Modelling Relationship Lending in the Overnight Interbank Market

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Abstract

The current paper aims at introducing an Agent-Based Model describing the arise of interbank long-term relationships in overnight transactions in the money market. Once the mechanisms has been understood, the paper aims at explaining how relationship lending may influence the stability and efficiency of the credit market during a period of financial distress. In particular this paper aims at determining: (i) if the capacity of the interbank market to reallocate liquidity is affected by the proportion of relationship lending; (ii) if and how relationship lending influences interbank market stability; (iii) if and how relationship lending is affected by periods of financial distress.

The model should also be able to predict the decisions of banks to leave the interbank market, possibly generating adverse selection, and the segmentation between domestic and foreign banks leading to poor market integration.

Keywords: Interbank market, agent-based modelling, relationship lending.
Introduction

The interbank market has always allowed credit institutions to exchange capital in order to overcome the effects of short-term liquidity shocks. This market attracted a significant amount of economists’ attention, given that its rates represent the marginal cost of capital for credit institutions (Angelini, Nobili and Picillo 2009). For this reason the dynamics of the interbank market produce important effects on the whole economic system.

The 2007 financial crisis has seriously impaired the working of the interbank market. Since the early development of the crisis, banks operating in the money market have suffered important increases in medium-term interest rates, furthermore the volumes exchanged in different maturities registered an important reduction over time. In addition the overnight interbank market has seen an increase in both the volatility and the dispersion of its rates (Angelini, Nobili and Picillo 2009).

The development of financial stress may have altered banks financing decisions, preventing them to efficiently use this source of short-term credit. The worsening of the financial condition has importantly modified the environment in which banks used to exchange capital among themselves.

The inter-bank exchanges have presented some peculiar patterns highlighting the formation of trading relationships among institutions (Cocco et al. 2009, Affinito 2011 and Brauning 2011). The reiterated exchanges among banks, together with their ability to monitor counter-parties (Furfine 2001), favoured the formation of preferred lending channels. The economic literature has largely analyzed bank-firm preferential lending, arising under reiterated interactions with the possibility of screening the counter-parties (Boot 2000). The study of preferential lending among bank institutions represent an important novelty in the literature.

The presence of interbank preferential lending has been recognized in both over-the-counter markets such the Portuguese and the German one (Cocco et al. 2009 and Brauning 2011), and transparent markets such as the e-Mid (Affinito 2011). The economic literature has normally focused on the analysis of bank-firm relationships of preferential lending. Preferential lending among banks developed well before the start of the 2007 financial crisis. The presence of such relationships has certainly influenced the working of the inter-bank credit market during the financial turmoil.

The economic literature has normally focused on the formation To this extent Affinito (2011) and Brauning (2011) show that interbank relationships established prior the financial meltdown continued to last during the crisis. This condition has helped counter-parties with a solid relationship to exchange liquidity at low rates.

This important result rises important theoretical questions concerning the role of such relationships on the efficiency of the inter-bank market. Specifically one may ask whether those relationships are an efficient way of exchanging capital, and whether they can reduce informational asymmetries, improving market stability over periods of financial distress.
Considering the results obtained in the literature of inter-bank relationships, this paper aims at developing an Agent-Based model under which interbank relationship may develop endogenously.

Furthermore the model aims at answering to a number of different questions. First of all the paper aims at describing how those inter-bank relationships lending may influence market under different settings. In particular the model will consider the dynamics of two different trading mechanisms among institutions: an over-the-counter market where bids are private information, and a transparent inter-bank market where bids are public information. The first scenario aims at simulating the working of markets like the Fedfunds, while the second one considers more transparent markets such as the e-Mid market.

The presence of inter-bank relationships will be used to test market stability, particularly under stressed conditions. In this sense the proposed model may provide additional results to the literature on financial stability and network structures.

An additional goal of the model is to understand how the provision of information on banks credit conditions by a Central Authority may alter the structure of inter-bank exchanges under a regime of preferential lending.

In periods of no financial distress the interbank market has been considered as a risk-free market. This view of the market held, regardless of the interbank exchanges being not collateralized. During the financial crisis started in 2007, the interbank money market achieved high levels of interest rates especially for maturities higher than three months. During the first phase of the crisis in August 2007 the three-months Libor-OIS spread, an important measure of the general health of the banking sector, increased of more than 50 basis points. A further increase of more than 100 basis points occurred with the beginning of the second phase of the turmoil in October 2008 (Michaud and Upper 2008, Heider, Hoerova and Holthausen 2009). A similar trend has been shared by the three month European Euribor rate (Heider, Hoerova and Holthausen 2009). A comparable trend was obtained by the Libor-Repo spread. This result provides an additional evidence of stress in the term money markets (Michaud and Upper 2008) (Taylor and Williams 2008).

The extraordinary level of stress experienced by financial markets during the crisis can be recognized by the dynamics of the IMF Financial Stress Index, reported in Figure 1. The IMF Financial stress index represents an overall assessment of financial conditions. This index is composed considering important elements of the financial market, which among others are: the levels of banking stocks, the TED spread (the spread between the interbank rates and the short-term rates of government debt), the slope of the yield curve, corporate bond spreads, stock market returns, its volatility, and the volatility of the exchange rate. The figure confirms that all developed countries experienced an increase in financial stress starting from August 2007, with a second increase in September 2009, after the failure of Lehman Brothers.

It is reasonable to expect that the market conditions of the inter-bank market
Figure 1: IMF financial stress indicator for different countries
Michaud and Upper (2008) highlight the severe influence of the crisis on the working of the inter-bank market. This result is shown in Figure 2, indicating the spread of three month liquidity over overnight liquidity in both secured (blue line) and unsecured markets (red line), and the average Credit Default Swaps spreads of main banks (green line) for three groups of countries: USA, EU, and UK.

For every economic system considered the short-term capital cost registered an abrupt increase immediately after the beginning of the crisis. A similar shock, with limited magnitude, can be observed also in the CDS spreads. The Libor-OIS spread indicates a measure of health of the banking sector, representing the risk of default in lending to other institutions. This spread can be considered as a measure of credit risk over a given time period (Thornton 2009). The increase of this spread during the crisis indicates the reduced trust of banks on their counter-parties.

During normal times the term rates on the interbank market should equal the expected value of overnight rates. The absence of this arbitrage condition indicates that some elements have impaired the traditional working of this market (Michaud and Upper 2008). The measure of banks CDS showed a similar pattern to the indicated spreads. Its dynamics, however, seemed to be loosely coupled with the two spreads in the short period, registering a certain difference among the two measures.

CDS spreads have been indicated by some authors as a partial proxy for banks credit risk (see Furfine 2001, Michaud and Upper 2008), and in general they have been considered as an instrument of indirect peer monitoring (Porzio and Battaglia et al 2009). According to Michaud and Upper, the higher value of the

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Figure 2: Three-month money market and credit spreads. Source: Bloomberg; BIS calculations.
Libor-OIS spread with respect to CDS premia could be addressed to liquidity reasons. This fact can be explained by two fundamental reasons: banks may hoard liquidity, and banks may default for both liquidity and solvency reasons (Michaud and Upper 2008). This condition indicates that banks expectations concerning liquidity risk provided a magnifying effect over the real risk of bank institutions, as indicated by the CDS premia. This result highlights the complexity of banks interactions during the 2007 financial crisis, highlighting its importance in expanding the effects of bank crisis.

It is worth noting from Figure 2 that in every market the CDS premia anticipated almost one week the increase in money market rates. This seems to indicate that the operators had some expectations concerning the worsening of the situation.

Figure 3: CDS and Liquidity Spreads

Figure 3 presents the dynamics of one year CDS and the Libor-OIS spread for exchanges with one year maturity. From this figure it immediately appears that the spread values in the interbank market have been generally higher than the spreads in underlying CDS. The one year Libor-OIS spread, and the one year CDS presented a cointegration relationship, hence the two measures were influenced in the medium term, but not necessarily in the short term. It is worth noting the shifted peak of CDS premia, with respect to the Libor-OIS one. This particular condition may indicate that the interaction, influenced by liquidity measures, had an increase in real credit risk, as measured by CDS premia, with some time delay. In this sense money markets were the first in reacting to the sudden worsen of the situation. The increase of intrinsic credit risk, as measured by banks CDS, has been reached only later in time.
The overnight money market

The majority of inter-bank exchanges generally occurred at short-term, or overnight (ON) transactions. In the Portuguese market overnight exchanges accounted for 75 percent of inter-bank transactions, while exchanges over the same maturity represent 90 percent of the turnover of the Italian e-Mid market (Cocco 2009, Gabrieli 2011). It is interesting therefore to analyze the dynamics of this market under the current financial turmoil.

Figure 4 indicates the values of the average overnight interest rate on the e-Mid, its spread with the policy rate, and its volatility, from January 2007 to November 2008. The spread to the policy rate indicates that before the crisis the market was liquidity short, while after August 2007 it became liquidity long. This is indicated by the spread being on average higher than the policy rate prior the crisis, and lower than the policy rate after the turmoil (Gabrieli 2011).

Furthermore the ON interest rate indicated an important increase in volatility, which increases immediately with the beginning of the crisis, to reduce after February 2008, and increasing again after the failure of Lehman Brothers. This tendency indicates that the crisis had indeed a significant effect on the terms of trade on the ON exchanges on the e-Mid, modifying the conditions under which banks may obtain liquidity.

Figure 5 shows the total volumes and the number of trades on the e-Mid market. From the figure it clearly appears that since the beginning of the financial crisis, both the number of transactions, and their value have constantly reduced over time. Assuming that the liquidity needs of banks were unchanged over such a short time period, it could be argued that either institutions recurred to other forms of capital, or they had a serious lack of short-term capital for their operations.

Some commentators have underlined additional variations in the dynamics of interbank exchanges during the turmoil. As an example Gabrieli recognizes that after the development of the crisis, non-Italian banks on the e-Mid platform incurred into higher interest rates (Gabrieli 2011). An interpretation of this result is that banks decided not to trust those institutions over which they had less information, asking them a premium on transactions. This interpretation points to an increase in risk perception of banks towards their counter-parties, indicating a change in banks funding environment after the turmoil.

To understand the working of the interbank market it is important to analyze the findings of the economic literature. The literature has presented two main explanations for the increase in spreads and the volume collapse in the money market during the recent turmoil: liquidity hoarding, and an increase in counter-party risk. The first argument suggests that banks were hoarding liquidity for internal needs to anticipate additional
Spread over the policy rate on the e-Mid market.

Standard Deviation of ON rate on E-Mid.

Figure 4: Overnight interest rate behaviour on the e-Mid
money demand coming from unexpected liquidity shocks. The second reasoning attributes the increase in liquidity costs to a rise on perceived counter-party risk.

As indicated in the following pages, asymmetric information played a fundamental role in the interbank dynamics during the turmoil. Asymmetric information may explain the phenomena of market segmentation with international banks, it may provide an incentive towards relationship lending and peer monitoring. Furthermore, asymmetric information may explain a problem of adverse selection in the market after the development of the crisis, providing a possible explanation for banks leaving the interbank market.

Heider, Hoerova and Holthausen (2009) propose a theoretical model to explain liquidity hoarding extending the framework introduced by Diamond and Dybvig (1983) concerning the maturity mismatch of banks assets and liabilities. The authors model describes how asymmetric information on risk location, together with an increased fear of default, has played a fundamental role during the 2007 financial crisis. The authors consider banks which manage funds on behalf of their costumers. Costumers have liquidity needs at date one and two and banks offer liquidity claims to costumers. Firms know the overall value of the long-term level of risk, however they hold private information on whether it is safer or riskier than expected.

Essentially in the proposed model banks face a trade-off between liquidity and return when dealing with their portfolio allocation. Banks compare the cost of accessing the interbank market with the one of liquidating their long-term

Figure 5: Volumes and value of trades on e-Mid
investment, thus deciding whether to enter the inter-bank market, or to use private capital in order to face their liquidity needs. Lenders in the interbank market are exposed to counter-party risk, given that borrowers might be insolvent. The model is considered under two different settings: symmetric and asymmetric information concerning the level of risk of counter-parties assets. Under perfect information, all the banks in the system know the level of risk of the assets of their counter-parties. In this case lenders may price the risk of their counter-parties, hence the interbank market works efficiently, preventing borrowers to liquidate their long-term investments. On the contrary with asymmetric information banks face a privately observable shock on the risk of their long-term asset. Lenders do not know which borrower is facing such additional risk, therefore they are not able to price effectively the risk of their counter-parties according to their level of risk. The effect of asymmetric information in this case produces a classical adverse selection problem. A small increase in counter-party risk increases the inter-bank interest rate, given that lenders are not able to distinguish the level of risk of their counter-parties. A further increase in counter-party risk induces lenders to start hoarding liquidity with safer borrowers exiting the market. The authors suggest a number of policies whose aim is to reduce asymmetric information: improve system transparency, improve liquidity requirements, liquidity provision by the Central Bank, and guarantees on interbank loans, or asset purchases.

Freixas and Jorge (2008) provide an alternative model for the working of the inter-bank market under asymmetric information. The aim of the two authors is to understand the transmission of monetary policy given the presence of frictions on the interbank market. In this case the friction consists in the presence of credit rationing arising as a result of asymmetric information. The authors include both a perfect and an asymmetric information case concerning the level of adverse liquidity shocks faced by borrowers. The presence of asymmetric information, in particular, introduces the presence of strategic defaulter. The presence of strategic defaulters imply that lenders decide to reduce the amount they offer to the interbank market, introducing credit rationing. The authors stress that this condition implies the presence of a magnitude effect, that is borrowers reduce their demand for both an increase in the required interest rate, and the credit rationing decision of lenders. In addition, the authors allow for an heterogeneity of banks liquidity conditions. The presence of this difference in banks liquidity availability have an important effect on the working of the interbank market. The authors show that banks with lower liquidity react more to a variation in the interest rate compared to the counter-parties with an higher availability of liquidity. This last liquidity effect, called Kashyap and Stein liquidity effect, has important consequences in the working of the interbank market when heterogeneity among institutions is introduced.

A different explanation on the inter-bank interaction is provided by Acharya,
Gromb and Yorulmazer (2008). The authors consider the relationship between two banks with opposite liquidity conditions: one with a liquidity surplus, and the other one with a liquidity deficit. In their model banks are allowed to satisfy their liquidity needs via interbank lending, and via assets selling. The theoretical framework described allows for three sources of frictions: liquidity concentration among few banks, bank-specific assets, and need of a costly investment monitoring by banks to obtain increased returns from their investments. The last element in particular may introduce moral hazard in the interbank exchanges. The interaction of this three effects reduces market efficiency. The introduction of moral hazard in particular may introduce predatory lending among institutions. In other terms banks with higher liquidity may exploit their position to obtain an higher interest on the capital provided.

The conclusion of the work of Acharya, Gromb and Yorulmazer is that states in which the liquidity is enough to satisfy the needs of the participants can be transformed in situations of liquidity shortage.

The result of predatory lending during periods of financial distress does not seem to be in line with the results obtained by the bank-to-bank relationship lending during the current financial crisis. According to Affinito and Brauning, the inter-bank relationships have lasted during the financial turmoil, and furthermore those banks which had a strong relationship paid less than other banks during the turmoil (Affinito 2011, Brauning 2011).

Also in the empirical literature the main interpretations to market inefficiency under a crisis are counter-party risk and the adoption of liquidity hoarding practices. Some of the papers from the empirical literature have been developed explicitly to understand the developments of the 2007 financial crisis (see Gabrieli 2011), while others have anticipated some issues concerning the working of overnight money markets (see Furfine 2001).

A fundamental work explaining the banks ability to monitor their counter-parties is provided by Furfine (2001). The author argues that banks are able to monitor the characteristics of their counter-parties. Looking at data on the Fedfunds Furfine identifies that, regardless of the side of the transaction big banks tend to have a more favourable condition in the exchange. Big borrowers pay a lower interest compared to small borrowers, and big lenders obtain an higher interest compared to small lenders. This result seems to point toward a "Too-Big-To-Fail" effect in the interbank market. Running a regression on Fedfunfds data with the interest rate as a dependent variable, and a vector of elements as explanatory variables (borrower credit risk, borrower and lender characteristics, transaction characteristics, borrower and lender relation- ship, day of the sample) the author realized that the price of Fedfunds partially reflects the credit risk of the borrowing institution. Banks which present higher profitability, a lower amount of troubled loans, and higher capital ratios, paid lower prices when transacting overnight.

This last result is central in our analysis, since it provides evidence that banks monitor their counter-parties, at least during normal times.
The analysis provided by Furfine (2001) does not include the dynamics of the interbank market during the 2007 financial crisis. Nonetheless, the prove that banks are able to monitor their counter-parties have important implications in analyzing the dynamics occurring in the interbank market during the current financial crisis.

The work by Acharya and Merrouche (2009) points towards the presence of liquidity hoarding on the inter-bank market. Based on an analysis of the sterling money market, the authors identify three main facts. First, UK banks liquidity holding increased by thirty percent in the period immediately after 9th August 2007. Second, the amount of liquidity held by banks is much influenced by the need of foreseeable payments activities. And finally, the authors identify a causal effect of market liquidity on interbank rates, in both secured and unsecured markets. The same effect had not been present before the crisis. According to the authors, banks liquidity hoarding has increased the rates in the interbank market providing a contagion effect.

Acharya and Merrouche address this effect to the highly tiered structure of the English banking system. In their analysis, the authors recognize that the English banking system is composed of different tiers, where the first tier is composed by high banks, while the second tier is composed of smaller institutions. According to the authors, the different tiers do not have the same access to liquidity. The banks of the first tier may in fact have access to the liquidity provision of the Central Bank. Due to the higher amount of competitions among banks, those institutions form the first tier provide liquidity vertically to the ones of the second tier. On the contrary, second-tier institutions provide liquidity also horizontally, that is they provide liquidity also to other second-tier banks. One negative effect of the tiered structure is that during the crisis the tiered structure forced big banks to hoard liquidity to self-insure against liquidity shocks. The previous result highlights the importance of the banking structure on the market dynamics during a turmoil. In these sense, the efficiency of monetary policy could be affected by the structure of the banking system.

Afonso, Kovner and Shoar (2010) analyze the role of liquidity hoarding and counter-party risk in the Fedfunds market during the 2008 financial crisis. The authors find elements of stress, however, they do not find a complete freeze of market activity. According to their results, counter-party risk played an higher role in reducing the efficiency of the Fedfunds, rather than liquidity hoarding. Concerning the borrowing dynamics of very risky institutions, the authors show that those institutions were experiencing credit rationing even in the pre-crisis period, rather than experiencing very high rates on the Fedfunds market. After the Lehman bankrupt, the market became more sensitive to bank-specific characteristics, both in the amount lent, and in the cost of borrowing. This empirical result provides important space for banks heterogeneity into a theoretical model able to explain the credit market condition under a period of financial stress.

The authors recognize a sudden increase in interest rate volatility around the
failure of Lehman Brothers. The increased dispersion of the interest rates paid by banks during the second phase of the crisis has been recognized also by Angelini, Nobili and Picillo (2009). This dispersion may play a central role in how banks process information during a crisis.

Angelini, Nobili and Picillo (2009) try to identify the role of bank-specific characteristics in the working of the interbank market looking at data on the e-Mid. The authors focus on the spread between collateralized and uncollateralized rates, in order to neutralize the effects of the Central Banks decisions. The authors regress spreads determined on individual transactions, on a set of bank specific characteristics and explanatory variables, allowing to estimate the cross-sectional distribution of rates paid. Looking at the Kernel probability density distributions of interbank interest rates with maturity ranging from one week to three months, they can recognize an increase in inter-bank dispersion with the beginning of the crisis. The rates dispersion registers a further increase after Lehman failure.

The authors argue that the bulk of the variability is mostly due to the market conditions, while a minor part is influenced by bank-specific characteristics. As an additional result the authors recognize that during the crisis the average borrower quality did not change, and the pool of lenders and borrowers seemed not to have changed much during the turmoil. This result may highlight the importance of understanding the factors determining agents beliefs on the risk-ness of their counter-parties.

According to Cassola, Drehmann, Hartman et al (2008) the emergence of information problems in new credit and money markets were at the roots of the spread of the crisis. Authors identify two kinds of information problems: general uncertainty (imperfect information), and adverse selection (asymmetric information). As specified by the authors, a reason for the increase of general uncertainty stands in the diffused perception that evaluation practices of market participants were unreliable. Both effects may have plaid a role during the crisis, influencing banks general perception of the market, and their caution in approaching counter-parties.

Looking at e-Mid data from January 2007 to January 2008 the authors identify a magnifying effect given by the general uncertainty of banks regarding the holders of toxic assets, such as toxic CDOs. Comparing the results prior and post the crisis, the average premia of banks CDS increased from 21.7 to 77.2, and the average volatility of banks CDS increased from 39.9 to 89.8. This shows both an increase in the average counter-party risk, and an increased market dispersion. Looking at the ratio between post- and pre-crisis values, the average increased more than the standard deviation. Authors consider this as the evidence that the average component of credit risk has increased more than bank-specific risk. The high increase in the average component of risk indicates the importance of the change in the general conditions of the market during the turmoil. This last condition indicates an important change in the environment in which all banks were operating.
Gabrieli (2011) makes an extensive empirical analysis to understand the working of the Italian e-Mid. According to the author, the impact of moral hazard and adverse selection plaid a major role on longer-maturities in the credit market, while it plaid only a minor role for the overnight maturities. Banks reputation, considered as the proxy of the rate paid by institutions in the period preceding the crisis, seems to have had a considerable role in influencing the market rates.

Via regression techniques, the author shows that the interest rate on the e-Mid has registered a downward pressure due to the Central Bank liquidity provision. The same liquidity provision has, however, a strong positive correlation with the increase in banks reserves. The increase of excess reserves induced an important reduction of liquidity demand, with a consequent reduction in the interest rates (crowding out effect).

Interestingly Gabrieli finds some diversification in the effects of banks capital borrowing in the market. In particular it appears that borrowing from an high number of counter-parties was more costly for banks in the e-mid during normal time. This effect has exacerbated with the spread of the financial crisis. This result may indicate that banks may think that borrowers asking for capital to an high number of lenders may be financially weak, therefore they might be perceived as risky from their counter-parties.

The latter result provides an additional evidence of the presence of strategic interaction in the interbank market among institutions.

Some empirical papers have highlighted the presence of lasting inter-bank relationships in inter-bank markets. The first paper highlighting this effect is provided by Cocco, Gomes and Martins (2009). Looking at data from the Portuguese interbank market running from January 1997 to March 2001, the authors find that banks trading on the interbank market develop long-term relationships. This relationships extends also outside the overnight market.

The authors create their own indicators of the relative importance of an exchange relationship. The first one is the Borrower Preference Index (BPI) between bank B and L, defined as the amount that bank B has borrowed from bank L over the total amount that bank B has borrowed from the interbank market. The Lender Preference Index (LPI) is created in a similar way. The authors recognize that more than 50 percent of the exchanges among banks are done with the three banks with higher BPI.

The authors consider the difference of the interest rates paid on all loans from bank L to bank B and the average interest rate of the transactions during the trading days in every quarter. This specification allows to determine the importance of the relationship between bank B and bank L, given the average market level of relationship across banks.

The authors run several regressions to identify which elements influence the interest rate measure previously defined. The result is that bigger banks obtain better interest rates regardless of their side in the transaction. Furthermore banks with higher amounts of surplus deposits pay on average lower rates. In-
Interestingly enough the BPI and the LPI tend to influence the interest rate. Higher BPI values tend to reduce the interest rate in interbank transactions, while higher LPI tends to reduce the interest rate of interbank transactions. Furthermore the authors recognize that small borrowers rely more on lending relationships. In addition small borrowers tend to have large banks as lenders, while small lenders tend to have relationships with bigger borrowers. Interestingly the authors find that borrowers with higher default risk tend to rely more on interbank relationships and to pay higher interest rates, but they tend to pay lower prices if they rely on those banks with whom they have an high BPI. Cocco et al. interpret the results obtained in stating that the observed relationships tend to provide a liquidity insurance among banks. The authors draw this conclusion noting that banks with larger reserve imbalances tend to borrow funds more frequently from those institutions with whom they have a relationship. A similar condition holds for banks with higher volatile liquidity shocks. In this terms long-term lending relationships among banks seem to be important an important in defining market dynamics.

A further analysis on inter-bank relationships is provided by Affinito (2011). The author determines the lasting of interbank relationships using a methodology extensively explored in labour economics to compute the lasting of unemployment. Looking at monthly data for the Italian interbank market, with a sample running from June 1998 to April 2009, the author estimates the probability of switching in interbank relationships, that is the probability of ending the relationship for even one month. The author uses that analysis to estimate the lasting of the relationships during the financial crisis. Affinito recognizes a negative duration dependence in the estimated model, that is banks relationships tend to reinforce over time. Borrowers who tend to have longer relationships are those who are: better capitalized and more profitable (as measured by their capital and their ROE), more focused on fees-generating services, rather than interest-generating activities (as measured by the non-interest income over net interest income), if they are either well-rated or non-rated, and finally if their lending activity is florid (as measured by their total loans). Lenders which are better capitalized, profitable, and liquid are more likely to have lasting relationships. The author then highlights two other important results: first those couple of banks who transact also outside the interbank market tend to have longer relationships. Hence the formation of interbank relationships seem to be part of a strategic decision among credit institutions. All the evidences of bank-specific characteristics in influencing the lasting of the relationship shows that market participants adopt indeed some form of strategic behaviour. In addition the author suggests that inter-bank relationships are influenced not only by continuous interaction, but banks also adopt a continuing monitoring of the banks with whom they have a relationship, indicating that bank-specific characteristics continue to play an important role. An important result by Affinito is that interbank-banks tend to last of the development of the crisis. This result is in contrast with the one described by
the theoretical literature of predatory lending in the inter-bank market during a turmoil.

Brauning (2011) provides another interesting result concerning the role of interbank relationship. Looking at German data of interbank transactions obtained from the TARGET payment system from March 2006 to November 2007, the author confirms the presence of lasting inter-bank relationships in overnight transactions. The aim of the author is to model the matching probability between bank $i$ and bank $j$, as well as the interest rate spread on the policy rate paid on banks overnight transactions. The first result is obtained using a Probit model for the probability of matching, while the second result is obtained via regression analysis.

To estimate the importance of relationships Brauning creates BPI and LPI similar to the ones used by Cocco et al., as well as a measure of the intensity of the exchanges. Those measures influence both the probability of connection between two banks, and the interest rate paid in the transaction. Also in this analysis banks interactions tend to reinforce over time. Considering the model estimated after the beginning of the crisis, the author recognizes that the importance of the BPI and LPI measures were unchanged after the turmoil. This result provides a further evidence that bank-to-bank relationships played an important role in the working of the interbank overnight market also under financial stress.

The author finds that before August 2007 relationship lenders imposed higher charges to banks with whom they had a relationship, however after the start of the crisis, lenders provided lower rates to their relationship counter-parties, compared to other institutions. The same result holds also for different specifications of the relationship measure. One interpretation of this result is that during normal times borrowers pay a premium to keep their lending relationship, however during periods of financial distress they receive a better rate due to the higher information at disposal of lenders.

A growing body of literature on the interbank market has used network analysis to explain the dynamics of interbank exposure. Gai, Aldane and Kapadia (2011), for example, use network analysis and simulations to estimate the effect of banks liquidity hoarding. The authors develop a random network structure, where the links among the different nodes are obtained with a fixed probability. Once the network is determined, banks face an idiosyncratic shock to their liquidity. Authors assume that banks react to a liquidity shock by hoarding a percentage of the liquidity it has provided to counter-parties. In their model the probability of contagion is non-monotonic in connectivity, at first increases and then it decreases. This indicates that a network of bank relationships could either improve or reduce market stability according to the frequency of those relations.

Some other papers have used agent-based models and simulations to analyze
the working of inter-bank exchanges. Ladley (2011) describes the behaviour of heterogeneous banks within a closed economy. In its framework there are two kinds of agents: households and a group of heterogeneous banks. The first ones provide their deposits to banks which maximize their expected returns in the short run, and borrow money for risky projects, while the second ones provide capital to households and other banks. From this framework the author obtains the following results: large banks are net borrowers, small banks are constrained in their level of equity, most banks lend few amounts to a large few banks, and Bankrupts increase with connectivity if external shocks are low, while they decrease with connectivity if shocks are high. Interestingly the author introduces interbank confidence. In this case banks are allowed to react negatively to the failures of other banks. The presence of inter-bank confidence amplifies the negative effect of the crisis on banks condition. This last element provides important insights concerning the aggregate effects of market agents beliefs.

From the results proposed so far it is clear that asymmetric information has plaid a central role in the reduction of th inter-bank market efficiency during the financial crisis. Rather than simple liquidity hoarding, or pure counter-party risk, it can be considered a general trust evaporation among institutions. The informational problem connected with this reduction of trust was partially solved by credit institutions through a careful choice of the counter-parties with whom to trade. This choice in turn was generally possible due to the banks ability to monitor other institutions. The repeated interaction among banks, and the continuous monitoring of counterparties has permitted the continuation of trades among banks with preferential relationships. Nonetheless the increase in financial tensions, together with the uncertainty on the general environment, has induced banks to reduce exchanges with the other banks in the market. The presence of this banks behaviour needs to be understood carefully in order to explore the working of the inter-bank market during periods of financial distress. For this reason a model of inter-bank transactions should include psychological elements and agents expectations.

The Model

The economy is populated by \( N \) banks. Time is divided into discrete periods \( t = 1, 2, \ldots, T \). Assume that a fraction \( \lambda \) of banks are borrowers, and a fraction \( (1 - \lambda) \) are lenders. Using \( i \) to indicate borrowers, and \( j \) to indicate lenders we have \( i \in \{1, 2, \ldots, \lambda N\} \), and \( j \in \{1, 2, \ldots, (1 - \lambda)N\} \). For the time being borrowers and lenders will play the same role over the whole simulation.

At every time period \( t \) every borrower \( i \) has a request of \( k_{it} \) amount of capital, while lenders have an amount \( k_{jt} \) to place in the interbank market. For the moment the analysis does not considers volumes, hence it could be assumed
that \( k_{it} = k_{jt} = 1 \ \forall \ i, j, t. \)

Every transaction between borrower \( i \) and lender \( j \) occurs at rate \( r_{ijt} \). Every interest rate on banks transactions is defined inside a corridor such that

\[
r_{db} < r_{ijt} < r_{dw},
\]

where the lower bound \( r_{db} \) represents the rate paid on the deposits at the Central Bank, and the upper bound \( r_{dw} \) is the rate paid at the discount window.

The strict inequality in equation 1 is given by the assumption that if the interest rate proposed in the transaction equals the upper (lower) bound, the borrower (lender) prefers to borrow (lend) money from the Central Authority.

The model will consider four different markets. In the first two markets borrowers bids are publicly known, while in the other two markets borrowers bids are private information. Every scenario is further divided in two cases, one considering homogeneous banks, and another one considering heterogeneous banks.

The aim of this subdivision is to create a reference case for each kind of market, in order to compare the results of the interbank transactions when banks heterogeneity is introduced.

The first market structure in which borrowers bids are public information aims at simulating a transparent inter-bank market such as the e-Mid. The second market structure where borrowers bids are private information bids aims at simulating the working of an Over-the-counter market such as the Fedfunds market.

The introduction of banks heterogeneity in the market with publicly observable bids aims at considering whether there are conditions for the formation of interbank relationships even under a regime of full information. The following pages will provide an explanation of the working of the market developing a model for each case.

**Model one: market with public bids and homogeneous banks.**

At every time \( t \) borrowers will post their bids on the interbank market. All borrowers bids and trades are visible to all banks operating in the system.

Borrowers are all equally risky and have a probability of default \( P(i) = p. \)

Lender are an homogeneous population. The rate at which lender are indifferent between lending to a risky borrower or keeping their reserves in central bank accounts is given by

\[
r^* = r_{db}/p.
\]

This assume lenders only look at expected returns from investment. Scenarios where lenders have a more complex utility function can also be considered.

We assume that lenders enter the market in random order and select among the available offers the one at the highest interest rate (as long as \( r_i > r^* \)).

Borrowers profits for every time \( t \) can be defined according to the following expression

\[
\pi_{r,t} = \begin{cases} 
  r_{db} - r_{ijt} & \text{if they have been selected by a lender,} \\
  r_{db} - r_{dw} & \text{if they have not been selected by a lender.}
\end{cases}
\]
In the previous equation the second case is obtained when banks have not been selected by lenders, therefore they need to withdraw at the discount window. Borrowers learn their bidding strategy via reinforcement learning. Borrowers will compare the higher profits of bidding a low interest rate, with the reduced probability of being selected from lenders.
In this setting borrowers learn to bid at \( r_i = r^* \).

**Model two: market with public bids and heterogeneous banks**

In this case heterogeneity is introduced among borrowers. For simplicity we assume that borrowers can be divided into two groups: \( G \) (good) and \( B \) (bad). The first category represents banks with a low probability of default \( p_g \), while the second one represents banks with a high probability of default \( p_b > p_g \). We assume that information about these probabilities is initially perfectly available to all the market participants via an exogenous source (for example via a credit rating system). This implies that lenders know with probability one whether the counter-party is a good or a bad borrower, or

\[
P^{ex}(i \in G) = 1 \quad if \quad i \in G,
\]

\[
P^{ex}(i \in G) = 0 \quad if \quad i \in B,
\]

Lenders rank the borrowers’ offer according to their expected profit

\[
\Pi^L_i = r_i \cdot p_i
\]

where \( p_i = p_g \) if \( i \in G \) and \( p_i = p_b \) if \( i \in B \). The ranking is common to all lenders. Lenders are neutral to lend to a bad lender or a good lender when

\[
r_b = r_g \frac{p_g}{p_b}
\]

where

\[
r_g = \frac{r_{db}}{p_g}.
\]

We assume that at some time \( \tau \) an exogenous shock hits the market and the exogenous information about borrower quality becomes imperfect. In this way we want to mimic the recent financial crisis, where lack of information about which banks were exposed to toxic assets, made it difficult to assess their default probabilities. For simplicity we assume that no exogenous information about the probabilities of default is available at all, or

\[
P^{ex}(i \in G) = 1/2 \quad if \quad i \in G,
\]

\[
P^{ex}(i \in G) = 1/2 \quad if \quad i \in B,
\]

At this point lenders try to identify good and bad borrowers by looking at the history \( F(t) \) of trades borrowers executed over time. Given such distribution
they infer the conditional probability $P^L_g(i, t) = P^L(i \in G \mid \mathcal{F}(t))$, $P^L_b(i, t) = P^L(i \in B \mid \mathcal{F}(t))$ of a given borrower to be good or bad. Lenders then identify the borrowers they can satisfactorily discriminate as good or bad, that is, those for which

$$P^L_g(i, t) > K \quad \text{or} \quad P^L_b(i, t) > K$$

(with $K$ a threshold level $0.5 < K < 1$ which is a parameter of the model) and rank their offers accordingly to the expected profit from the trade

$$\Pi^L(i) = r_i \cdot p_g \cdot P^L_g(i, t) + r_i \cdot p_b \cdot P^L_b(i, t)$$

The ranking is common to all lenders. Lenders enter the market at random. The matching in this case is implemented under the assumption of bounded rationality in which case lenders select a borrower with a probability $p_{ji}$ proportional to the profit from its trade, according to

$$p_{ji} = \frac{e^{-\beta \Pi^L(j)}}{\sum_{i \in O(j)} e^{-\beta \Pi^L(i)}}$$

where $O(j)$ is the set of borrowers that $j$ can confidently screen, that is that satisfy

$$\max(P^L_g(i, t), P^L_b(i, t)) > K \quad \text{or} \quad \max(P^L_g(i, t), P^L_b(i, t)) > K$$

where $P^L_j(i, t)$ is the probability that lender $j$ infers about borrower $i \in G$ using private information, that he can acquire following the mechanism below. If a lender $j$ enters the market at time $t_0$ when no more borrower are left for which condition eq. 4 is satisfied, lender $j$ may decide to acquire additional private information on one of the remaining borrower $i$ paying a screening cost $\delta$. We assume that such cost is lower whenever the lender wants to obtain additional information on a borrower with whom it has already traded according to

$$\delta = \delta_0 (1 - LPI_{i,j,t})$$

$$LPI_{i,j,t} = \frac{\sum_{l=1, l \in \tau}^L L_{ij}}{\sum_{j=1}^{(1-\lambda)N} \sum_{l=1, l \in \tau}^L L_{lj}}$$

Further, we assume that the quality of the private information on the borrower is perfect when acquired, that is

$$P^L_g(i, t_0) = P^L(i \in G) = 1 \quad \text{if} \quad i \in G,$$

$$P^L_b(i, t_0) = P^L(i \in G) = 0 \quad \text{if} \quad i \in B,$$

but decreases over time according to the following expression

$$P^L_g(i, t) = P^L_g(i, t_0) \min(0.5, \exp^{-r(t-t_0)}) + (1 - P^L_g(i, t_0)) \min(0.5, \exp^{r(t-t_0)})$$

$$P^L_b(i, t) = P^L_b(i, t_0) \min(0.5, \exp^{-r(t-t_0)}) + (1 - P^L_b(i, t_0)) \min(0.5, \exp^{r(t-t_0)})$$
where \( t_0 \) represents the time at which the lender has paid the screening cost.

Under this new market setup lenders may not always be able to distinguish among good and bad borrowers and their choices of counter parties will become slowly more random. As a consequence the reinforced learning mechanism on the side of the borrowers will also not work well leading to an increased dispersion in the rate offered by individual borrowers. This in turn makes it even more difficult for the lender to discriminate the borrowers generating a feedback loop that provides on one side a market mediated coordination (indirect herding) of lenders assessment on the borrowers quality, thus possibly leading to panic and a generalised trust evaporation. On the other side it creates incentives for lenders to pay the screening cost to gather private information on borrowers, thus leading to more relationship lending which, with informed lenders revealing better quality information to the overall market via trading, may possibly become a stabilising factor.

Model three, market with private bids, and homogeneous banks

At every time period \( t \) every borrower faces the binary choice between contacting a fixed number of random lenders \( z \), or contacting the lender with whom it has the strongest past relationship. For borrower \( i \) the preferred lender is the one with higher LPI index as defined in equation 6. In case of two or more lenders \( j \) having the same LPI with a borrower \( i \), the preferred lender of borrower \( i \) will be randomly determined. At every time period \( t \) the problem of borrower \( i \) is to choose between contacting its preferred lender or alternatively contacting \( z \) random lenders. The borrower solves this problem considering the expected profits of the two options. Hence borrower \( i \) problem becomes:

\[
\max \{ E(\pi_{rel,it}), E(\pi_{search,it}) \}, \tag{8}
\]

where \( E(\pi_{rel,it}) \) represents the expected profits of contacting the lender with whom borrower \( i \) has the strongest past relationship, and \( E(\pi_{search,it}) \) represents borrower \( i \)’s expected profits of contacting \( z \) random lenders in the market. At the end of every period \( t \) each borrower will consider the payoff it has obtained from the transaction at that particular rate. Borrowers payoff will be defined according to the following equation

\[
\pi_{r,q} = \begin{cases} 
    r_{db} - r_{ijt} - \theta q & \text{if they have been selected by a lender}, \\
    r_{db} - r_{dw} - \theta & \text{if they have not been selected by a lender}.
\end{cases} \tag{9}
\]

Differently from model one, this case introduces a contacting cost \( \theta \) for each counter-party contacted, where \( q \) represents the number of contacted counter-
parties. In this model borrowers need to compare the expected profits of contacting the preferred lender with the expected profits of contacting \( z \) random lenders.

Also in this model borrowers modify the probabilities of choosing one particular interest rate via reinforcement learning.

Lenders only know bids from those borrower by whom they are contacted. The lenders proposals acceptance works according to the following mechanism. Lenders receive proposal from borrowers. Every lender orders the received proposals from borrowers and it chooses the highest one. When multiple lenders receive the same proposal, the one which will conclude the transaction is selected at random. Once decided which lender will perform the transaction, the specific proposal will be removed from the set of proposals arrived to other lenders. All the other lenders must then choose again from their set of proposals removing the one which has already been assigned. The process is reiterated until there are no proposals left. The result of model one will be used as a reference for the following case.

Model four, market with private bids and heterogeneous banks

In this case borrowers have own specific characteristics. Banks’ heterogeneity is considered as representing banks credit rating.

The borrowers problem remains unchanged compared to model three. Differently from model two lenders are not able to obtain information on their counter-parties looking at the history of previous bids. The only possibility for lenders to know the characteristics of counter-parties is to pay a screening cost \( \delta \) defined as in equation (5).

Once paid the screening cost the lender will have some additional information on borrower \( i \). The value of this information will decrease over time according to expression (7).

The payment of the screening permits the lender to know the exact default probability of the borrower. Once the information on the borrower reaches zero the lender will consider the borrower as a random borrower. The lender assumes that the default probability of lenders on which he has no information, named \( p_{\text{gen}} \), will be distributed according to the following expression

\[ p_{i}^{\text{gen}} \sim N(\mu_t, \sigma_t). \] (10)

The parameters \( \mu_t \) and \( \sigma_t \) in expression (10) are determined over time according to the news which are coming from the market. It is assumed that the parameter \( \mu \) will increase if news point towards an increase in market risk, while it reduces otherwise.

Lender’s \( j \) profits are determined according to

\[ \Pi_{j,i}^L = r_{i,j} \cdot p_i, \] (11)
where the probability $p_i$ is borrower-specific whenever the lender has some information on the counter-party, while it is equal to $p^*$ for those borrowers on which the lender has no information.

The lender registers the amount of previous period profits. Every lender computes the ratio between the volatility of previous period profits, named $\sigma_{\Pi^L_{j,i}}$, with the average previous period profits $\Pi^L_i$. If such ratio is higher than a threshold level $\Psi$ the lender decides to pay the screening cost on the borrower from which it has the strongest relation. Formally this happens if

$$\frac{\sigma_{\Pi^L_{j,i}}}{\Pi^L_i} > \Psi.$$  \hspace{1cm} (12)

The introduction of banks heterogeneity modifies the incentive structure of lenders. Similarly to the previous case, lenders have the incentive to continue the relationship with a particular borrower once they have paid the screening cost $\delta$. Nevertheless in those cases in which the lender has contacted a borrower whose features are lower than the average of other borrowers, the lender may find it optimal to decide not to continue its relationship over time.

Over time lenders screening decisions will affect borrowers bidding strategies modifying their expected probabilities of concluding the transaction. Under this case the screening costs should provide a minimum requirement for the development of inter-bank relationships.

We are currently developing some simulations with the models presented so far. The final results of those simulations will be provided in the final draft of the paper.
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