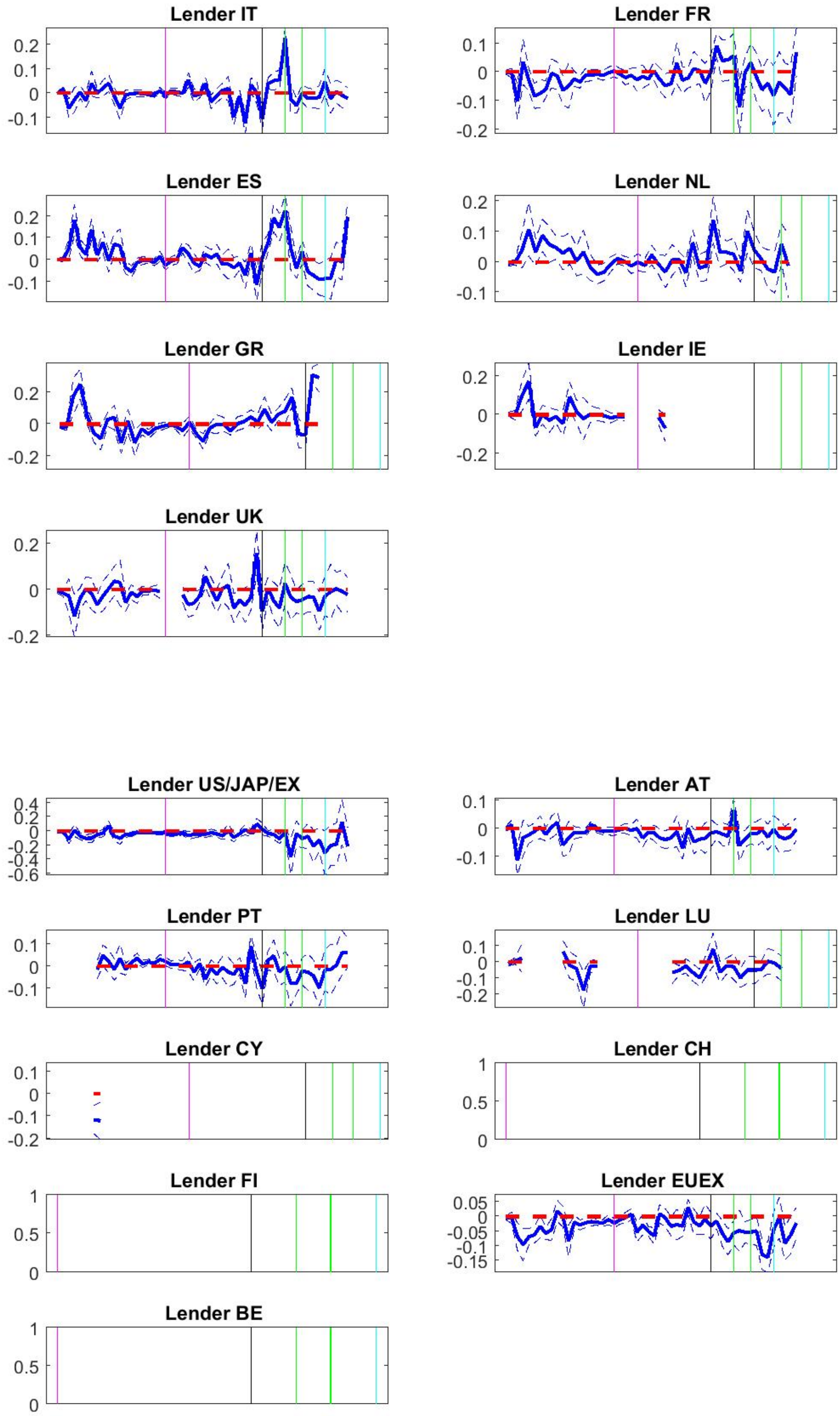
Notes: See Figure 1, Figure 4 and Figure 7.

Figure 9: Rate equation - Lender and borrower balance sheet effects.



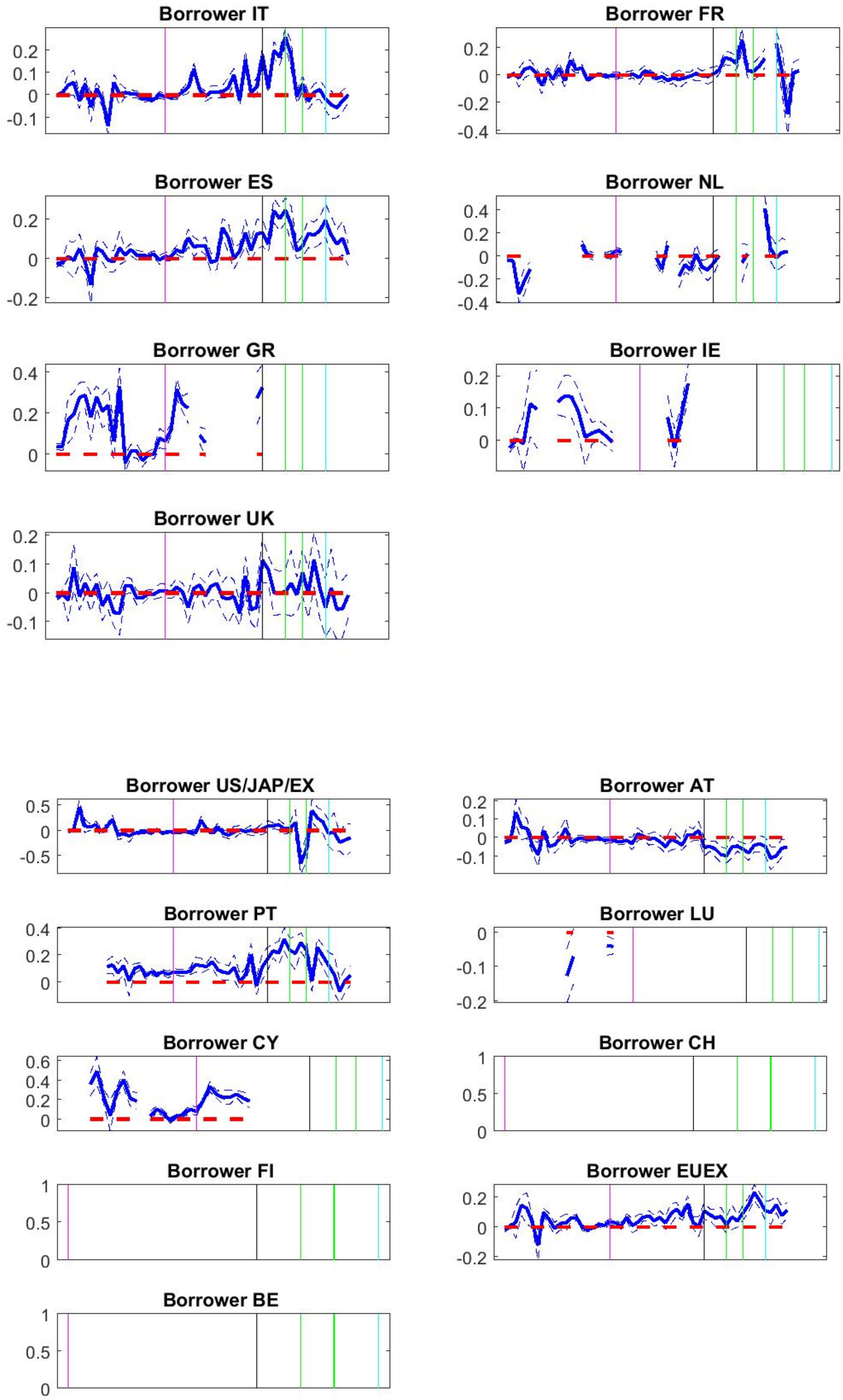
Notes: See Figure 1 and Figure 4. Estimates are obtained using the parametric model described in the Appendix. The bold lines represent repeated cross-section OLS estimates that include the correction terms (lender and borrower Mills ratios). The controls (x) listed in Section 6.2 are on the RHS. The model is estimated including all the covariates.

Figure 10: Rate equation - Lender's country effects.



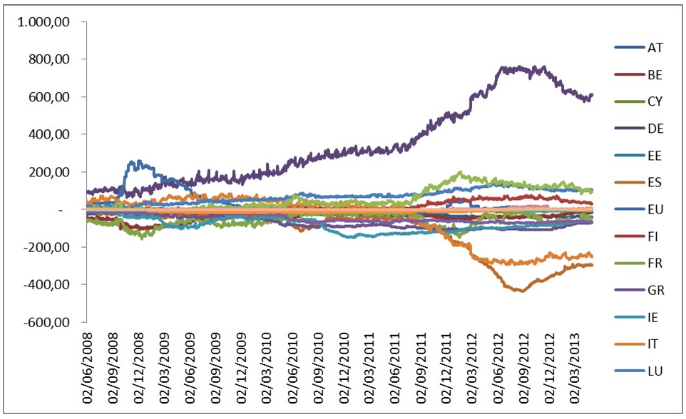
Notes: See Figure 1, Figure 4 and Figure 9. Missing observations may occur if there are no observations with that characteristic.

Figure 11: Rate equation - Borrower's country effects.



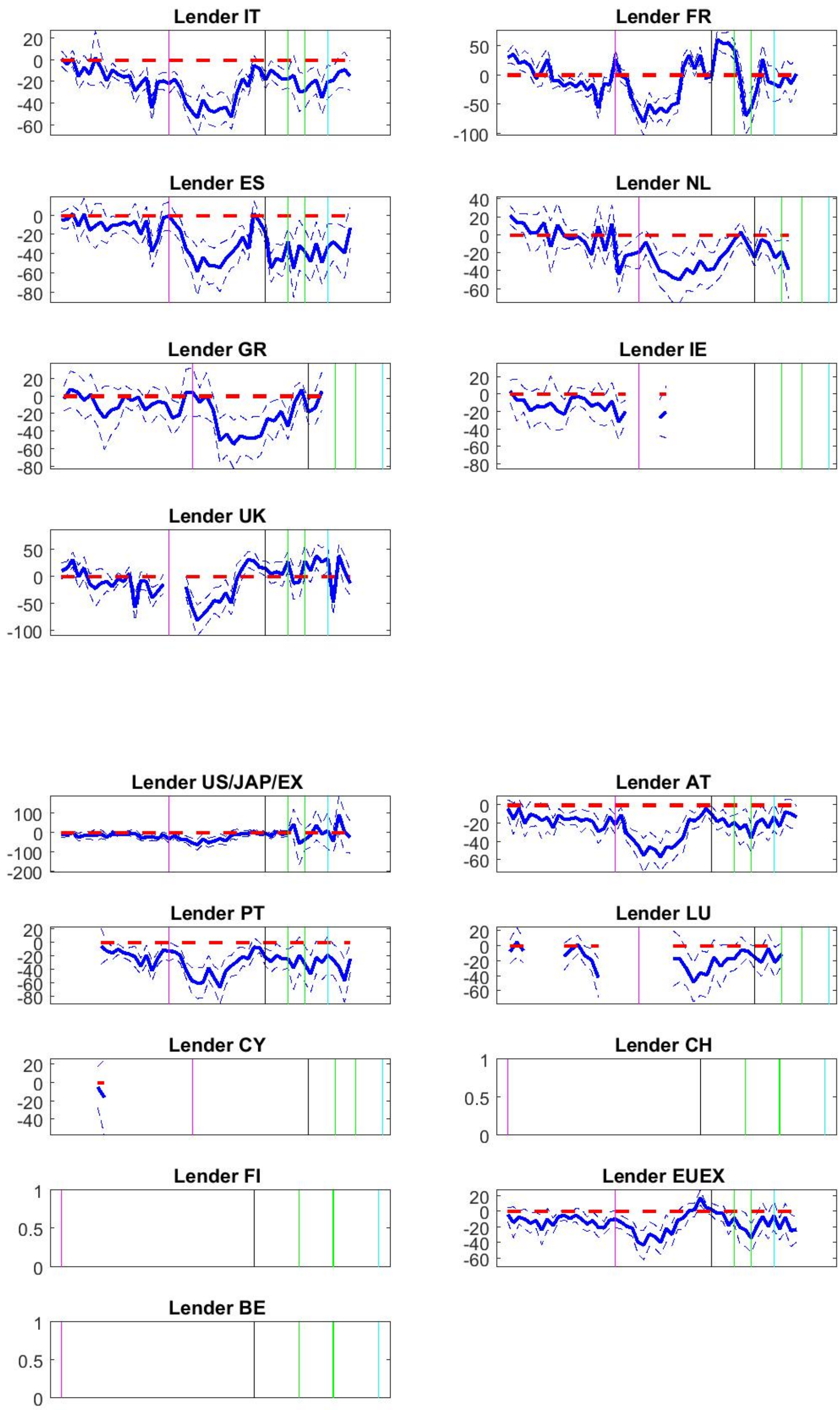
Notes: See Figure 1, Figure 4, Figure 9 and 10.

Figure 12: TARGET2 balances.



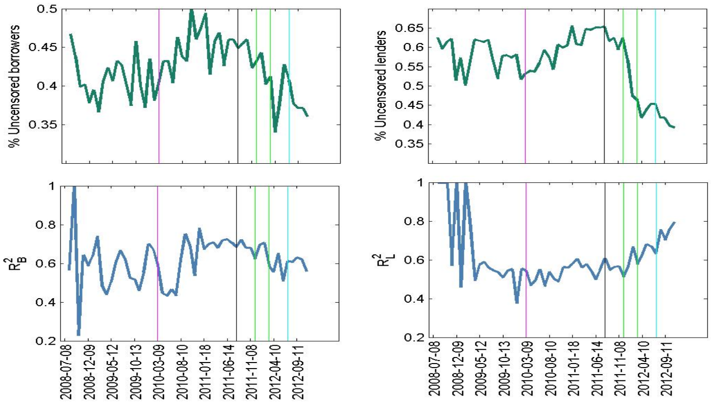
Notes: Daily TARGET2 balances expressed in billions of euro.

Figure 13: Quantity equation - Lender's country effects.



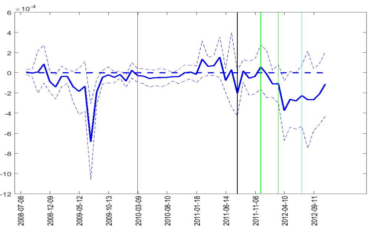
Notes: See Figure 1, Figure 4, Figure 9 and 10.

Figure 14: Rate equation diagnostics - Mills ratios non linearity and percentages of uncensored lenders and borrowers.

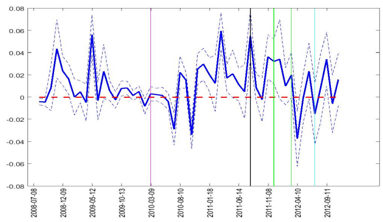


Notes: See Figure 1. The upper panels report the percentage of uncensored borrowers (left) and lenders (right). The lower panels report the R^2 of a regression having the borrower (left) and lender (right) Mills ratios on the LHS and all the controls in the outcome equations (x) on the RHS.

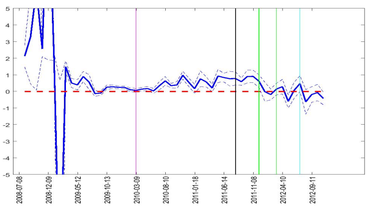
Figure 15: Rate equation - Quantity, previous relationships effects and time FE.



(a) Quantity



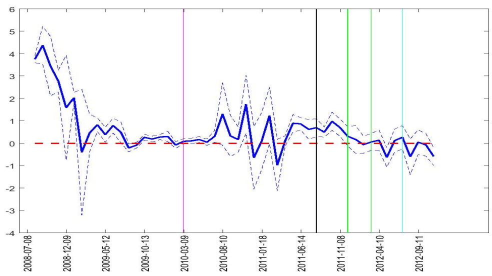
(b) Previous relationship



(c) Time

Notes: See Figure 1, Figure 4, Figure 9 and 10.

Figure 16: Rate equation with semiparametric estimation - Time FEs.



Notes: See Figure 1, Figure 4, Figure 9 and 10.

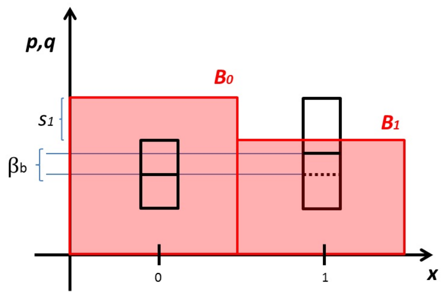
APPENDIX

Appendix A: Three Simple Examples with Unobservables

In this section we provide three simple examples that give insights on the endogeneity issues introduced in Section 5. In the first two, market's sides are treated separately to ease the exposition, in practice both can materialize simultaneously, further exacerbating the selectivity bias.

Endogenous Borrower Searching Costs Suppose we are interested in estimating the marginal effect β_b of a borrower exogenous dummy variable $x_b = \{0, 1\}$ on p_{lb} or q_{lb}. For example x_b takes value 1 if the bank is in country A and 0 otherwise. W.l.o.g assume that the searching costs are different from zero only for banks belonging to country A -i.e. $s_1 > s_0 = 0$- and that ϵ_{lb} is correlated with s_b. Let us focus on rates, the same arguments apply for quantities. Such heterogeneity implies that the distribution of rates for country A borrowers is upper bounded, while for other borrowers is not. It turns out that we observe just a censored distribution of rates for country A borrowers. In the heuristic example provided in Figure A.1, this censoring downward biases the estimated difference between $E(p_{lb}|x_b = 0)$ and $E(p_{lb}|x_b = 1)$ leading it to zero instead of β_b.

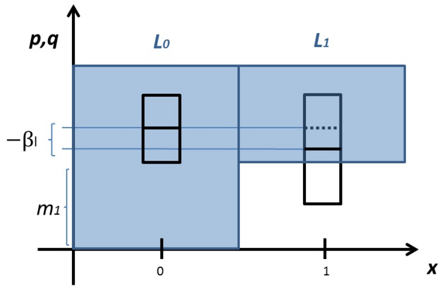
Figure A.1: Borrower Correlated Unobservable Searching Costs.



Notes: Red areas refer to borrowers acceptable regions. The B_1 red area refers to borrowers in country A. The B_0 red area refers to the other borrowers. The box plots represent the distributions of data points conditional on x_b. The middle line represents the true mean while the dotted one represent the biased mean.

Endogenous Lender Monitoring Costs In a specular way we could be interested in estimating the marginal effect β_l of a lander exogenous dummy variable $x_l = \{0, 1\}$ on p_{lb} or q_{lb}. As before, assume x_l takes value 1 if the bank is in country A and 0 otherwise. Assume that the monitoring costs are different from zero for banks belonging to country A and zero for the others -i.e. $m_1 > m_0 = 0$- and that ϵ_{lb} is correlated with m_l. This censoring implies that the distribution of rates for country A lenders is lower bounded, while for other lenders is not. In the example provided in Figure A.2, this censoring upward biases β_l leading it to zero.

Figure A.2: Lender Correlated Unobservable Monitoring Costs.



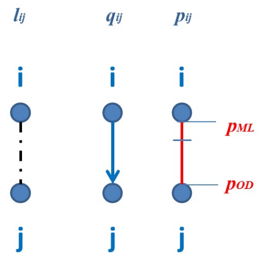
Notes: Blue areas refer to lenders. The L_1 blues area refers to lenders in country A. The L_0 blues area refers to the other lenders. The box plots represent the distributions of data points conditional on x_l. The middle line represents the true mean while the dotted one represent the biased mean.

In general, it is worth to mention that these cost-based unobservables are just two possible sources of endogeneity. Other unobservables may hamper the consistent estimation of the pairwise equations parameters in this environment. Nevertheless, the shadow rates model proposed here is general enough to control for the presence of different types of unobservable, like endogenous intermediation (see Babus and Hu, 2017, for example).

Importantly, we may conduct such an analysis to assess market fragmentation, segregation or integration. If we are interested in understanding whether borrowers from country A systemically pay more, we want a consistent estimate of β_b. Ignoring such endogeneity issue may prevent it.

Endogenous Meeting Process One possible interpretation of our empirical model is as reservation rates in a search process, where banks endogenously meet, match and exchange (Figure A.3). Upon a meeting (say l_{ij} between bank i and bank j), the rate follows according to equation (6). After seeing the rate both parties decide whether to accept the deal or not according to conditions (11). If both accept, i.e. $p^*_{B,j} \geq p_{ij} \geq p^*_{L,i}$, they trade at rate p_{ij} the quantity q_{ij}. Otherwise, they continue meeting other counterparties. Banks that do not find any deal in the market have to go to the central bank's standing facilities and lend at p_{OD} or borrow at p_{ML}. Observe that the meeting does not need to be random, because we allow for possible correlation between unobserved factors affecting the meeting probability and unobservables determining the rate and the quantity exchanged. This feature is particularly appealing for the analysis of OTC interbank markets, where many determinants of meetings, rates and quantities remain unobserved by the econometricians. Furthermore, such unobservables can be correlated among themselves and generate significant bias due to endogenous selection. In the next section we propose a method to deal with this issue and get unbiased estimates for rate and quantity parameters.

Figure A.3: Endogenous meeting process.



Notes: nodes i and j are two banks. The dotted line l_{ij} represents a meeting between i and j, the blue arrow q_{ij} represents the amount and the direction of central bank money exchanged, the blue segment on the red line marks the agreed rate of the loan, the latter is bounded by p_{OD} and p_{ML}.

Appendix B: Estimation

In this section, we propose two possible procedures to consistently estimate the parameters in the empirical model outlined in Section 5. Both apply a control function approach. The first method is parametric, while the second is semiparametric. Such an approach allows also the dyadic model to capture general equilibrium effects of reserves, payment volatility and the effects of market access by some banks.[29]

Parametric Estimation

If we assume that $f(.)$ in (15) is a trivariate normal, $g(p_{lb}, q_{lb})$ becomes a bivariate normal density function and $P(\cdot)$ a bivariate cumulative normal density function in (13),[30] so that the likelihood function is known and has nice properties. Maximizing it brings to consistent, unbiased and efficient parameter estimates. The drawback of ML estimation is that it is computational intensive, in this context we are interested in estimating these parameters for a wide time span, thus ML is excessively time demanding.[31] Heckman (1979) proposed a two step procedure as an alternative way of estimating parameters for this kind of sample selection models. In his model one selection equation determines whether the outcome of an agent is observed or not. In our framework we have two selection equations, one for the lender and one for the borrower, thus the estimation is a little bit more complicated. Poirer (1980) investigated a similar model in which the outcome reflects the choices of two decision-makers in a different context. From this distributional assumption it thus follows that

$$\begin{aligned} E[p_{lb}|s_b = 1, s_l = 1] &= \beta_0 + \beta_1 x_{lb} + \alpha q_{lb} \\ &+ \frac{\sigma_{\epsilon v_B}}{\sigma^2_{v_B}} \frac{\phi(\kappa^* r_b)\Phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})} \\ &+ \frac{\sigma_{\epsilon v_L}}{\sigma^2_{v_L}} \frac{\phi(\omega^* r_l)\Phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})}, \end{aligned} \tag{17}$$

[29]Technically, it is made possible by conditioning on r_l, r_b, $u_{L,l}$ and $u_{B,b}$ that can contain these endogenous variables.

[30]Note that given that the condition $p^*_{B,b} \geq p_{lb} \geq p^*_{L,l}$ can be represented as an interval of real numbers in $\Re$, $P(\cdot)$ can be computed as the difference of two univariate cumulative normal density functions.

[31]We also estimated the model using ML for one MP, results are available upon request.

where $\omega^* = \frac{1}{\sigma_{v_B}}\omega$, $\kappa^* = \frac{1}{\sigma_{v_L}}\kappa$. One way to estimate this system, is to run a bivariate probit in the first step. Using a Maximum Likelihood estimator one can simultaneously estimate the parameters of both the selection equations as well as the correlation between the two errors ($\sigma_{v_B v_L}$). Another way is to estimate separately the two selection equations, in a quasi-maximum likelihood approach, ignoring the correlation between the residuals. After this step one can estimate $\sigma_{v_B v_L}$ computing the correlation between the generalized residuals (Gourieroux et al., 1987). The OLS brings to consistent parameter estimates of the following model

$$p_{lb} = \beta_0 + \beta_l x_l + \beta_b x_b + \alpha q_{lb} + \delta_B \hat{\lambda}_B + \delta_L \hat{\lambda}_L + \epsilon_{lb} \tag{18}$$

where $\hat{\lambda}_B$ and $\hat{\lambda}_L$ are consistent estimates of $\lambda_B = \frac{\phi(\kappa^* r_b)\Phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})}$, $\lambda_L = \frac{\phi(\omega^* r_l)\Phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})}$, the two multivariate Mills ratios, $\hat{\delta}_B = \frac{\hat{\sigma}_{\epsilon v_B}}{\hat{\sigma}^2_{v_B}}$ and $\delta_L = \frac{\sigma_{\epsilon v_L}}{\sigma^2_{v_L}}$. Details about how to derive and estimate the relative consistent standard errors are provided in Appendix B. Observe that a FIML method can be also used to estimate the parametric model.

Consistent Parametric Standard Errors Let us focus on the errors' conditional variance for the rate equation. Specular derivations can be done for the quantity equation, they are omitted for brevity. From system (15) and the normality assumption we have that

$$\begin{aligned} \tilde{\sigma}_{\epsilon,bl} &= E(\epsilon_i^2 | s_l = 1, s_b = 1) = \sigma^2_\epsilon - \sigma^2_{\epsilon,v_B}\kappa^* r_b \lambda_L - \sigma^2_{\epsilon,v_L}\omega^* r_l \lambda_B \\ &+ \nu_{lb}[2\sigma_{\epsilon,v_B}\sigma_{\epsilon,v_L} - \sigma_{v_L,v_B}(\sigma^2_{\epsilon,v_B} + \sigma^2_{\epsilon,v_L})] - (\sigma_{\epsilon,v_B}\lambda_L - \sigma_{\epsilon,v_L}\lambda_B)^2 \\ &= \sigma_{\epsilon,i} + \zeta_{lb}, \end{aligned} \tag{19}$$

where $\nu_{lb} = \phi(\kappa^* r_b, \omega^* r_l, \sigma_{v_B,v_L})/\Phi(\kappa^* r_b, \omega^* r_l, \sigma_{v_B,v_L})$, so that the following is the estimator of σ_ϵ.

$$\hat{\sigma}_\epsilon = \frac{1}{N_u}(\sum_{bl \in U} d_{lb} - \hat{\zeta_{lb}}). \tag{20}$$

where d_{lb} are the estimated residual by OLS of model. Let us call $\tilde{\Sigma}$ the diagonal matrix containing these variances. The correct variance-covariance matrix for the estimated parameters is obtained in the following way. Given the double selection mechanism, the residuals of equation (6) are

$$e_{lb} = \delta_B(\lambda_B - \hat{\lambda}_B) + \delta_L(\lambda_L - \hat{\lambda}_L) + \epsilon_{lb} \tag{21}$$

Let $\tau = (\kappa^*, \omega^*, \rho_{v_B v_L})$ and take the fist-order approximation of $\hat{\lambda}_B$ and $\hat{\lambda}_L$

$$(\lambda_{B,i} - \hat{\lambda_{B,i}}) = \frac{\partial \lambda_{B,i}}{\partial \tau}(\tau - \hat{\tau}) \tag{22}$$

$$(\lambda_{L,i} - \hat{\lambda_{L,i}}) = \frac{\partial \lambda_{L,i}}{\partial \tau}(\tau - \hat{\tau}) \tag{23}$$

Let $X^* = (\iota, x_l, x_b, \hat{\lambda}_B, \hat{\lambda}_L)$, $\beta^* = (\beta_0, \beta_l, \beta_b, \delta_B, \delta_L)$ and $C_i = (\delta_B \frac{\partial \lambda_{B,i}}{\partial \tau} + \delta_L \frac{\partial \lambda_{L,i}}{\partial \tau})$, then

$$(\hat{\beta}^* - \beta^*) = (X^{*'} X^*)^{-1}(X^{*'} e_{lb}) = (X^{*'} X^*)^{-1}(\epsilon_{lb} + C(\tau - \hat{\tau})), \tag{24}$$

then we have the following variances for each parameter:

$$\begin{aligned} diag(var(\hat{\beta}^*)) &= (X^{*'}X^*)^{-1}X^{*'}(\tilde{\Sigma}+C\ var(\hat{\tau})C')X^*(X^{*'}X^*)^{-1} \\ &= (X^{*'}X^*)^{-1}(X^{*'}\tilde{\Sigma}X^*+X^{*'}C\ var(\hat{\tau})C'X^*)(X^{*'}X^*)^{-1} \end{aligned} \tag{25}$$

For computing this matrix we need $C = (\delta_B \frac{\partial\lambda_B}{\partial\tau} + \delta_L \frac{\partial\lambda_L}{\partial\tau})$, a $N_u \times 2k+1$, where k is the dimension of r_b and r_l (suppose it is the same), and consequently $\frac{\partial\lambda_B}{\partial\tau}$ and $\frac{\partial\lambda_L}{\partial\tau}$. Given that

$$\lambda_B = \frac{\phi(\kappa^* r_b)\Phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})},$$

$$\lambda_L = \frac{\phi(\omega^* r_l)\Phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})}.$$

We just need to compute the following partial derivatives. The first k columns of C are given by $\delta_B \frac{\partial\lambda_B}{\partial\kappa^*} + \delta_L \frac{\partial\lambda_L}{\partial\kappa^*}$, where

$$\begin{aligned} \frac{\partial\lambda_B}{\partial\kappa^*} &= \frac{\kappa^* r_b\phi(\cdot)\Phi(\cdot) - r_b\rho_{v_B v_L}/(1-\rho^2_{v_B v_L})^{\frac{1}{2}}\phi(\cdot)\phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\cdot)} - \frac{\Phi_{ns}(\omega^* r_l, \rho_{v_B v_L}\kappa^* r_b, (1-\rho^2_{v_B v_L}))\phi(\cdot)\Phi(\cdot)}{[\mathbf{\Phi}^2(\cdot)]^2} \\ &= \lambda_B(\kappa^* r_b - r_b\rho_{v_B v_L}/(1-\rho^2_{v_B v_L})^{\frac{1}{2}}\frac{\phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\Phi(\cdot)} - \frac{\Phi_{ns}(\omega^* r_l, \rho_{v_B v_L}\kappa^* r_b, (1-\rho^2_{v_B v_L}))}{[\mathbf{\Phi}^2(\cdot)]}) \end{aligned}$$

because from normal distribution properties we have

$$\frac{\partial\phi(\kappa^* r_b)}{\partial\kappa^*} = \kappa^* r_b\phi(\kappa^* r_b),$$

$$\frac{\partial\Phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\partial\kappa^*} = \frac{\partial\Phi(t)}{\partial t}\frac{\partial t}{\partial\kappa^*} = \phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})r_l/(1-\rho^2_{v_B v_L}),$$

$$\frac{\partial\mathbf{\Phi}^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})}{\partial\kappa^*} = \frac{\partial}{\partial\kappa^*}\int_{-\infty}^{\omega^* r_l}[\int_{-\infty}^{\kappa^* r_b}\phi(a,b,\rho_{v_B v_L})db]da = \int_{-\infty}^{\kappa^* r_b}\phi(\omega^* r_l, b, \rho_{v_B v_L})db = \Phi_{ns}(\kappa^* r_b, \rho_{v_B v_L}\omega^* r_l, (1-\rho^2_{v_B v_L})),$$

where $\Phi_{ns}(\cdot)$ is a non standardized normal cdf. Following the same rules we have

$$\begin{aligned} \frac{\partial\lambda_L}{\partial\kappa^*} &= \frac{r_b/(1-\rho^2_{v_B v_L})^{\frac{1}{2}}\phi(\cdot)\phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\cdot)} - \frac{\Phi_{ns}(\omega^* r_l, \rho_{v_B v_L}\kappa^* r_b, (1-\rho^2_{v_B v_L}))\phi(\cdot)\Phi(\cdot)}{[\mathbf{\Phi}^2(\cdot)]^2} \\ &= \lambda_L(r_b/(1-\rho^2_{v_B v_L})^{\frac{1}{2}}\frac{\phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\Phi(\cdot)} - \frac{\Phi_{ns}(\omega^* r_l, \rho_{v_B v_L}\kappa^* r_b, (1-\rho^2_{v_B v_L}))}{[\mathbf{\Phi}^2(\cdot)]}). \end{aligned}$$

The second k columns of C are given by $\delta_B \frac{\partial\lambda_B}{\partial\omega^*} + \delta_L \frac{\partial\lambda_L}{\partial\omega^*}$, where

$$\begin{aligned} \frac{\partial\lambda_B}{\partial\omega^*} &= \frac{r_l/(1-\rho^2_{v_B v_L})^{\frac{1}{2}}\phi(\cdot)\phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\cdot)} - \frac{\Phi_{ns}(\kappa^* r_b, \rho_{v_B v_L}\omega^* r_l, (1-\rho^2_{v_B v_L}))\phi(\cdot)\Phi(\cdot)}{[\mathbf{\Phi}^2(\cdot)]^2} \\ &= \lambda_B(r_l/(1-\rho^2_{v_B v_L})^{\frac{1}{2}}\frac{\phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\Phi(\cdot)} - \frac{\Phi_{ns}(\kappa^* r_b, \rho_{v_B v_L}\omega^* r_l, (1-\rho^2_{v_B v_L}))}{[\mathbf{\Phi}^2(\cdot)]}), \end{aligned}$$

and

$$\begin{aligned}
\frac{\partial \lambda_L}{\partial \omega^*} &= \frac{\omega^* r_l \phi(\cdot)\Phi(\cdot) - r_l \rho_{v_B v_L}/(1-\rho^2_{v_B v_L})^{\frac{1}{2}}\phi(\cdot)\phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\cdot)} - \frac{\Phi_{ns}(\kappa^* r_b, \rho_{v_B v_L}\omega^* r_l, (1-\rho^2_{v_B v_L}))\phi(\cdot)\Phi(\cdot)}{[\mathbf{\Phi}^2(\cdot)]^2} \\
&= \lambda_L(\omega^* r_l - r_l \rho_{v_B v_L}/(1-\rho^2_{v_B v_L})^{\frac{1}{2}}\frac{\phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\Phi(\cdot)} - \frac{\Phi_{ns}(\kappa^* r_b, \rho_{v_B v_L}\omega^* r_l, (1-\rho^2_{v_B v_L}))}{[\mathbf{\Phi}^2(\cdot)]}).
\end{aligned}$$

The last column of C are given by $\delta_B \frac{\partial \lambda_B}{\partial \rho_{v_B v_L}} + \delta_L \frac{\partial \lambda_L}{\partial \rho_{v_B v_L}}$ where

$$\begin{aligned}
\frac{\partial \lambda_L}{\partial \rho_{v_B v_L}} &= \frac{\rho_{v_B v_L}(1-\rho^2_{v_B v_L})^{-\frac{1}{2}}[(1-\rho^2_{v_B v_L})^{-1}(\omega^* r_l - \kappa^* r_b \rho_{v_B v_L}) - \kappa^* r_b 1/\rho_{v_B v_L}]\phi(\cdot)\phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\cdot)} \\
&- \frac{\phi^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})\phi(\cdot)\Phi(\cdot)}{[\mathbf{\Phi}^2(\cdot)]^2} \\
&= \lambda_L(\rho_{v_B v_L}(1-\rho^2_{v_B v_L})^{-\frac{1}{2}}[(1-\rho^2_{v_B v_L})^{-1}(\omega^* r_l - \kappa^* r_b \rho_{v_B v_L}) - \kappa^* r_b 1/\rho_{v_B v_L}]\frac{\phi((\kappa^* r_b - \rho_{v_B v_L}\omega^* r_l)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\Phi(\cdot)} \\
&- \frac{\phi^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})}{[\mathbf{\Phi}^2(\cdot)]}),
\end{aligned}$$

given that

$$\begin{aligned}
&\frac{\partial \Phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\partial \rho_{v_B v_L}} = \frac{\partial \Phi(t)}{\partial t}\frac{\partial t}{\partial \rho_{v_B v_L}} \\
= \;&\phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})\rho_{v_B v_L}(1-\rho^2_{v_B v_L})^{\frac{1}{2}}[\omega^* r_l(1-\rho^2_{v_B v_L})^{-1} - \kappa^* r_b \frac{1}{\rho_{v_B v_L}} - \kappa^* r_b \rho_{v_B v_L}(1-\rho^2_{v_B v_L})^{-1}],
\end{aligned}$$

$$\frac{\partial \mathbf{\Phi}^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})}{\partial \rho^2_{v_B v_L}} = \phi^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L}),$$

from Plackett (1945), and

$$\begin{aligned}
\frac{\partial \lambda_L}{\partial \rho_{v_B v_L}} &= \frac{\rho_{v_B v_L}(1-\rho^2_{v_B v_L})^{-\frac{1}{2}}[(1-\rho^2_{v_B v_L})^{-1}(\kappa^* r_b - \omega^* r_l \rho_{v_B v_L}) - \omega^* r_l 1/\rho_{v_B v_L}]\phi(\cdot)\phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\mathbf{\Phi}^2(\cdot)} \\
&- \frac{\phi^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})\phi(\cdot)\Phi(\cdot)}{[\mathbf{\Phi}^2(\cdot)]^2} \\
&= \lambda_L(\rho_{v_B v_L}(1-\rho^2_{v_B v_L})^{-\frac{1}{2}}[(1-\rho^2_{v_B v_L})^{-1}(\kappa^* r_b - \omega^* r_l \rho_{v_B v_L}) - \omega^* r_l 1/\rho_{v_B v_L}]\frac{\phi((\omega^* r_l - \rho_{v_B v_L}\kappa^* r_b)/(1-\rho^2_{v_B v_L})^{\frac{1}{2}})}{\Phi(\cdot)} \\
&- \frac{\phi^2(\kappa^* r_b, \omega^* r_l, \rho_{v_B v_L})}{[\mathbf{\Phi}^2(\cdot)]}).
\end{aligned}$$

Plugging in the consistently estimated parameters allow us to have consistent standard errors as well.

Semiparametric Estimation

So far we assumed that the joint distribution of unobservables is normal. Nevertheless, in financial phenomena it is sometimes hard to assume shocks' normality. In this section we outline a procedure to control for selectivity without imposing any distributional assumption. The asymptotic properties of the two-step estimator for semiparametric sample selection models have been derived by Newey (2009). His estimator works as the theoretical basis for ours. A notable application of semiparametric methods with multi-choice selection is Dahl (2002).

From system (15) without the normality assumption we have that

$$E[p_{lb}|s_b = 1, s_l = 1] = \beta_0 + \beta_1 x_{lb} + \alpha q_{lb} + \psi(m_{lb}), \tag{26}$$

where

$$\psi(m_{lb}) = E(\epsilon_{lb}|s_b = 1, s_l = 1) = E(\epsilon_{lb}|\omega, \kappa, r_l, r_b),$$

is an unknown function. Thus, equation (26) implies that the mean of the outcome disturbances depends only on $m_{lb} = m(\omega, \kappa, r_l, r_b)$ conditional on the selection process, where $m(.)$ is an unknown function.[32] If we assume normality, the function $\psi(m_{lb})$ becomes the multivariate inverse Mills ratio. The term is a generalization of the correction term considered by Heckman and Robb (1985). Let us define $\tau(m, \eta)$ as a strictly monotonic transformation of each entry of the index m, depending on the parameter η. Let $P^K(\tau) = (P_{1K}(\tau), \ldots, P_{KK}(\tau))'$ be a vector of functions such that for large values of K a linear combination of $P^K(\tau)$ can approximate an unknown function of $\tau(\cdot)$. Let $\hat{\tau_{lb}} = \tau(\hat{m_{lb}}, \hat{\eta})$ and $\hat{p_i} = P^K(\hat{\tau_{lb}})$. Let us assume also that the approximating functions are power series given by $P_{kK}(\tau) = \tau^{k-1}$.[33] Thus, we can write model (26) as

$$E[p_{lb}|s_b = 1, s_l = 1] = \beta_0 + \beta_1 x_{lb} + \alpha q_{lb} + \sum_{k=1}^{q} \gamma_k \tau_{lb}^{k-1}. \tag{27}$$

In practice, to consistently estimate the parameters of this equation, we obtain $\hat{\tau_{lb}}$ from the first step using a fully parametric specification or distribution-free estimators that are available in the literature, including those of Manski (1975), Cosslett (1983), Powell et al. (1989), Ichimura (1993), Klein and Spady (1993) and Khan (2013). We then plug in those estimates in the second step, approximating the unknown conditional expected value of disturbances. See Newey (2009) for the asymptotics and the standard errors computation of such estimators.

[32] This restriction is implied by the assumption of independence between disturbances and regressors.

[33] Other approximating functions can be used. Spline approximation can be used as approximating functions. See, e.g. Newey (2009).

Appendix C: Estimation with False Positive

The data used in this paper are actually the output from an algorithm, as detailed in Arciero et al. (2016). To test the accuracy of their algorithm, they compare the output of this algorithm to a variety of statistics on unsecured interbank lending. They estimate that the type I error of the algorithm is quite low, meaning that the algorithm captures almost all of the interbank loans settled over TARGET2. The type II error is estimated to be larger, meaning that the algorithm is finding more interbank loans. Armantier and Copeland (2012) find similar results when testing a similar algorithm using U.S. payments data. In what follows we outline the assumptions needed for consistency using data from this algorithm. To simplify the notation, let us suppress the bilateral subscript lb and consider only the covariates. The rate equation in vector terms then becomes

$$P = \beta_0 + \beta_1 X + \epsilon, \tag{28}$$

Suppose loans can be split in true and false, then $P = [P_T'; P_F']'$ and $X = [X_T'; X_F']'$ and

$$P_T = \beta_{0,T} + \beta_{1,T} X_T + \epsilon_T, \tag{29}$$

$$P_F = \beta_{0,F} + \beta_{1,F} X_F + \epsilon_F, \tag{30}$$

For $\hat{\beta}_{OLS}$ to be a consistent estimator of $\beta_T = [\beta_{0,T}'; \beta_{0,F}']'$ we need the following assumptions.

A1 $\beta_F = \beta_T$

A2 $E(X_T \epsilon_T) = E(X_F \epsilon_F) = 0$

If the algorithm is randomly picking false loans across pairs of banks, it is plausible to think that the relationship between X, Y and ϵ is not structurally different between the true loans subpopulation and the whole sample. Nevertheless, A1 and A2 are less strong assumptions. Under these assumptions, picking systematically a pair of banks in the sample, when they do not exchange money, does not imply a bias *per se*. A1 and A2 allow for systematic inclusion of pairs of banks in the sample as long as they are associated with random rates. Bias emerges when the pair is systematically wrongly included and associated with non random rates. For example if bank A and bank B are systematically included with high rates. If A and B are wrongly included but rates are drawn randomly, $\hat{\beta}_{OLS}$ is not biased.[34] From our viewpoint, it is difficult to find a priori an argument for false loans systematically associating rates and banks characteristics in a biased way. We thus believe that A1 and A2 are plausible in our context. Furthermore, we aggregate loans across the maintenance period, thus our variables are less prone to measurement error. In the empirical analysis we also show that selection bias is not a big issue for our sample, an evidence that supports randomness in measurement error. In addition, the estimated coefficients are in line with the findings in other studies, see Section 6.

[34] In such a case only standard errors are upward biased, but this eventually works against finding significant marginal effects, thus leaning on the safe side.

Appendix D: MP1 and MP2 Selection Equations

Tables D.1 - D.4 describe the first steps, showing the results for the likelihood to trade as a borrower or lender -i.e. the selection of the counterparty-. This is the information that we use to control for the selectivity bias in rates and quantities. For the sake of brevity we comment only on Tables D.1 and D.2, which report respectively on the borrower and lender selection equations in MP1. The probability of engaging the market is modeled with a probit link as described in Appendix B.[35]

From Table D.1 we can see that having borrowed from a higher number of counterparts increases the probability of being a borrower significantly. Big and well-capitalized banks are more likely to borrow money. Having more fixed (and thus less liquid) assets makes more likely a bank borrow in the money market. On average, it is more likely to observe Italian borrowers, while it is less likely that they are French, Spanish, Dutch, Irish, English, Belgian or from outside the EU.[36]

On the supply side, Table D.2 reports that banks are more likely to lend if they have lent to an higher number of counterparts and less likely if they lent more in the past. Banks with more deposits and short-term funding or other interest bearing liabilities are less likely to operate as lenders. Nationality seems to matter less, only Italian lenders are more frequent while French ones are less.

[35] Results obtained with a bivariate probit are almost identical to the ones from two independent probit estimates.

[36] The reference country is Germany.

Table D.1: Borrower selection equation MP1

Dependent Variable: borrower bilateral trade		
Borrowing rate at $t-1$	-0.2623	
	(0.5147)	
Borrowed value at $t-1$	0.000	
	(0.0000)	
Borrower's counterparts at $t-1$	0.0021***	
	(0.0004)	
	Own	Counterpart
A loan	-0.0042**	-0.0035***
	(0.0013)	(0.0013)
A fix as	0.1677***	0.0664**
	(0.0278)	(0.0279)
A non ern	0.0001	-0.0064*
	(0.0039)	(0.0039)
L dep sh fun	0.0023	-0.0051
	(0.0045)	(0.0045)
L oth int bea	-0.0020	-0.0054
	(0.0046)	(0.0047)
L oth res	0.0087	-0.0123
	(0.0147)	(0.0147)
L equ	0.0249***	-0.0024
	(0.0062)	(0.0062)
A tot asset	0.0037***	0.0001
	(0.0002)	(0.0002)
IT	0.0194***	0.0060***
	(0.0009)	(0.0010)
FR	-0.0100***	0.0019
	(0.0015)	(0.0015)
ES	-0.0047***	-0.0021*
	(0.0012)	(0.0012)
NL	-0.0065***	-0.0010
	(0.0013)	(0.0013)
GR	-0.0016	0.0015
	(0.0016)	(0.0016)
IE	-0.0080***	-0.0060***
	(0.0023)	(0.0023)
UK	-0.0097***	-0.0027
	(0.0021)	(0.0021)
US/JAP/EX	-0.0071***	-0.0010
	(0.0016)	(0.0016)
AT	0.0009	0.0018
	(0.0011)	(0.0012)
PT	0.0005	-0.0014
	(0.0014)	(0.0014)
LU	-0.0030	-0.0015
	(0.0022)	(0.0022)
CY	0.0046**	0.0009
	(0.0022)	(0.0022)
CH	-0.0148***	0.0012
	(0.0029)	(0.0029)
FI	-0.0024	0.0008
	(0.0023)	(0.0023)
EUEX	-0.0035***	-0.0003
	(0.0009)	(0.0009)
BE	-0.0093***	-0.0001
	(0.0022)	(0.0023)
Constant	-0.0328***	
	(0.0071)	
Time interval	2010-01-20 - 2010-02-09	
Maturity	1 to 3 days	
Observations	124962	

Notes: * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Only country fixed effects with more than 1% of observations are included in the model. The time interval is a maintenance period, $t-1$ refers to the previous time interval. A stands for assets, L for liabilities. Country fixed effects are reported using the usual labels, EX means other foreign countries w.r.t. the eurozone, EUEX means other countries in the eurozone that are not included with individual fixed effects.

Table D.2: Lender selection equation MP1

Dependent Variable: lender bilateral trade at time t		
Lending rate at $t-1$	0.1335	
	(0.4743)	
Lent value at $t-1$	-0.0001***	
	(0.0000)	
Lender's counterparts at $t-1$	0.0020***	
	(0.0004)	
	Own	Counterpart
A loan	0.0012	-0.0035***
	(0.0013)	(0.0013)
A fix as	-0.0453	0.1184 ***
	(0.0291)	(0.0277)
A non ern	-0.0047	-0.0048
	(0.0039)	(0.0039)
L dep sh fun	-0.0111**	-0.0029
	(0.0045)	(0.0045)
L oth int bea	-0.0131***	-0.0080*
	(0.0046)	(0.0046)
L oth res	-0.0228	0.0005
	(0.0146)	(0.0146)
L equ	-0.0077	0.0091
	(0.0062)	(0.0062)
A tot asset	-0.0000	0.0020 ***
	(0.0002)	(0.0002)
IT	0.0075 ***	0.0209 ***
	(0.0010)	(0.0009)
FR	-0.0042***	-0.0003
	(0.0015)	(0.0015)
ES	-0.0000	-0.0009
	(0.0012)	(0.0012)
NL	-0.0009	-0.0019
	(0.0013)	(0.0013)
GR	0.0021	0.0031 *
	(0.0016)	(0.0016)
IE	-0.0015	-0.0039*
	(0.0023)	(0.0023)
UK	0.0018	-0.0060***
	(0.0021)	(0.0021)
US/JAP/EX	-0.0001	-0.0053***
	(0.0016)	(0.0016)
AT	0.0009	0.0054***
	(0.0012)	(0.0011)
PT	0.0005	0.0030**
	(0.0014)	(0.0014)
LU	0.0032	-0.0024
	(0.0022)	(0.0022)
CY	0.0019	-0.0002
	(0.0022)	(0.0022)
CH	0.0009	-0.0005
	(0.0029)	(0.0029)
FI	0.0007	-0.0021
	(0.0023)	(0.0022)
EUEX	0.0001	-0.0004
	(0.0009)	(0.0009)
BE	0.0007	-0.0071***
	(0.0022)	(0.0022)
Constant	-0.0075	
	(0.0071)	
Time interval	2010-01-20 - 2010-02-09	
Maturity	1 to 3 days	
Observations	124962	

Notes: See Table D.1.

Table D.3: Borrower selection equation MP2

Dependent Variable: borrower bilateral trade at time t		
Borrowing rate at $t-1$	-1.6495 ***	
	(0.2030)	
Borrowed value at $t-1$	0.0000	
	((0.0000))	
Borrower's counterparts at $t-1$	0.0088 ***	
	(0.0007)	
	Own	Counterpart
A loan	0.0016	-0.0003
	(0.0015)	(0.0014)
A fix as	0.0301	-0.0009
	(0.0256)	(0.0244)
A non ern	0.0042	-0.0022
	(0.0040)	(0.0040)
L dep sh fun	0.0032	0.0025
	(0.0045)	(0.0045)
L oth int bea	-0.0021	-0.0061
	(0.0047)	(0.0047)
L oth res	0.0144	-0.0005
	(0.0167)	(0.0166)
L equ	0.0079	0.0030
	(0.0063)	(0.0062)
A tot asset	0.0010 ***	0.0023 ***
	(0.0002)	(0.0002)
IT	0.0014	0.0191 ***
	(0.0010)	(0.0010)
FR	-0.0039 **	0.0019
	(0.0016)	(0.0016)
ES	0.0002	0.0028 **
	(0.0013)	(0.0013)
NL	0.0009	-0.0028 *
	(0.0015)	(0.0015)
GR	-0.0006	0.0003
	(0.0018)	(0.0017)
IE	0.0039	0.0065 ***
	(0.0025)	(0.0024)
UK	-0.0090 ***	-0.0073 ***
	(0.0023)	(0.0023)
US/JAP/EX	-0.0012	-0.0038 **
	(0.0017)	(0.0017)
AT	0.0028 **	0.0035 ***
	(0.0012)	(0.0012)
PT	0.0024	0.0004
	(0.0016)	(0.0016)
LU	0.0002	-0.0007
	(0.0024)	(0.0024)
CY	0.0010	-0.0016
	(0.0024)	(0.0024)
EUEX	-0.0014	-0.0034
	(0.0031)	(0.0031)
FI	0.0029	-0.0038
	(0.0024)	(0.0024)
EUEX	0.0007	0.0018 *
	(0.0010)	(0.0010)
BE	-0.0007	-0.0095 ***
	(0.0024)	(0.0024)
Constant	-0.0377 ***	
	(0.0072)	
Time interval	2009-02-11 - 2009-03-10	
Maturity	1 to 3 days	
Observations	123552	

Notes: See Table D.1.

Table D.4: Lender selection equation MP2

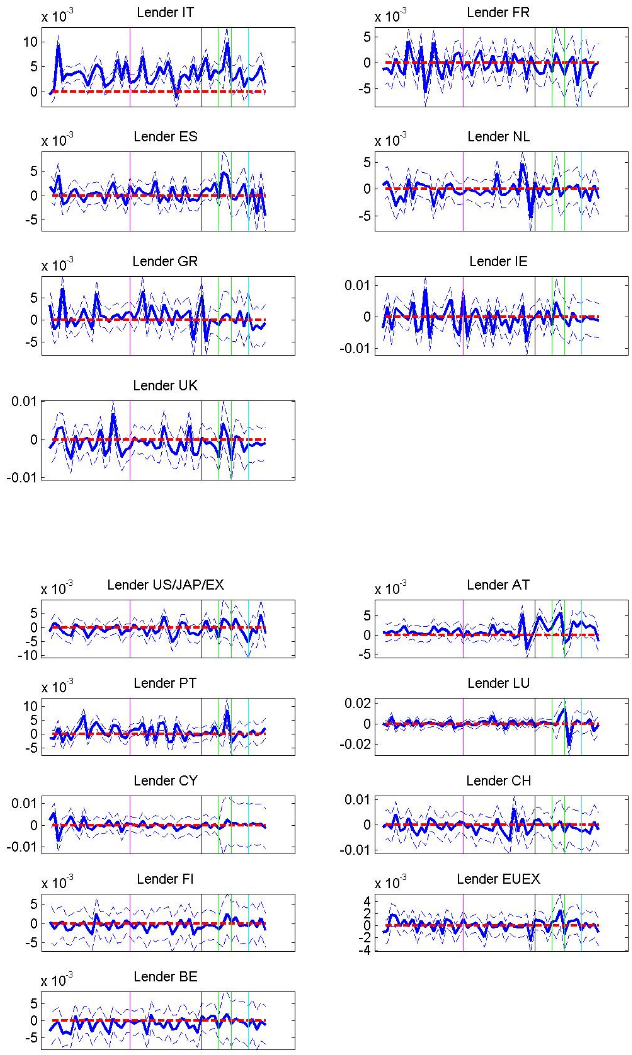
Dependent Variable: lender bilateral trade		
Lending rate at $t-1$	0.4553	
	(0.2817)	
Lent value at $t-1$	0.0000 ***	
	(0.0000)	
Lender's counterparts at $t-1$	0.0011	
	(0.0009)	
	Own	Counterpart
A loan	-0.0016	-0.0041 ***
	(0.0015)	(0.0014)
A fix as	-0.0024	0.2570 ***
	(0.0246)	(0.0246)
A non ern	-0.0015	0.0007
	(0.0040)	(0.0040)
L dep sh fun	0.0071	0.0090 **
	(0.0046)	(0.0046)
L oth int bea	0.0064	0.0114 **
	(0.0047)	(0.0047)
L oth res	0.0061	0.0236
	(0.0168)	(0.0167)
L equ	0.0052	0.0357 ***
	(0.0063)	(0.0063)
A tot asset	0.0006 ***	0.0047 ***
	(0.0002)	(0.0002)
IT	0.0041 ***	0.0129 ***
	(0.0011)	(0.0010)
FR	0.0007	-0.0107 ***
	(0.0017)	(0.0016)
ES	-0.0002	-0.0066 ***
	(0.0014)	(0.0013)
NL	-0.0019	-0.0098 ***
	(0.0015)	(0.0015)
GR	-0.0001	-0.0056 ***
	(0.0018)	(0.0018)
IE	0.0046 *	-0.0075 ***
	(0.0025)	(0.0025)
UK	-0.0026	-0.0156 ***
	(0.0023)	(0.0023)
US/JAP/EX	-0.0000	-0.0058 ***
	(0.0017)	(0.0017)
AT	0.0009	-0.0019
	(0.0012)	(0.0012)
PT	0.0028 *	-0.0039 **
	(0.0016)	(0.0016)
LU	-0.0019	-0.0038
	(0.0024)	(0.0024)
CY	-0.0026	0.0036
	(0.0025)	(0.0025)
EUEX	-0.0021	-0.0199 ***
	(0.0031)	(0.0031)
FI	-0.0005	-0.0014
	(0.0025)	(0.0024)
EUEX	0.0010	-0.0049 ***
	(0.0010)	(0.0010)
BE	-0.0025	-0.0001
	(0.0024)	(0.0023)
Constant	-0.0629 ***	
	(0.0072)	
Time interval	2009-02-11 - 2009-03-10	
Maturity	1 to 3 days	
Observations	123552	

Notes: See Table D.1.

Appendix E: Additional Results on Trading Patterns during the Sovereign Crisis (Section 6.3.2)

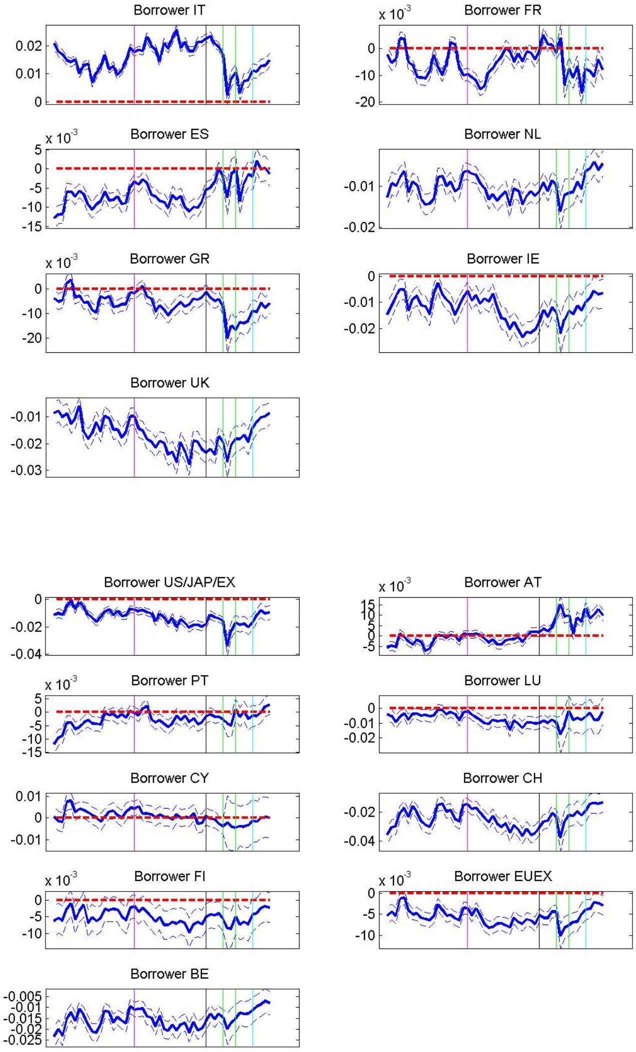
Probability to Trade

Figure E.1: Probability to trade - Lender's country dummies.



Notes: See Figure 1, Figure 4, Figure 9 and 10.

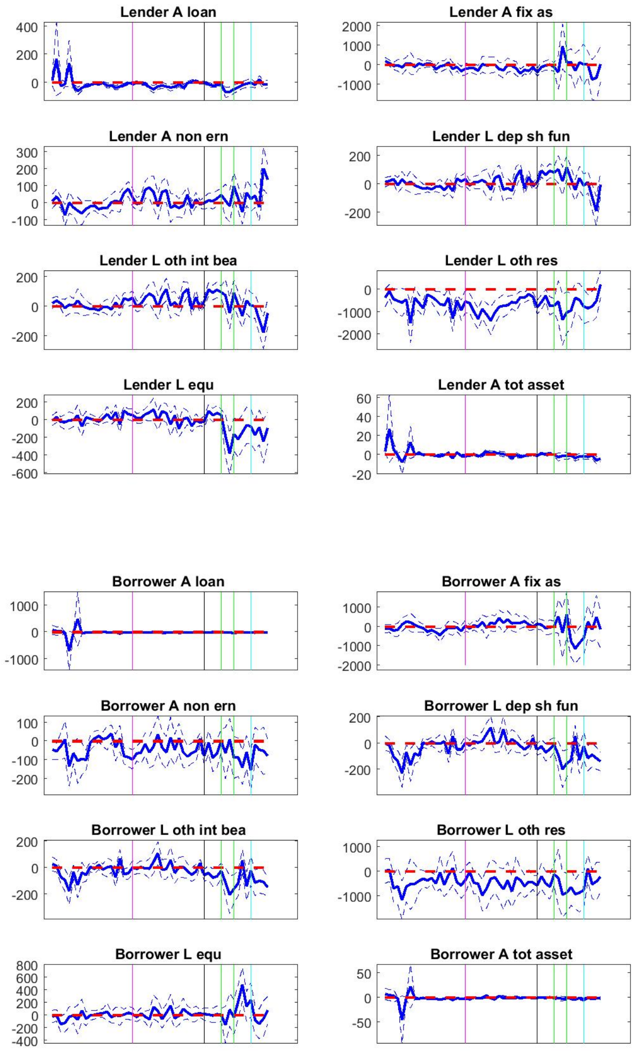
Figure E.2: Probability to trade - Borrower's country dummies.



Notes: See Figure 1, Figure 4, Figure 9 and 10.

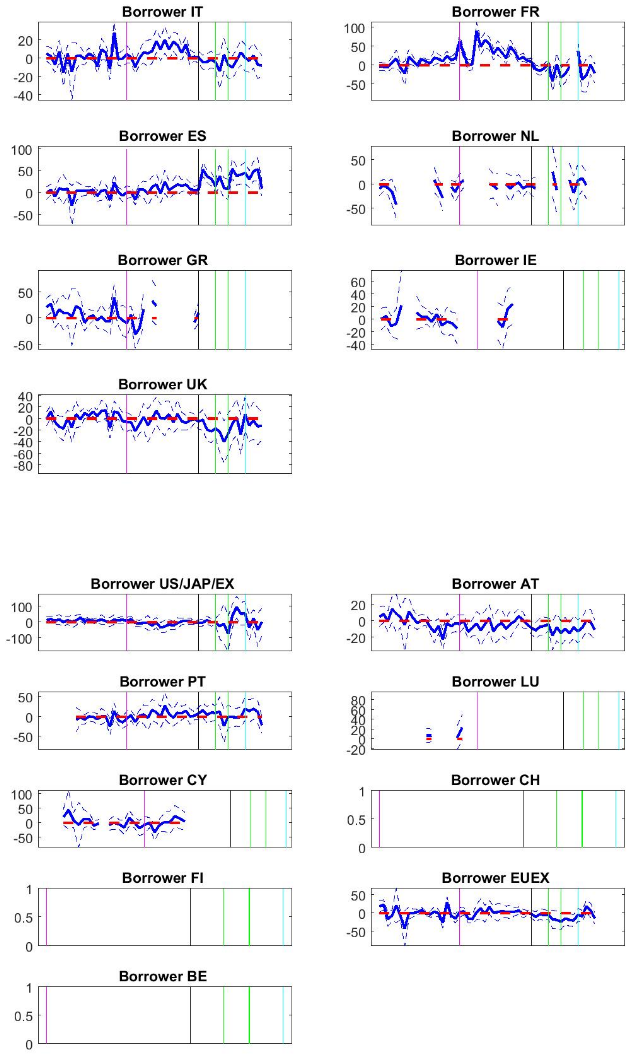
Quantity Exchanged

Figure E.3: Quantity equation - Lender and borrower balance sheet covariates.



Notes: See Figure 4 and 15.

Figure E.4: Quantity equation - Borrower country dummies.



Notes: See Figure 1, Figure 4, Figure 9 and 10.

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