Counterparty choice, maturity shifts and market freezes: lessons from the e-MID interbank market

Susanna Saroyan

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Susanna SAROYAN
Institute for New Economic Thinking
Oxford Martin School
University of Oxford
Susanna.Saroyan@inet.ox.ac.uk

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Abstract

We explore the impact of relationship lending on the interbank debt maturity structure of banks using data from the e-MID market covering both pre- and post-Lehman periods. We study the term structure and maturity shortening of interbank lending as an indicator of risk in times of stress. We identify bank-level and pair-level variables which are shown to contain information about the behaviour of lending relations during times of stress. Using a two-part fractional response model we show that durable liquidity relationships increase the probability of contracting term loans, but do not prevent maturity shortening during periods of acute stress. Finally, we find that lenders with concentrated short-term interbank liability structure tend to reduce their own long term lending, which confirms the roll-over risk viewpoint of term interbank market freeze. Our findings are relevant for the modeling of interbank networks under stress and the design of forward looking stress tests for the banking system.

Keywords: Interbank markets; liquidity; market freeze; maturity shift; relationship lending; roll-over risk; interbank networks; network dynamics; counterparty risk.

JEL Classification Numbers: E44, E58, G01, G21, G28, C25.

Contents

1 Introduction

The malfunctioning of interbank markets during the 2007-2008 financial crisis underlined the role of central banks (CBs) as liquidity providers of last resort and led them to readjust their monetary policy frameworks. This centralized liquidity allocation persisted and gave rise to the question of whether the CB should continue to be the unique counterparty of the whole banking system even in tranquil periods. The theoretical argument in favor of liquidity reallocation via markets rather than by a central bank is mainly based on the disciplinary role of the former and the idea that banks are incentivized to monitor each another and price the risk adequately (Rochet and Tirole, 1996). Rochet and Tirole (1996) also emphasize that decentralized lending can effectively incentivize banks to monitor peers, if and only if the regulator credibly commits not to rescue the so called Systemically Important Financial Institutions (SIFIs).

This paper studies the impact of durable interbank relations on liquidity risk, as expressed through the maturity structure of of unsecured interbank loans. We use the e-MID database of interbank transactions to gain insights into the dynamics of interbank lending relationships in normal times and in times of stress, using the Lehman stres scenario as a case study. Drawing on the empirical literature on relationship lending, we identify bank-level and pair-level variables which are shown to contain information about the behaviour of lending relations during times of stress. In contrast with previous studies, we focus on the term structure of interbank lending at bank level and we identify *maturity shortening* as the dominant behaviour during stress periods.

Empirical studies on relationship banking often set hypotheses based on theoretical models on lending under asymmetric information (Freixas et al., 2000; Freixas and Jorge, 2008; Rochet and Tirole, 1996). In the framework of bank-bank and bank-firm lending, relationship banking is commonly considered both as a source of benefit and cost. On one hand it may have a positive mpact by easing credit access due to the reduction of information asymmetry between the lender and the borrower. On the other, the lender can use this soft information to exert market power on the borrower who relies heavily on this liquidity supply relationship, which creates a negative "hold-up" effect of relationship banking.

Cocco et al. (2009), Bräuning and Fecht (2012), and Affinito (2012) use interbank transactions data to conclude that private information or concentrated lending enhances market discipline. However, as in the bank-firm literature, these authors also state that the impact of relationship lending on credit terms is not straightforward. Craig et al. (2015) study the ECB's primary Main Refinancing Operations and show that during periods of high stress relationship dependencies, expressed as trade concentration, even increase borrowers' liquidity risk and induce to higher interest rates. Benefits from liquidity supply diversification are evidenced also by Gabrieli and Georg (2014). They show that banks having a concentrated refinancing network as a borrower tend to reduce lending to their pairs.

1.1 Contributions

We complement previous empirical studies by testing the impact of relationship lending on the maturity structure of inter-bank loans, which is especially important in times of acute stress. The intuition behind our study is that maturity shifts that have been observed in the world's largest interbank markets during the Global Financial Crisis (GFC) are motivated by reputational concerns of market players. The LIBOR manipulation scandal during the same period shows that banks were aiming to hide creditworthiness concerns reflected in rising borrowing rates. However, unlike the level of interest rates, maturity shortening of interbank debt is not easily monitored by market participants and is not used as a risk indicator. First, this information is not publicly available, and, second, it is not easily accommodated in commonly used credit risk models. Thus, during periods of stress, shortening of maturities could be another way to slow down the increase in term premia perceived as creditworthiness downgrade and could harm banks' access to funding (both unsecured and secured). In times of stress, banks would borrow long-term only if the rate is sufficiently low to signal good creditworthiness. This signaling mechanism is particularly important in the framework of transparent money markets. Therefore, in the transparent e-MID market under study here, maturity shifts appear to be a robust indicator of borrower's credit or roll-over risk (Acharya and Skeie, 2011).

Results from the first part of our model, evidence that relationship lending contributes to the stability of medium or long term funding relations in times of stress. At the same time, the second part of the model indicates that relationship lending does not prevent maturity shortening in times of stress. These findings are consistent with recent empirical studies on interbank markets which have shown that negative "hold-up" effects of relationship lending may prevail and translate into less favorable liquidity conditions for partner banks (see Kobayashi and Takaguchi, 2018).

Our work furthermore identifies variables which govern the dynamics of term interbank funding networks, in contrast with existing literature on interbank networks which focuses on overnight lending. This contribution is especially relevant in the framework of current transition from LIBOR to overnight benchmark rates. These new transaction-based overnight rates are definitely more reliable and robust, but they fail to capture banks' marginal term funding costs. Our work contributes to a better understanding of term liquidity network dynamics under stress, which is of interest in a context where transaction-based term benchmarks are being introduced (Schrimpf and Sushko, 2019; Berndt et al., 2020; Duffie and Stein, 2015).

Outline The remainder of this paper is organized as follows. Section 2 positions this research with respect to the related literature. Section 3 describes the data sample and stylized facts concerning maturity shift and counterparty concentration on both the O/N and term sectors. Section 4 presents the variables used in our regressions. In Section 5, we explain methodology used and present our main results. Section 6 concludes the paper.

2 Related Literature

2.1 Relationship and network variables

Studies using network variables usually take into account both local and global network effects on funding conditions. They often find that the impact of direct counterparties on interbank rates is much more pronounced and significant compared to indirect effects (e.g. Bräuning and Fecht, 2012; Craig et al., 2015). These results are not surprising, because when a bank prices its counterparty's credit or liquidity risk, it usually does not have full information about the position of the latter in the network. Moreover, even if the counterparty's systemic importance is known, the "too-connected-to-fail" moral hazard effect would prevent it from being priced. Appropriate centrality-based prudential regulation would allow to internalize the SIFI risk, which otherwise would escape market discipline and risk pricing for above-mentioned reasons (see Alter et al., 2015). Therefore, when one aims at understanding key drivers of credit and liquidity risks from individual banks' perspective in the absence of any SIFI prudential regulation, direct network effects or relationship lending variables are suitable candidates.

Network metrics are often based on a snapshot of the link configuration and do not account for relationship dynamics. In order to account for both dynamic and preference effects on interbank funding conditions we focus on bank-pair relationship variables.

The choice of an appropriate relationship variable is not straightforward either. In the original bank-firm relationship lending literature partnerships are proxied by their duration (Ongena and Smith, 2001), strength (Petersen and Rajan, 1994), geographical distance (Degryse and Ongena, 2005; Beck et al., 2018), or number of permanent partners (Farinha and Santos, 2002). In the framework of interbank markets the most commonly used relationship variables are relationship concentration variables, which indicate the relative importance of a counterparty for a lender or a borrower (Cocco et al., 2009).

Kobayashi and Takaguchi (2018) criticise these counterparty preference variables for interbank relationships, pointing out the fact that they should depend on bank-specific characteristics, such as size and liquidity needs. Like Affinito (2012) they also conclude that statistically significant ties are long lasting, which confirms our intuition that relationship duration variables are suitable relationship proxies. Based on these insights, we build a relationship duration variable to analyse its impact on the maturity shift.

2.2 Maturity structure as a risk indicator

Empirical research on interbank relationship lending has been focused on the overnight (O/N) interbank interest rates (Cocco et al., 2009; Bräuning and Fecht, 2012; Furfine, 2001; Affinito, 2012; Afonso et al., 2013; Iori et al., 2008).The share of O/N trading is usually dominant compared to term loan volumes in interbank unsecured markets. However, the opposite becomes true if one thinks in terms of outstanding loans, rather than turnovers. Therefore, studying longer term interbank transactions is relevant for counterparty risk analysis.

The focus on overnight lending has also been related to data availability. There was originally a technical difficulty with algorithm-based identification of longer-term loans from among multiple transactions in TARGET2 and FedWire payment systems (Furfine, 1999; Arciero et al., 2016). In this paper we use transaction data from the e-MID interbank market and extend the existing literature by studying maturity shortening in interbank trade in times of stress, which we consider an attention-worthy but yet unexplored indicator of risk.

Several previous studies have exploited the rich information in the e-MID dataset Angelini et al. (2011); Iori et al. (2008); Temizsoy et al. (2015). Angelini et al. (2011) conclude in favour of credit risk to explain the post-Lehman rise in interbank term spreads. Counterparty risk related increase in Fed market O/N spreads has been also evidenced by Afonso et al. (2011), who observe that O/N transaction volumes have not decreased post-Lehman.

What actually happened in both European and Fed markets was a substitution of term loans by O/N trades after Lehman's collapse. Kuo et al. (2013) and Gabrieli and Georg (2014) using data from payment systems, provide evidence of this post-Lehman maturity shortening episode respectively in Fed and European interbank markets. These stylized facts, also observed in e-MID data (see Figure 1), have motivated our focus on maturity structure as a risk indicator. Looking at this non-price contract term makes sense in times of acute stress, when long maturity loans are rather replaced than priced. In the present work, rather than analysing transaction volumes for each maturity separately (Kuo et al., 2013; Gabrieli and Georg, 2014), we focus on the *shift* from one maturity structure to another through time.

Acharya and Skeie (2011) suggest a theoretical model supporting the idea that episodes of maturity shortening in times of stress are not exclusively explained by counterparty risk, but rather the result of liquidity hoarding on term loans by lenders who apprehend not being able to rollover their short-term debt. Acharya and Merrouche (2012) supports this precautionary hoarding hypothesis, using data from reserves of the largest UK settlement banks. We test this hypothesis using a short-term funding concentration variable per lender.

Acharya and Skeie (2011) also outline that even from borrower bank's viewpoint, maturity shortening could be rollover-risk related. Borrowers could be averse to trade at historically high long-term rates in order to preserve their creditworthiness reputation for short-term debt renewal. Motivated by a similar idea this paper focuses on trade volumes, especially in the framework of transparent e-MID transactions, where price signaling effects are even more pronounced than for over the counter (OTC) transactions.

3 Data

We analyze data from the e-MID Italian electronic platform covering the period from January 2, 2006, to May 7, 2009. The last day of the sample corresponds to the ECB's announcement to conduct one-year long-term refinancing operations (LTROs) via fixed rate full allotment (FRFA) tenders up to the end of the year.

The e-MID provides a glimpse of effective interbank transactions and covers around 20% of transaction on European interbank loans. Before the crisis, this screen-based interbank trade was very popular at European scale. However, during the turmoil and especially with the beginning of the sovereigns' fiscal difficulties, the market started to exhibit domestication tendencies. This overall fragmentation of the European interbank markets has been argued to arise from cross-border informational asymmetries (see Cassola et al., 2008). Thus, we restrict our analysis to the Italian interbank market to avoid cross-border risk issues and have a relatively balanced panel of banks for the overall sample under study, which covers both pre- and post-crisis periods.

Beyond the aforementioned motivations, the Italian interbank market is an interesting case to study from the perspective of private information for two reasons. First, it is a market where interbank relationships exist and persist over time, as Affinito (2012) demonstrated using 11-year data on interbank exposures. Second, the Italian banking system has proven to be relatively resilient in times of crisis, which might be related to the existing and persisting liquidity networking (Draghi, 2009).

Loan maturities on the e-MID unsecured market go from O/N to one-year terms. In this paper, we regroup inter-bank trades into three maturity classes: short term (ST) regrouping overnight, tomorrow next, and spot next loans; medium term (MT) representing loans with maturities ranging from one week to three months; and long term (LT) comprising loans with maturities from four months to one year.

The existence of an interbank market freeze during the GFC is debatable, as we observe stable and even increasing O/N trade volumes after Lehman bankruptcy (Afonso et al., 2011). What actually happened was a substitution of MT and LT loans by O/N trade (Gabrieli and Georg, 2014; Kuo et al., 2013). Figure 1, which displays daily traded volumes of LT, MT and O/N maturity groups surrounding Lehman's default (August 15 to Nov 15, 2008), evidences this stylized fact in e-MID interbank market. one can observe a simultaneous and persisting decrease in longer maturities for the benefit of O/N volumes post-Lehman and prior to the ECB's Fixed Rate Full Allotment policy (FRFA) implementation announcement. As in TARGET2 data, the O/N sector earned about 4% of additional share in total e-MID traded volumes. Figure 1 also shows that this post-Lehman maturity shortening has been followed by a maturity lengthening episode after the ECB's FRFA policy implementation on October 15, 2008.

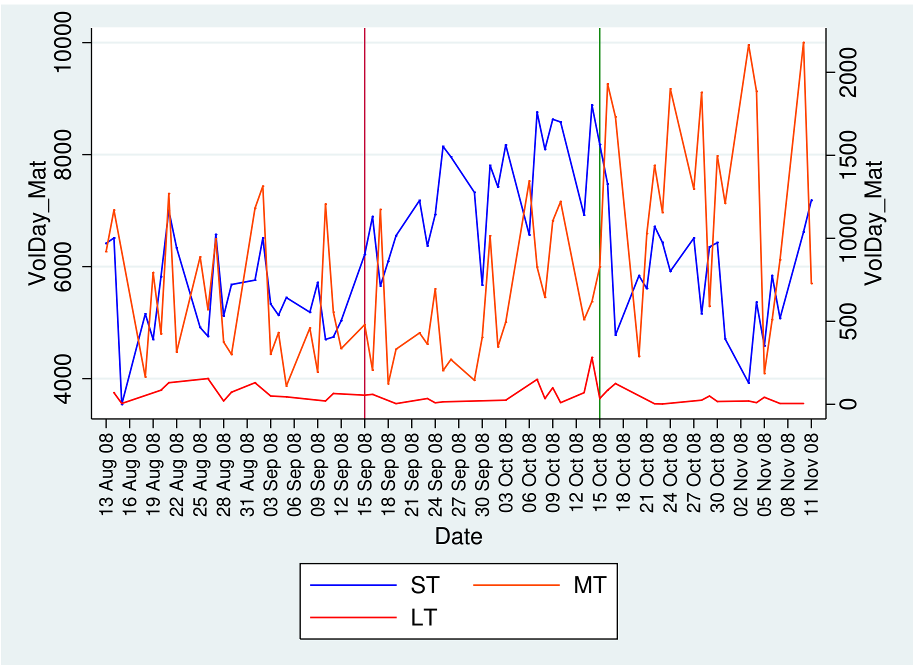

Figure 1: E-MID volumes per maturity around the Lehman default.
The first vertical red line represents Lehman's default (September 15, 2008). The second green vertical line corresponds to the implementation of the ECB's FRFA policy on October 15, 2008. Right side $VolDay_Mat$ axes represents the scale for ST and the left side one for MT and LT maturities.

To follow the evolution of the liquidity network in e-MID market, we first compute the number of unique counterparties each bank lends to and borrows from within one Reserve Maintenance Period[1](RMP), equivalent to banks' out- and in- degrees in network terminology. Even if the average absolute in- and out- degree tend to be smaller for term maturities then for O/N trade, those trades are much rarer as well. We therefore normalize out- and in- degrees by the number of lending and borrowing transactions respectively. These ratios illustrate well to what extent banks tend to concentrate their interbank trading on few liquidity partners. Figures 2 and 3 and below displays the per RMP average value of these variables for our panel of lenders and borrowers. Note that the smaller this ratio, the more concentrated the liquidity network is.

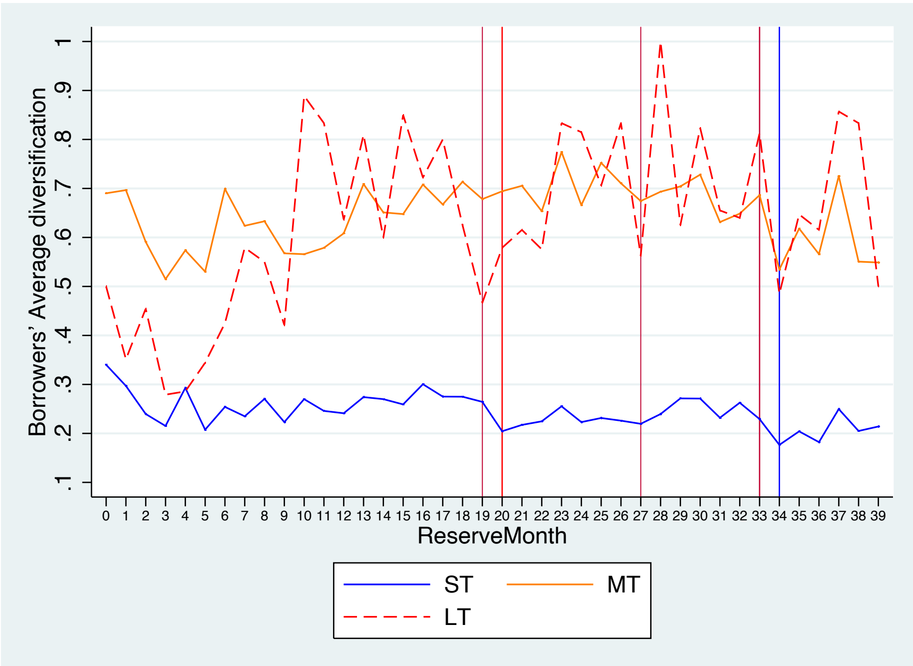

Figure 2: Average normalized number of lenders per borrower: RMP average for borrowers
Average normalized number of borrowers per borrower: The first vertical line represents the RMP when Bear Stearns start to encounter the first sub-prime difficulties. The second one marks the month when the sub-prime crisis spilled over the interbank market after the BNP events in August 2007 (the beginning of interbank crisis). The third vertical line marks the RMP incorporating the Bear Stearns repurchase by JP Morgan in March 2008. The fourth one indicates the Lehman default. Finally, the fifth vertical line corresponds to the RMP when the FRFA was first implemented.

Figures 2 and 3 show that the normalized average number of lenders and borrowers (per transaction) are sensitive to adverse events marked by horizontal red lines, especially for LT trades (red dash line). For example, the network became more concentrated post-Lehman

[1]In the Euro area, the legal requirement is to maintain a bank's balance sheet based amount of average reserves over a period called the Reserve Maintenance Period. Thus, banks' manage their reserves on daily basis within these RMPs defined by the ECB. We use the ECB website to extract data on RMP periods, as well as Main Refinancing Operations' announcement and allotment dates.

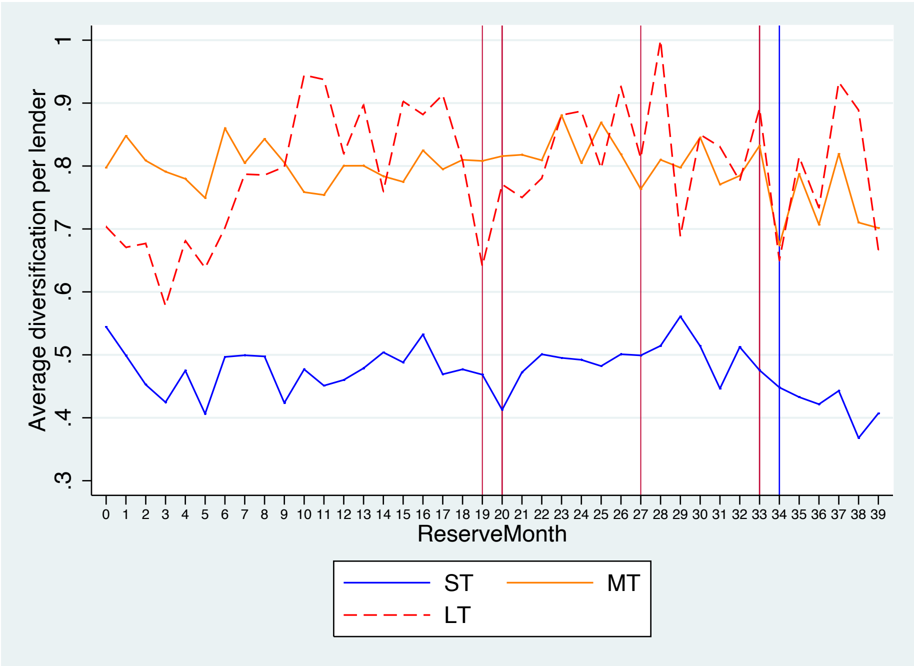

Figure 3: Average normalized number of borrowers per lender: The first vertical line represents the RMP when Bear Stearns start to encounter the first sub-prime difficulties. The second one marks the month when the sub-prime crisis spilled over the interbank market after the BNP events in August 2007 (the beginning of interbank crisis). The third vertical line marks the RMP incorporating the Bear Stearns repurchase by JP Morgan in March 2008. The fourth one indicates the month of the Lehman default. Finally, the fifth vertical line corresponds to the RMP when the FRFA was first implemented.

for all three maturity sectors (the forth red line), but especially for the term sector. On the LT sector of e-MID, the normalized number of counterparties dropped from 0.9 to 0.64 for lenders and from 0.8 to below 0.5 for borrowers. The MT sector, which is relatively stable in terms of average normalized counterparties pre-Lehman, became suddenly much more concentrated after the Lehman default. The O/N network's structure changed as well, but the drop of number of counterparties (per transaction) is less pronounced compared to the long term sector.

Our findings are in line with those of Gabrieli and Georg (2014) who argue that what changed most post-Lehman was the network structure of medium- and long-term interbank transactions, with the network exhibiting a smaller and more pronounced core, less connected to the periphery than before.

4 Methodology

4.1 Maturity structure as a dependent variable

We focus on the maturity shifts of interbank trades and explain the phenomenon by relationship variables that might impact both counterparty and liquidity risks of banks. In order to capture the maturity shift from term to O/N trading, we compute our dependent variable as a Long and Medium Term loan ratio as follows:

$$LMTRatio_{ijt} = \frac{LMTVol_{ijt}}{Vol_{ijt}} \tag{1}$$

LMTRatio is the fraction of the MT and LT loans in the total volume lent by lender bank j to borrower i within the RMP t. Thus, a change in *LMTRatio* implies a change in maturity structure of the interbank debt between the given pair ij of banks. Given the aforementioned stylized facts and the existing debate around maturity shifts, we use the maturity structure of interbank trades as an indicator of counterparty and/or roll-over risk.

4.2 Relationship variables

4.2.1 At bank pair level

Bank pair-level variables enable us to distinguish spot trading networks from relational ones and asses the informational value of the link. The choice of relationship variables is quite large in the original bank-firm customer relationship literature. Relationships are proxied by their duration Ongena and Smith (2001), strength Petersen and Rajan (1994), geographical distance (Degryse and Ongena, 2005; Beck et al., 2018), or number of permanent partners Farinha and Santos (2002). In the interbank market framework, the most commonly used relationship variables are strength variables, introduced by Cocco et al. (2009). In this paper, we first compute similar relationship variables and name them as in Cocco et al. (2009), namely, *Borrower Preference Index (BPI)* and *Lender Preference Index (LPI)*. These variables indicate the relative importance of one particular counterparty for a lender or a borrower.

The *BPI* is computed as the amount borrowed by bank i from its lender j over the total interbank liabilities of the borrower i within the lagged-RMPs preceding the RMP t. The *LPI* is measured as the volume lent by bank j to its borrower i over the overall interbank assets of lender i during a given period. *BPI* and *LPI* are defined respectively by equations 2 and 3 below.

$$BPI\_nRMP_{ijt} = \frac{\sum_{\tau=t-1}^{t-n} Vol_{ij\tau}}{\sum_k \sum_{\tau=t-1}^{t-n} Vol_{ik\tau}} \tag{2}$$

$$LPI\_nRMP_{ijt} = \frac{\sum_{\tau=t-1}^{t-n} Vol_{ij\tau}}{\sum_k \sum_{\tau=t-1}^{t-n} Vol_{kj\tau}} \tag{3}$$

We do not limit the computation of the *BPI* to the RMP preceding the RMP t(i.e., $n = 1$) because a very strong relationship could be interrupted or weakened within just one RMP and restart later. Thus, we compute the *BPI* and *LPI* for a minimum of two RMPs preceding the RMP t by taking $n = 2$ and $n = 3$. In this paper we display results from the specifications using LPI_2RMP_{ijt} and BPI_2RMP_{ijt}. Regression results do not change qualitatively with $n > 2$.

One should note that the two relationship strength variables, apart from identifying the relational partners for both borrowers and lenders, are also liquidity and credit risk concentration indicators. The first one, *BPI*, measures the extent of the borrower's interbank liability concentration. A borrower depending heavily on a single or few lenders is subject to a more important liquidity risk if its principal counterparties default or just stop granting credit. The second one, *LPI*, indicates the concentration of the lender's interbank assets on one borrower. A high *LPI* implies concentration on one borrower and thus higher non-diversified credit risk . At the same time, lenders with such a lending structure are expected to better monitor their borrowers and get private information on their creditworthiness.

Finally we build a second relationship duration variable which we think represents more straight-fully the "liquidity friendship". This variable, despite its slight positive correlation with the *BPI* and *LPI*, differs qualitatively from them, as it assesses the private information the lender banks acquire about their borrowers through their lasting and repeated interactions. We compute this relationship measure as the natural logarithm of the number of days within past consecutive RMPs the pair ij has interacted with each other (i as borrower and j lender). The variable is computed as follows:

$$Rel_{ijt} = ln(1 + \sum_{\tau=t-1}^{t-n} Nofdays_{ij\tau}) \tag{4}$$

4.2.2 At bank level

To take into account the rollover risk of the lender (Acharya and Skeie, 2011), we compute an *HHI*-type variable, which represents the liability structure of the lender bank *j*. This concentration variable can be written as follows:

$$HHI_{jt} = \sum_{k=1}^{n} \left[\frac{BorrVol_{jkt-1}}{\sum_{k=1}^{n} BorrVol_{jkt-1}} \right]^2 . \tag{5}$$

In equation 5 above, n represents the total number of borrowers k the lender j had at time *t-1*. HHI_{jt} is a Herfindhal index, measuring lender j's ST network concentration as borrower. We assume that a lender borrowing very concentrated and short term faces higher roll-over risk. Therefore it would shorten even more its term lending in times of crisis, as argued by Acharya and Skeie (2011). HHI_{jt} is computed as a one-RMP-lagged Herfindhal index for the ST borrowing of lender *j*.

To separate the role of relationship lending during different sub-periods, we cross all relationship variables with sub-period dummies. We generate four dummy variables: *PreCrisis, PreLehman, PostLehman*, and *FRFA* corresponding to the respective RMPs. The *PreCrisis* dummy is equal to 1 for RMPs from January 2, 2006, to August 9, 2007. The *PreLehman* dummy covers RMPs from August 9, 2007, to the Lehman default, that is, September 15, 2008. The *PostLehman* dummy covers the period from the Lehman collapse to the FRFA of the ECB (October 15, 2008). Finally, the *FRFA* dummy is equal to 1 from October 15, 2008, to May 7, 2009, corresponding to the announcement of the first FRFA 1-year LTRO of the ECB.

4.3 Liquidity risk control variables

Entering into interbank relationships is motivated by individual liquidity needs and liquidity risk for both lenders and borrowers. Thus, we introduce liquidity variables at borrower and lender level separately. Using e-MID transactions we construct a volatility-based liquidity risk variable for each lender and borrower. For both lenders and borrowers, we first compute the daily net liquidity positions (lendings-borrowings). If the bank is net lender, we assume that it has been hit by a positive liquidity shock in the given day, and if it is a net borrower, it has undergone liquidity shortage. To measure the liquidity shock volatility for each borrower i or lender j, we compute *LIQURisk*, which is the standard deviation of daily liquidity shocks (interbank positions) for each bank within the given RMP.

We have also run specifications with correlations of liquidity needs between ij computed using daily liquidity positions. We expect that a pair of banks ij will more probably exchange on interbank market if their liquidity shocks are negatively correlated. Those specifications provide robust results concerning our variables of interest, namely relationship variables. The summary statistics of main variables discussed in Section 5 is presented below.

All regressions are conducted at bank pair level. Thus, to account for unobserved bank level heterogeneity, we include both borrower- and lender-fixed effects in all our specifications.

Table 1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
$LMTRatio_{ijt}$	0.118	0.3	0	1	65792
$LIQURisk_{it}$	206.596	235.315	0	1703.125	65751
$LIQURisk_{jt}$	157.025	225.135	0	1703.125	65779
HHI_{jt}	0.167	0.256	0	1	65792
BPI_2RMP_{ijt}	0.029	0.074	0	1	61979
LPI_2RMP_{ijt}	0.039	0.078	0	1	62301
Rel_{ijt}	2.927	1.429	0	6.515	59589

4.4 Methodology

As mentioned previously, banks prefer to trade O/N to adjust their daily reserve requirements. Thus, our dependent variable, namely, the share of LT and MT trades per bank pair *LMTRatio*, is heavily concentrated at zero. For the sample under study, 75% of trades are made O/N. Apart from its high concentration at zero, the dependent variable is a fraction varying between 0 and 1, and thus a linear ordinary least squares (OLS) estimation approach in such a context is not suitable, as the predicted value of the variable is not guaranteed to lie in the unit interval. To resolve this methodological error which concerns a range of empirical studies in finance (e.g. leverage ratios, shareholders) Papke and Wooldridge (1996) propose an alternative, non-linear specification called Fractional Response Models (FRM) using a quasi-maximum likelihood estimation of parameters.

In this paper we use an extended version of a FRM called two-part fractional response model (2P-FRM), in order to deal with the distributional particularity of the dependent variable and simultaneously with the unit interval constraint. This model was introduced by JS Ramalho and da Silva (2009) who show that their approach is the best alternative to Tobit for modeling leverage ratios or any other fractional data heavily concentrated on one limit value. One of the arguments advanced by the authors in favor of 2P-FRM compared to Tobit, is the ability of the former to provide an upper bound for the dependent fraction variable. They also highlight the stringency of Tobit model in terms of assumptions, requiring normality and homoskedasticity of the latent dependent variable.

The 2P-FRM especially fits to our data, because it takes into account the high probability of not observing term interbank loans.

We define

$$Y^* = \begin{cases} 0 & \text{if} \quad Y = 0 \\ 1 & \text{if} \quad Y \in (0,1] \end{cases} \tag{6}$$

$$\begin{aligned} E(Y|X) &= P(Y \in (0,1]\,|X) \cdot E(Y|X, Y \in (0,1]) + P(Y=0|X) \cdot E(Y|X, Y=0) \quad (7) \\ &= P(Y \in (0,1]\,|X) \cdot E(Y|X, Y \in (0,1]) \\ &= F(X\beta_{1P}) \cdot M(X\beta_{2P}) \end{aligned}$$

In contrast to a Tobit model, a 2P-FRM model allows the same variable to impact differently banks' decision of contracting LT or MT (the first part), and its decision on the share of LT and MT loans (the second part). Thus, the first part of a 2P-FRM model is a binary model with non-linear specification $F(X\beta_{1P})$ (here a logit) and a vector of coefficients β_{1P}, which explains the impact of independent variables on the probability of contracting long term. The second part $M(X\beta_{2P})$ is specified as a non-linear link function obeying the unit interval constraint (here a conditional logit, $0 \leq M(X\beta_{2P}) = \frac{e^{X\beta}}{1+e^{X\beta}} \leq 1$). It estimates the fraction of the term exposure (the share of LT and/or MT contracts) between the borrower i and lender j if there exists any term contract. Quasi Maximum Likelihood estimates are computed with the 2P-FRM specification.

We have also run a Tobit model for robustness check purposes. Tobit specification assumes that instead of observing Y^* the latent variable, we observe Y defined as follows: $Y = Y^*$ if $Y^* > 0$ and $Y = 0$ otherwise. It also assumes that Y^* is normally distributed, and a linear relationship exists between the latent variable and covariates $E(Y^*|X) = X\beta$, and that the error term $u = Y^* - E(Y^*|X)$. However, as in the leverage ratio literature, we are interested in the observed Y variable and thus our Tobit specification is defined as follows:

$$E(Y|X) = \Phi\left(\frac{X\beta}{\sigma}\right) X\beta + \sigma\phi\left(\frac{X\beta}{\sigma}\right), \tag{8}$$

where $\Phi()$ and $\phi()$ are respectively the standard normal distribution and density function, and σ is the standard deviation of the error term u.

The Tobit model does not allow the same variable to impact differently (in signs) the probability of term contracting and the decision about the term share of interbank loans, if any. However, running simultaneously the Tobit model in this paper allows first to check the robustness of results from 2P-FRM and then to obtain the total (unconditional) marginal effects. We find that these final marginal effects from Tobit are quite similar to the partial effects from the first part of our main 2P-FRM. This is certainly related to the 0-inflated nature of the dependent variable (Stewart, 2013). We present and comment below results from the 2P-FRM model.

5 Results

Table 2 reports the estimation results of the first and second parts of the 2P-FRM. As both parts of the model are non-linear, we present in Table 3 the marginal effects (at mean values of other variables) for both first and second parts of the model.

As discussed previously, we have run 2P-FRM specifications with two different types of relationship variables, *BPI, LPI* (See Columns 1 and 2 of Table 2 and of Table 3 for partial effects) and *Rel* (See Columns 3 and 4 of Table 2 and Table 3), both defined in Section 4. All our relationship variables are crossed with sub-period dummies *PreCrisis, PreLehman, PostLehman*, and *FRFA* defined in Section 4 too. Note that by construction in 2P-FRMs, the sign and the significance of the estimated coefficients (Table 2) correspond to those of partial effects, which are presented in Table 3 and computed at the mean values of all other variables.

The control variables *LIQURisk_borr* and *LIQURisk_lend* which measure respectively the volatilities of borrowers' and lenders' liquidity positions are significant in almost all regressions. Unsurprisingly, a borrower confronted to more volatile liquidity needs has a lower probability to enter in a long term lending relationship and, even if he does, he will obtain less long term loans if its liquidity needs become more volatile. The mechanism is different for lenders: a rise of their liquidity risk increases the probability that they enter in a long term relation with borrowers but decreases the share of long term loans between ij pairs afterwards.

5.1 Probability of term contracting

Columns 1 and 3 from Table 2 and Table 3, display respectively estimation coefficients and partial effects from the 1st part of the 2P-FRM specification. Globally, we find that the probability of contracting LT and/or MT in our case modeled by a conditional logit is positively impacted by relationship variables. However, the statistical significance and magnitude of the variables' impact change according to the sub-period studied and the relationship variable type.

With regard to the *BPI*, we find that a 1% increase in *BPI* leads to a 0.35% increase in probability of contracting long-term post-Lehman, compared to 0.12% pre-Lehman, at the mean value of all other variables (see Column 1 of Table 3). These findings show that the positive effects of relationship lending prevail on negative "lock-in" mechanisms before and during the crisis. In times of acute stress, post-Lehman it is more probable for a borrower to get term (riskier) loans from its main lender.

The *LPI* variable performs slightly differently. As *BPI*, it impacts significantly and positively the probability of transacting LT and/or MT in the beginning of the crisis and before Lehman's default. However the effect becomes simultaneously much less important and insignificant post-Lehman. Note that apart from being a relationship variable *LPI* implies also a non-diversified credit risk, which might explain this post-Lehman effects.

The relationship duration variable *Rel* that we think reflects more straightforwardly interbank partnerships affects significantly and positively bank-pair's decision to transact long term. This becomes larger during the crisis highlighting the importance of private information during stressed times, in line with Bräuning and Fecht (2012) and Affinito (2012).

Note that all relationship variables keep on affecting positively and significantly the probability of contracting long term after the ECB switched to FRFA MROs. Moreover, the magnitude of coefficients is even more pronounced which might suggest that counterparty risk concerns have lasted after the ECB's intervention and attenuated by relational lending.

We find that the *HHI lend*, which we consider as lenders' rollover risk measure, affects negatively and significantly the probability of entering into term relationships post-Lehman.

This is in line with Abbassi et al. (2022) who find that if lender's own funding network is non-diversified then the same lender tends to restrict loan renewal to others. Craig et al. (2015) show that banks with concentrated borrowing structure overbid during the ECB's Main Refinancing Operation auctions, fearing not being funded in interbank market.

In the first part of the 2P-FRM, combining bank-pair level and bank level liquidity concentration variables we find that during times of high uncertainty, banks that borrow themselves concentrated at short term were reluctant to lend long term motivated by roll-over risk concerns. The impact is inverted when the ECB has launched its FRFA policy, which probably has dampened banks' liquidity concerns.

Simultaneously borrowers were more likely to obtain long-term loans from their partner lenders possessing enough information on them. This effect has become stronger post-Lehman and persisted after the ECB's FRFA policy implementation.

5.2 Fraction of long- and medium-term lending

Columns 2 and 4 of Table 2 and Table 3 represent, respectively, the estimation results and marginal effects from the second part of 2P-FRM. Here the dependent variable is the ratio LT and MT loan volumes for the bank-pair ij, given that the fraction is non-zero. We find that globally bilateral relationship variables impact negatively and significantly the share of term loans, and the effect has persisted post-Lehman.

In the second part of the model, the *HHI lend* variable performs almost similarly as in the first part, by suggesting that lenders who borrow themselves concentrated reduce the share of long term lending to other banks post-Lehman, which is in line with the roll-over risk viewpoint of maturity shortening.

Finding that the share of LT and MT maturity transactions is lower for partner banks during the crisis is not surprising. First, because those banks tend to transact more frequently with each other, and therefore more on overnight basis. Second, because e-MID is a transparent screen-based platform which could be used as a creditworthiness showcase. Worried about their access to interbank liquidity, relational borrowers who can easily transact OTC, would chose to borrow long term on e-MID if and only if the rate is low enough to signal high creditworthiness.

The negative impact of concentrated borrowing on volumes of term interbank loans is, however, not unique to the e-MID market. Abbassi et al. (2022) use Target 2 European data to evidence that relationship lending hardens access to interbank term markets, especially post-Lehman.

The second part of the model provides evidence that, in terms of maturity shift, benefits from liquidity diversification prevail over gains from private information acquired due to concentrated trading (Craig et al., 2015). This supports the roll-over risk view of maturity shortening.

Table 2: 2-PART FRMs with different relationship variables

	(1) BPILPI 1st Part logit	(2) BPILPI 2nd Part logit	(3) Rel 1st Part logit	(4) Rel 2nd Part logit
main				
LIQURisk borr	-0.0003*	-0.0013***	-0.0002	-0.0012***
	(0.0001)	(0.0002)	(0.0002)	(0.0002)
LIQURisk lend	0.0005***	-0.0008***	0.0007***	-0.0008***
	(0.0001)	(0.0001)	(0.0001)	(0.0002)
HHI lend*PreCrisis	-0.5961***	-0.2830*	-0.2040*	-0.3754**
	(0.0909)	(0.1179)	(0.1008)	(0.1382)
HHI lend*PreLeh	0.5146***	0.1143	0.3841***	0.0667
	(0.0823)	(0.1001)	(0.0929)	(0.1089)
HHI lend*PostLeh	-0.8306*	-0.7027*	-0.9690*	-0.5380
	(0.3898)	(0.3384)	(0.4373)	(0.3931)
HHI lend*FRFA	0.4766***	-0.2234	0.0313	-0.1420
	(0.1309)	(0.1665)	(0.1442)	(0.1753)
BPI_2RMP*PreCrisis	2.3597***	-2.3998***		
	(0.3480)	(0.3204)		
BPI_2RMP*PreLeh	1.3370***	-2.0295***		
	(0.3459)	(0.3090)		
BPI_2RMP*PostLeh	3.5952**	-2.2802		
	(1.1250)	(1.6406)		
BPI_2RMP*FRFA	1.5864***	-1.4427**		
	(0.4701)	(0.4616)		
LPI_2RMP*PreCrisis	1.4724***	-4.0250***		
	(0.2738)	(0.5041)		
LPI_2RMP*PreLeh	1.6755***	-1.9373***		
	(0.3404)	(0.3970)		
LPI_2RMP*PostLeh	0.3752	-5.0762***		
	(0.8876)	(1.4104)		
LPI_2RMP*FRFA	1.9132***	-1.1017		
	(0.4102)	(0.6213)		
Rel*PreCrisis			0.1775***	-0.2786***

			(0.0237)	(0.0270)
Rel*PreLeh			0.1989***	-0.1556***
			(0.0204)	(0.0232)
Rel*PostLeh			0.2055***	-0.2031***
			(0.0328)	(0.0409)
Rel*FRFA			0.2584***	-0.1481***
			(0.0228)	(0.0272)
Constant	-2.5876***	1.5227***	-2.9682***	1.7722***
	(0.1896)	(0.2396)	(0.2078)	(0.2866)
Observations	61610	10688	59553	10327

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Marginal Effects of 2-PART FRMs with different relationship variables

	(1) ME 1st Part BPILPI	(2) ME 2nd Part BPILPI	(3) ME 1st Part Rel	(4) ME 2nd Part Rel
main				
LIQURisk borr	-0.00002 *	-0.0002***	-0.00002	-0.0002***
	(0.000)	(0.000)	(0.000)	(0.000)
LIQURisk lend	0.00005***	-0.0001***	0.00006***	-0.0001***
	(0.000)	(0.000)	(0.000)	(0.000)
HHI lend*PreCrisis	-0.055***	-0.045*	-0.019*	-0.062**
	(0.008)	(0.019)	(0.009)	(0.023)
HHI lend*PreLeh	0.048***	0.018	0.036***	0.011
	(0.008)	(0.016)	(0.009)	(0.018)
HHI lend*PostLeh	-0.077*	-0.113*	-0.09*	-0.089
	(0.036)	(0.054)	(0.041)	(0.065)
HHI lend*FRFA	0.044***	-0.036	0.003	-0.023
	(0.012)	(0.027)	(0.013)	(0.029)
BPI_2RMP*PreCrisis	0.219***	-0.385 ***		
	(0.032)	(0.051)		
BPI_2RMP*PreLeh	0.124***	-0.325***		

	(0.032)	(0.049)		
BPI_2RMP*PostLeh	0.345**	-0.365		
	(0.105)	(0.026)		
BPI_2RMP*FRFA	0.148***	-0.231 **		
	(0.048)	(0.074)		
LPI_2RMP*PreCrisis	0.137***	-0.645***		
	(0.025)	(0.080)		
LPI_2RMP*PreLeh	0.155***	-0.311***		
	(0.032)	(0.064)		
LPI_2RMP*PostLeh	0.035	-0.815***		
	(0.083)	(0.226)		
LPI_2RMP*FRFA	0.178***	-0.177		
	(0.038)	(0.099)		
Rel*PreCrisis			0.016***	-0.046***
			(0.002)	(0.004)
Rel*PreLeh			0.018***	-0.026***
			(0.001)	(0.004)
Rel*PostLeh			0.019***	-0.034***
			(0.003)	(0.007)
Rel*FRFA			0.024***	-0.025***
			(0.002)	(0.004)
Observations	62506	10807	59553	10327

Robust Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

6 Discussion

We have introduced concentration and duration variables of relationship lending and shown how these variables affect maturity shortening in unsecured inter-bank markets. Using e-MID interbank data to construct pair- and bank- level relationship variables, we have evaluated the impact of concentrated and durable relationships on the probability of long term lending and the maturity structure of interbank loans.

Our main findings are the following. First, we find that durable partnerships increase a bank's chance to transact long term both before and during times of stress. We attribute this merit to the private information the lender acquires about its borrowers due to recurrent relationships. At the same time, we find that relationship lending does not prevent maturity shortening.

The disciplinary benefit from relationship lending, especially in times of stress, is far from being evidenced empirically, given the heterogeneous, and sometimes contradictory findings in existing studies. Using both pair- and bank-level variables, our work adds to the empirical literature by contrasting private information benefits from concentrated trading with benefits from funding diversification. This study extend the existing literature by studying for the first time the interbank maturity shortening in times of stress, which is an attention-worthy but yet unexplored indicator of risk. Looking at this non-price contract term makes sense in times of acute stress, when long maturity loans are rather replaced than priced.

The interest of central bankers and scholars in wholesale funding networks and relationships has grown since the Global Financial Crisis. Network models have been increasingly adopted for financial stability analysis and systemic stress testing in the context of payment systems (Eisenberg and Noe, 2001) and the banking system as a whole (Anand et al., 2013; Cont et al., 2013; Georg, 2013).

Criteria such as interconnectedness or non-substitutability have been introduced in order to identify systemically important financial institutions for regulatory purposes(Financial Stability Board, 2009, 2013). Note that both criteria are tightly related to a bank's role as relationship lender. From liability-side perspective of contagious defaults, identifying lending partnerships implies detecting banks that are systemically important, because the failure of those well-informed partners lead to a distress of borrowers who rely heavily on them (Bräuning and Fecht, 2012). From this perspective, our paper complements previous work on the modeling of interbank networks (Cont et al., 2013; Craig et al., 2015; Gabrieli, 2012; Gabrieli and Georg, 2014; Kraenzlin and von Scarpatetti, 2011). With a few exceptions, the majority of these studies assume a static network topology representing current interbank exposures or lending relations. Our study indicates that the network of interbank lending relations has a dynamic behaviour during stress periods, leading to a significantly different network topology, which is the one relevant for liquidity stress testing.

Our findings, which are consistent with empirical studies on the e-MID market Iori et al. (2008) and payment system data sets (Abbassi et al., 2022; Du et al., 2019), imply that in order to correctly represent bank's liquidity management in times of stress one needs to account for the dynamics of interbank lending relationships and maturity structure.

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