A functional perspective to financial networks*

Edoardo Gaffeo†
University of Trento - Department of Economics and Management

Massimo Molinari‡
Sapienza University of Rome - Department of Economics and Law

Abstract

The financial sector is a critical component of any economic system, as it delivers key qualitative asset transformation services in terms of liquidity, maturity and volume. Although these functions could in principle be carried out separately by specialized actors, in the end it is their systemic co-evolution the determines how the aggregate economy performs and withstands disruptions. In this paper we argue that a functional perspective to financial intermediation can be usefully employed to investigate the functioning of financial networks. We do this in two steps. First, we use previously unreleased data to show that focusing on the economic functions performed over time by the different institutions exchanging funds in an interbank market can be informative, even if the underlying topological structure of their relations remains constant. Second, a set of alternative artificial histories are generated and stress-tested by using real data as a calibration base, with the aim of performing counterfactual welfare comparisons among different topological structures.

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†Edoardo Gaffeo, Department of Economics and Management, University of Trento, Via Inama 5, I-38100 Trento, Italy. *email:* edoardo.gaffeo@unitn.it

‡*Corresponding Author*: Massimo Molinari, Department of Economics and Law, Sapienza University of Rome, Via del Castro Laurenziano 9, 00161 Rome, Italy.
email: massimo.molinari@uniroma1.it

1 Introduction

Financial networks have been subject to substantial scrutiny over the last two decades, and a vast literature based on complex system analysis has actively contributed to enhance our understanding of contagion-related phenomena in modern financial systems. Recognizing the pervasiveness of cyclical interdependencies (A has obligations to B, who has obligations to C, who in turn has obligations to A) and higher-order feedbacks, complex network models have been rightfully employed both by academics and analysts in central banks for the assessment of systemic risk, and have so far provided promising guidance as to how such risk maps onto the topological structure of the web of transactions that link financial institutions together. A large body of empirical studies have indeed focused on the characterization of such properties in real-world financial networks[1], whereas simulation models have been developed to assess the extent of system-wide disruption under different capitalization scenarios, network topologies, resolution procedures, alternative contagion channels, types of shocks, heterogeneity in interbank exposures and consolidation policies.[2]

The rationale for this huge research effort is that financial intermediaries are a key component of any economic system, since they deliver services - or functions, according to the conceptual framework put forth by Robert Merton and Zvi Bodie (Merton, 1995; Merton and Bodie, 1995, 2005) and - that are critical for the saving-investment process, like the clearing and settlement of payments, the provision of credit and liquidity, the management and pricing of risk, and the deployment of mechanisms for dealing with the incentive problems associated to asymmetric information. While the institutional structure of financial systems - in terms of the prevailing institutions, instruments and markets - can vary substantially over space and time, the basic functions at the root of their existence remain basically the same. An obvious corollary descending from such a perspective is that the analysis of how a financial system works should be primarily focused on what kind of functions are activated by each financial institution, how they evolve over time, and how they interact and co-evolve with those performed by other actors.

In performing their core functions, bank-like financial intermediaries act as qualitative asset transformers by issuing claims with different attributes to their borrowers and lenders, respectively (Bhattacharya and Thakor, 1993; Gorton and Winton, 2003). In particular, intermediaries finance illiquid assets with liquid liabilities (liquidity transformation), fund long-term investments by issuing short-term debts (maturity transformation), and hold on their books assets with larger unit size than their liabilities (volume transformation). As shown by Craig and Von Peter (2014) and Fricke and Lux (2015), they do so not only for their nonfinancial customers - i.e., firms and households - but also for other financial institutions: interbank markets are typically tiered architectures, with a small number of banks (forming the core) intermediating between a large number of banks that do not extend credit among

[1] See, among others, Boss et al. (2004); Iori et al. (2006); Soramäki et al. (2007); Martinez-Jaramillo et al. (2014); Bargigli et al. (2015).

[2] Nier et al. (2007), Gai et al. (2011), Battiston et al. (2012), Krause and Giansante (2012), Anand et al. (2013) and Gaffeo and Molinari (2015, 2016).

themselves (populating the periphery).

In the literature dealing with financial networks, the role of each of the three qualitative transformation functions performed by financial intermediaries inside the financial sector has been so far mostly analyzed as a separate phenomenon. In reality, in a financial network the liquidity, maturity and volume transformations occur simultaneously and interact, although with possibly different specializations occurring at different nodes. Furthermore, the very same intermediary can convert its transformative core function over time - for instance, by switching from being mainly a liquidity transformer to a volume transformer - so that the functioning of the network, as well as its vulnerability to external shocks or to the unfolding of endogenous risk, can vary even if the topological structure remains constant.

This has profound policy implications. Besides the conventional concern of regulating banks according to their contribution to systemic risk - which is clearly related to their degree of interconnectedness - the focus on the actual functions provided by financial intermediaries as heterogeneous nodes of a financial network speaks directly to the transmission mechanism of monetary policy. Malfunctions in one or more critical nodes ensuring qualitative asset transformation services for the rest of the financial system exert an impact on the central bank's ability to affect the real economy through the bank-lending or the risk-taking channels as it moves interest rates. Furthermore, the effectiveness with which a central bank acting as a lender-of-last-resort channels funds to restore normal market conditions during a crisis depends on the specialized function enacted by the class of intermediaries chosen as the insertion point of extra liquidity.

The purpose of this paper is partly empirical and partly methodological. On the one hand, we provide evidence documenting that the functional perspective to financial intermediation can indeed represent an improvement of our understanding on how actual financial networks work, as well as on how policy actions impinge upon them. On the other hand, we propose a novel approach to comparatively assess the functional performance of alternative institutional structures. This is grounded on the idea of comparing the historical evolution of the actual institutional setting under alternative stress-testing scenarios, with those that one would have obtained if the structure of the financial system - in our case, the topology of the interconnections linking financial intermediaries - had been different.

We have access to a unique dataset that allows us to provide a thorough inspection and characterization of a financial sytem in which several of the transformative functionalities recalled above can be explored with a good degree of accuracy. More in detail, we exploit a network approach to offer an empirical assessment of the double role played by Cassa Centrale Banca (henceforth CC) - a money center offering intermediation services (although not exclusively) to a large number of small cooperative credit banks in the North-East of Italy [3] - as a provider of qualitative asset transformation for other intermediaries on the one hand, and as an entry point

[3]Within the Italian cooperative credit system, comprising 364 intermediaries at the end of 2015, it is possible to distinguish between rural banks, cooperative credit banks and Raiffeisen banks. All of them are mutual not-for-profit cooperatives, operating with a small number of branches (the average for the system in 2015 was 8) on local markets. In what follows we use the expression "cooperative credit banks" as a shortcut to comprise them all.

for liquidity injections by the central bank, on the other one.

The financial network under scrutiny is characterized by a star-shaped topology. Due to their tiny size, most of the cooperative credit banks involved have no direct access to the official interbank market to accommodate their surpluses and deficits of liquidity. They use instead a sort of liquidity pool - CC itself, which is a dedicated company hold by a large majority of the cooperative banks operating in the three regions of the North-East of Italy (Trentino-Alto Adige, Veneto and Friuli Venezia-Giulia) - that, in addition to accepting deposits from and extending loans to banks, has direct access to the wholesale funding market and to the refinancing facilities of the Bank of Italy. Our dataset comprises previously unreleased overnight and non-overnight records of interbank flows intermediated by CC over the period 2001-2011 among 224 credit cooperative banks and 69 shareholders banks, together with detailed information on the liquidity injections provided by the Bank of Italy. The time span covered by the dataset is particularly appealing, as it sequentially comprises a period of substantial tranquility, the local reverberation of the global financial turmoil of 2007-08, and the outbreak of the European sovereign debt crises in 2010, which caused the monetary authority to activate a sizable program of Long Term Refinancing Operations (LTROs) to restore normal market conditions.

Recent research has highlighted that in interbank markets systemic losses due to liquidity shortages crucially depends on the structure of interactions between surplus and deficits units (Acharya et al., 2012). Thus, our main focus of interest is on the role of the money center CC as an intermediary between these two types of actors. In the period of time considered, we can identify three distinct stages: i) at first, CC acts as an intermediary between surplus cooperative banks and deficit shareholder banks; ii) during an intermediate phase, CC works as a liquidity distributing device also among cooperative banks, with excess liquidity deposited at the central bank; iii) at the very end of our observation period, CC performs as a key node in the transmission of monetary policy.

Our main empirical findings can be summarized as follows. First, the degree of interconnectedness in the network has remained stable until the onset of the 2007-08 financial crisis, and it has increased exponentially during the sovereign debt crisis. Second, the persistence of bilateral trading between the hub and leaf nodes of the star has been significantly higher and more stable for borrowing. A structural break appeared as the central bank starts to provide liquidity to the market in the first half of 2010. Third, the role of CC has changed over time from being a net lender to become a net borrower. Fourth, until the end of 2005 CC operated as a maturity transformer for the system by acting as a net borrower in the overnight market and a net lender in the non-overnight market. By the end of 2010 this function was completely reversed. Fifth, the presence of CC were also conducive to a volume transformation of interbank flows. It did so by intermediating liquidity from a large number of surpluses units to a small pool of deficit banks, whose liquidity requirements were much larger in volume.

Clearly, none of these functions could have been executed if the liquidity exchanges flowing through the network were somehow interrupted, due for instance to external liquidity shocks causing serious disruptions of the interbank market through contagion-like cascades. A core tenet of the functional perspective advanced by Merton and Bodie is that the institutional structure of a financial system - in which we encompass the network of relations linking intermediaries - is evolutionary driven towards efficiency by continuous competition and innovation. Is this prediction true for the interbank system we are studying? Notice that other competing market architectures (e.g., alternative interbank arrangements; direct refinancing at the central bank) were in fact available, while CC has been deliberately created an instance of innovation by other actors to smooth and coordinate their interactions.

When read in the light of the literature dealing with the relationship between network topology and the vulnerability of the financial system to systemic risk, therefore, the functional perspective to financial intermediation encourages us to advance additional questions, which we tried to answer by adopting a counterfactual history approach. Was a star-shaped topology really efficient in limiting the risk of aggregate disruptions due to liquidity shocks, or would other network architectures have been capable to ensure better results? What kind of outcomes would we have achieved if the central bank's liquidity injections had been made through the money center, as it actually occurred, but banks were allowed instead to exchange funds also bilaterally? What if the central bank could inject liquidity without the intermediation of CC?

In order to answer these questions we use computer simulations to generate a set of "what if" alternative histories. We artificially alter the underlying structure of the interbank network and compare the actual star-shaped one to alternative architectures, paying attention to maintain the total amount of interbank credit and external liquidity injections equal to the ones observed in real data. In simulations, contagion dynamics are triggered by artificial exogenous (homogenous and targeted) shocks that take the form of unforeseen bank runs on deposits. Banks respond to these unexpected liquidity shortages by recalling their interbank assets. These orders work as a funding shock to their interbank borrowers who, in turn, will also call in their interbank claims. The process brings about a series of complex knock-on effects that amplify bank distress. We calculate final interbank losses by solving a fixed-point equation in a fashion similar to that presented in Lee (2013), that allows us to compute both first-order direct losses and contagion multipliers under a set of alternative network topologies. Results from our historical stress testing exercises suggest that the benefits associated with the presence of a money center, such as CC, has to be carefully pondered against the higher systemic liquidity risk flowing through the interbank market. In particular, the relative efficiency of a star-shaped institutional structure in limiting damages if a shock hits the network depends on the metric a policymaker employs in measuring welfare losses. Therefore, the role of public authorities in the dynamic process towards efficiency of a financial system is not just related to the regulation of private intermediaries or the fix of market failures, but also in the setting of policy goals.

The remainder of the paper is organized as follows. Section 2 presents an analysis of the topological structure of our dataset, with a focus on the qualitative asset transformation services operated over time by CC. Section 3 discusses the role of the hub in a star-shaped network in transferring liquidity to the whole system, and sets the stage for the subsequent counterfactual history experiment. Section 4 presents simulation results. Section 5 concludes.

2 Network Topology and the Role of CC

Cassa Centrale Banca (CC) is a financial institution created in 1974 and participated by a large number of small cooperative credit banks operating in the North-East of Italy, whose role is that of providing financial and technical assistance to its participants, as well as to other non-member local banks with different governance systems.[4] CC offers to its customers a wide range of services comprising the centralized management of payment systems and liquidity needs, the organization of syndicated corporate loans, the provision of retail and institutional asset management solutions, the supply of standardized and integrated ICT systems and advising on risk management models and processes. The data used in this study come from a confidential extraction of records regarding interbank loans intermediated directly by CC as part of the liquidity management service offered to its bank clients. We have detailed information of the loans extended and the deposits accepted by CC both overnight and non-overnight (one week or more), pooled together by single bank on a biannual basis over the period 2001-2011. Furthermore, data cover borrowing/lending transactions between CC and the central bank. While pointing primarily towards the role of CC as a liquidity pool, our data speaks more broadly to the functional perspective of financial intermediation in the tradition of Merton and Bodie (1995). CC provides funding liquidity services on both sides of its balance sheet, in that acting a critical actor in the processes through which commercial banks hedge themselves against the risks they bear in transforming liquidity on behalf of their customers - i.e., the interbank market - and public authorities manage disruptions by acting as a lender-of-last-resort. As we will show, however, CC allows the financial system to perform additional qualitative asset transformation functions. Furthermore, its role in performing these functions changes sensibly over time.

Once organized as a network, our dataset returns a typical star shape like the one reported in Figure 1. The center of the star CC borrows funds from and extends credit to a large number of private banks, both cooperative credit (CCBs) and shareholder (SHBs) ones. Private banks, in turn, do not have bilateral transactions among themselves. Furthermore, CC operates as the point of entrance of liquidity injections by the central bank (in our case, the Bank of Italy (BoI)), to which CC can turn to deposit its excess reserves. All links are therefore bidirectional. Notice that, contrary to small CCBs that in general do not access directly the electronic Market for Interbank Deposits (e-MID) or the MTS Repo platforms, CC and (at least) the larger SHBs in our sample do. Hence, the network we are considering represents a hitherto never analyzed cluster of a much larger interbank network, which has instead be the subject of deep analysis in several papers.[5]

The star is a topology that requires the minimum number of links to connect

[4] The Italian law admits several alternative governance systems for banks. In addition to cooperative credit banks, bank intermediaries can be chartered as Banche Popolari (cooperative banks with somehow lighter constraints on the fraction of loans deliverable to non-member borrowers and the distribution of dividends, and the possibility to go public), Casse di Risparmio (Savings and Loan associations, typically coming with the form of joint stock companies) and standard shareholder banks. In what follows we will group them all under the heading "shareholder banks".

[5] See, among the others, Iori et al. (2008), Finger et al. (2013), Hatzopoulos et al. (2015) and Mancini et al. (2016).

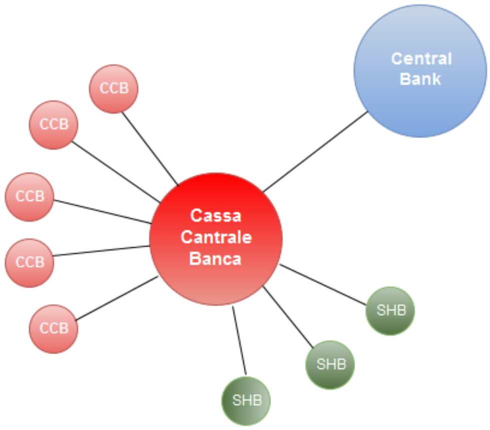

Figure 1: Schematic representation of the network

N nodes, which in our case is equal to N - 1 = 294 [6], and in which the diameter - i.e., the length of the shortest path between the most distanced nodes - is the lowest possible. Given that each transaction can be bidirectional, as we consider the overnight and the non-overnight segments pooled together the maximum number of potential transactions over the network at any point of time is 588. This figure corresponds to the potential higher order degree of the central node. Figure 2 shows that, with the exception of the first half of 2001, when the market happened to be rather rarefied, the number of active links connecting the hub remained almost stable until the onset of the 2007-08 financial crises, and it increased exponentially during the sovereign debt crises. This is in sharp contrast to the generalized squeeze of interbank activity registered in almost all countries with the insurgence of the Global Financial Crisis. This finding suggests that the presence of a money center, which was likely to be perceived as more solid than other more opaque and smaller counterparties, allowed to significantly limit the increase in counterparty risk during the crisis event. In turn, the sharp increase of interconnectedness intervened since 2010 is a signature of the role played by CC as a distributor of the extra liquidity injected by BoI through the LTROs.

The evolution over time of the in-degree (borrowing) and out-degree (lending) centrality of the hub is shown in Figure 3. It appears that CC intermediated funds by accepting deposits from a number of banks sensibly greater than that to which it lent money. Furthermore, as shown in Figure 4, the persistence of trading between the hub and the spokes - measured as the correlation coefficient between active links at two consecutive time periods - has been significantly higher and more stable for borrowing. A sudden crash appeared only when the central bank started to provide liquidity to the market in the first half of 2010, probably due to short-run adjustments in the asset-liability management strategies pursued by private banks in response to changing market conditions.

Thoroughly consistent with this general picture, the average size of transactions has been in general greater for the loans extended by CC, compared to the average size of the deposits that CC accepted (Figure 5). The two variables tend to move

[6] For a random network, the corresponding figure is N(N - 1)/2 = 43365.

together just at the end of the period, when the bulk of market activity was driven by the liquidity injections orchestrated by BoI. During normal times, CC transformed volumes by intermediating between a large pool of surplus CBBs and a smaller number of deficit SHBs, whose fund requirements were significantly larger. This can be further appreciated by looking at Figure 6, which reports quantile graphs for four selected semesters.

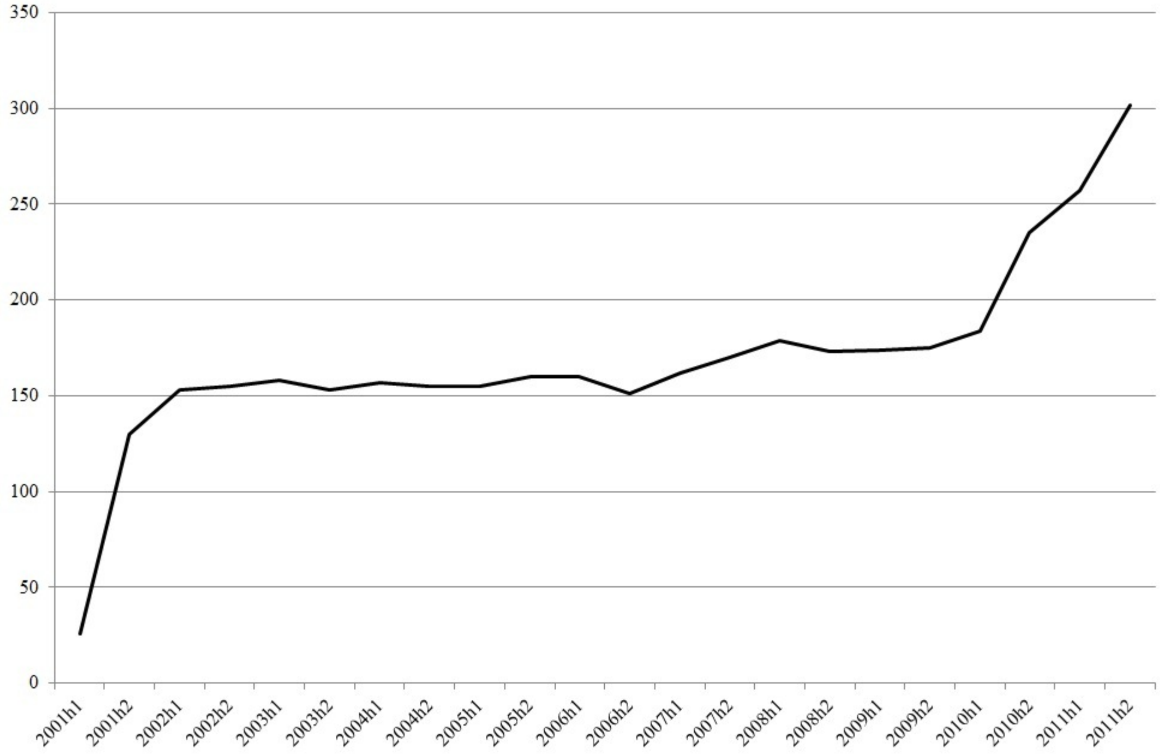

Figure 2: Number of active links

The fact that until 2009 borrower banks demand larger amounts and engage in less stable relationships with CC seems to be consistent with the findings of Craig et al. (2015) for the German interbank market. Borrowers banks are for the most part SBHs, whose size is sensibly greater than that of CCBs. Although we do not have data to verify our conjecture, is seems plausible to argue that SHBs held a plurality of interbank relationships outside the small network we are studying. Under smooth operating conditions, the informational pros of a stable borrowing relationship with CC must be weighed in with the cons of the lack of diversification of liquidity sources that SHBs could obtain on alternative interbank platforms. As shown by Craig and his co-authors, the incentives of diversifying liquidity risks through multiple lenders tend in fact to play a more important role than the benefits of stable relationships.

The empirical analysis of interbank flows reveals some interesting additional facts. First, the net position of CC in the market has changed over time. In particular, from the top panel of Figure 7 we can appreciate how in the first part (let alone 2001) of the time-window considered CC was a moderate net-lender in aggregate terms. From 2006 onwards, however, it started to be a net-borrower, and

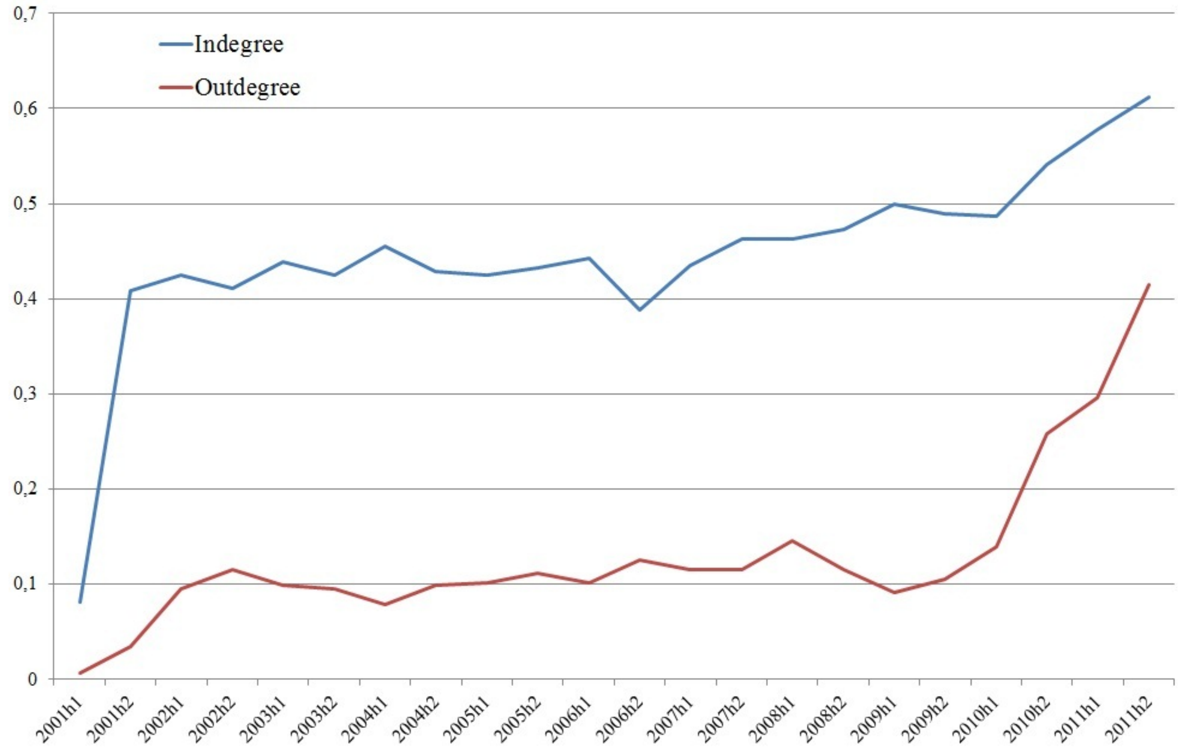

Figure 3: In-degree and out-degree centrality of CC

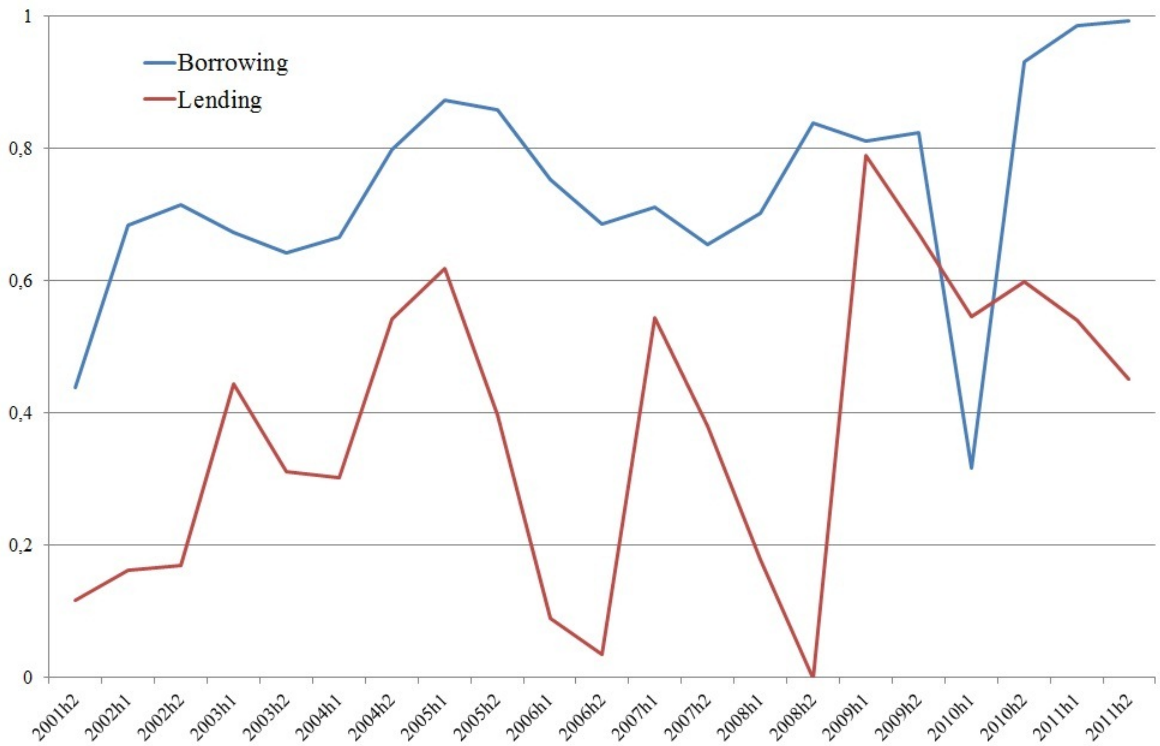

Figure 4: Correlation between CC's lending and borrowing links existing at times t -1 and t.

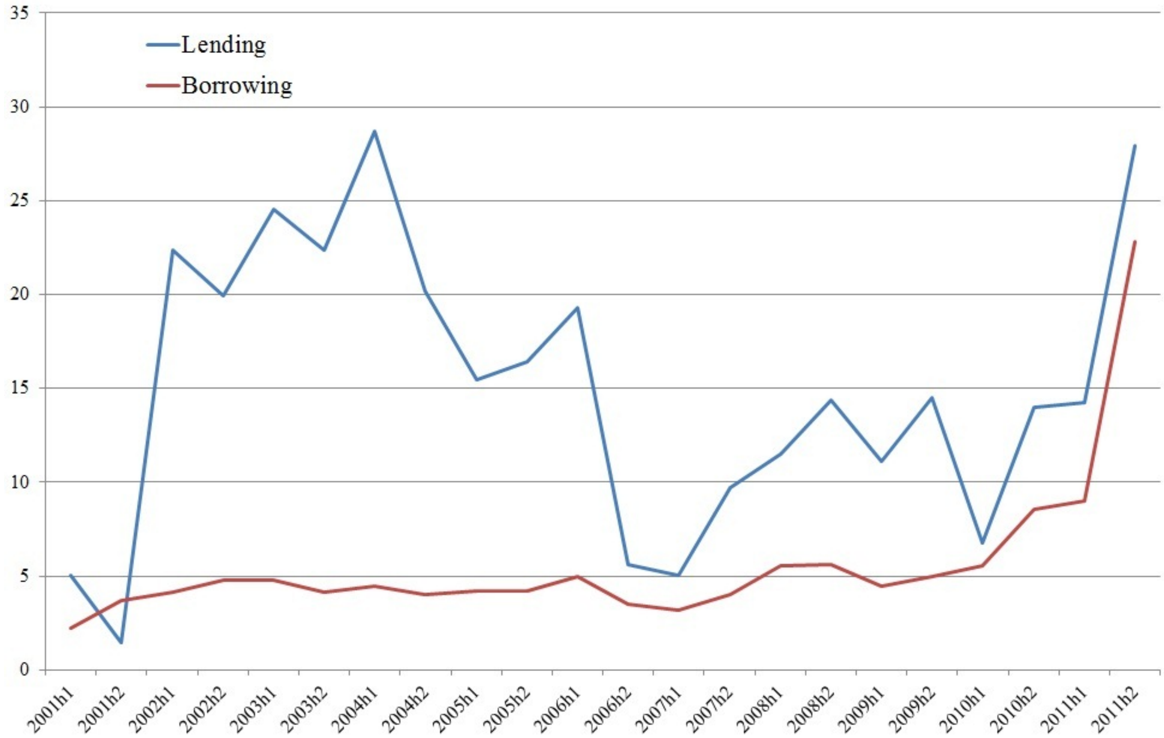

Figure 5: Average volumes of CC's lending and borrowing transactions

by the end of the time-span - when the LTROs were put in place - this position became significantly stronger. Second, the whole picture gets even more interesting when we stratify the market with respect to the maturity of flows.The top-panel of Figure 7 displays the overnight and non-overnight net flows intermediated by the center of the star. As one can see three periods can be identified, if we exclude again 2001. At the beginning, CC was a net borrower in the overnight market and acted as a net lender in the non-overnight market. On the one hand, this suggests that CC was operating as a maturity transformers. On the other hand, it is also clear that CC did not only simply transform maturities, but it also added to some extent further financing to the market, as the net effect is positive. By the end of 2005, the positive net lending in the non-overnight market was almost entirely financed by the excess-borrowing in the overnight market. From 2006 to the first half of 2010 CC acted as net borrower in both markets, and from the second half on 2010 onwards - when the Sovereign Debt Crisis started to unfold - its net positions in the interbank market switched sign, so that it acted as a net lender in the overnight market and a net borrower in the non-overnight market.

This is mainly due to the effect of the massive liquidity injections coming from the BoI, as one can see from the top panel in Figure 8. Let us note that this extra liquidity was mainly non-overnight. A visual inspection of the top and middle panels of Figure 8 makes clear that such medium-term liquidity was basically entirely distributed to CCBs, without much change in terms of maturity. We can also note that the net CC overnight flows towards CCBs have always remained negative, meaning that CC has worked as a net borrower. In contrast to that, the non-

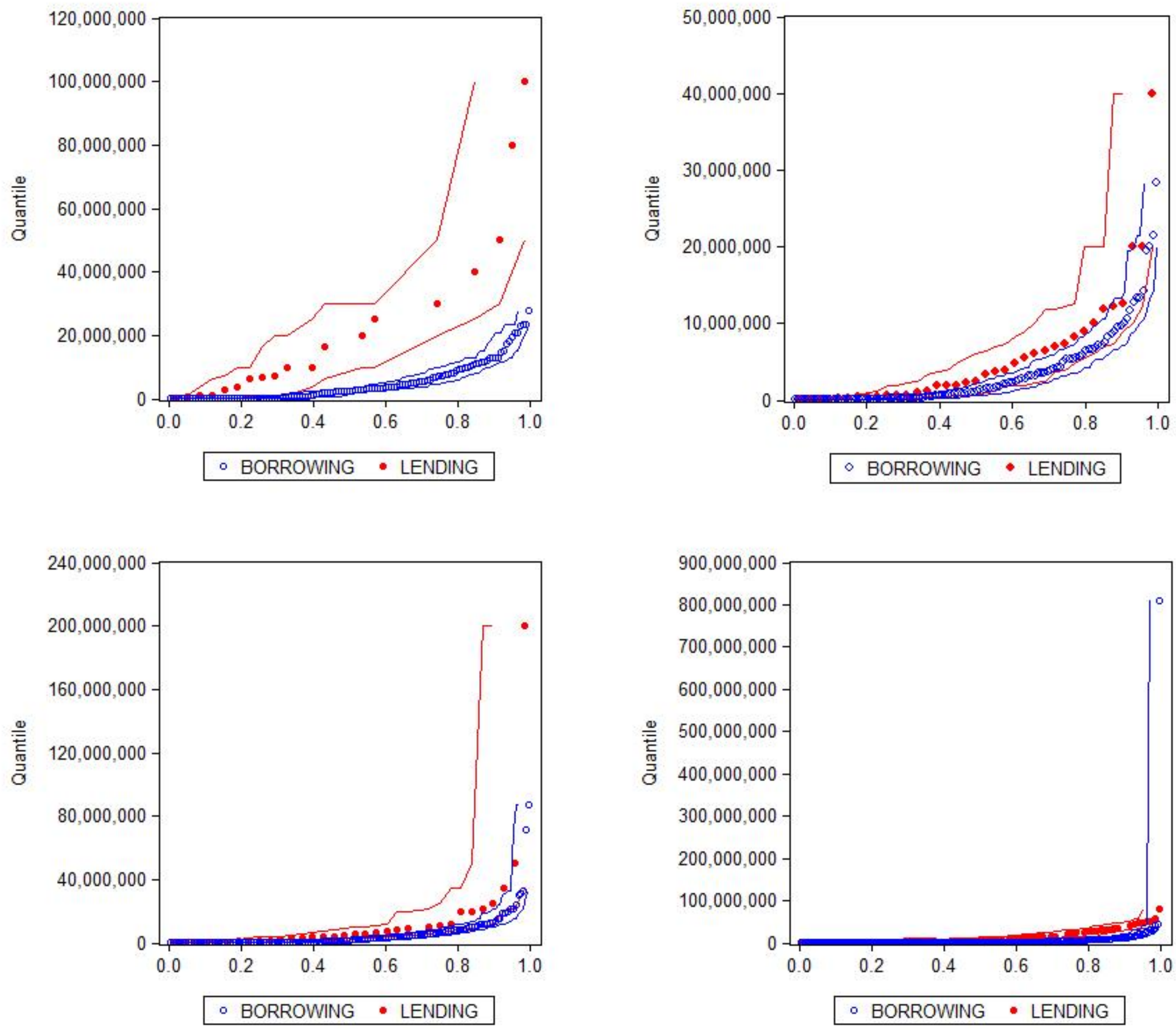

Figure 6: Quantile plots. Clockwise order: 2003-I; 2006-II; 2008-II; 2011-I.

overnight flows with CCBs were initially negative and became positive at the end of the period considered. Let us also notice that CC has worked as a net lender across the entire period for SHBs, both in the overnight and non-overnight markets.

The observed net-lending pattern signals that CC did not simply transform volumes and maturities and distribute liquidity across the market, but did so also intertemporally. At the end of the time span considered CC hoarded part of the liquidity injected by BoI. This suggest that it played an active role as a forward-looking market stabilizer, by saving excess liquidity in the face of increasing uncertainty on the evolution of the main interbank market and policy rates.

3 Liquidity risk and interconnectedness

Interbank funds are typically used to manage liquidity and minimize the associated risk, i.e. the possibility that a single bank finds itself temporary short of funds.

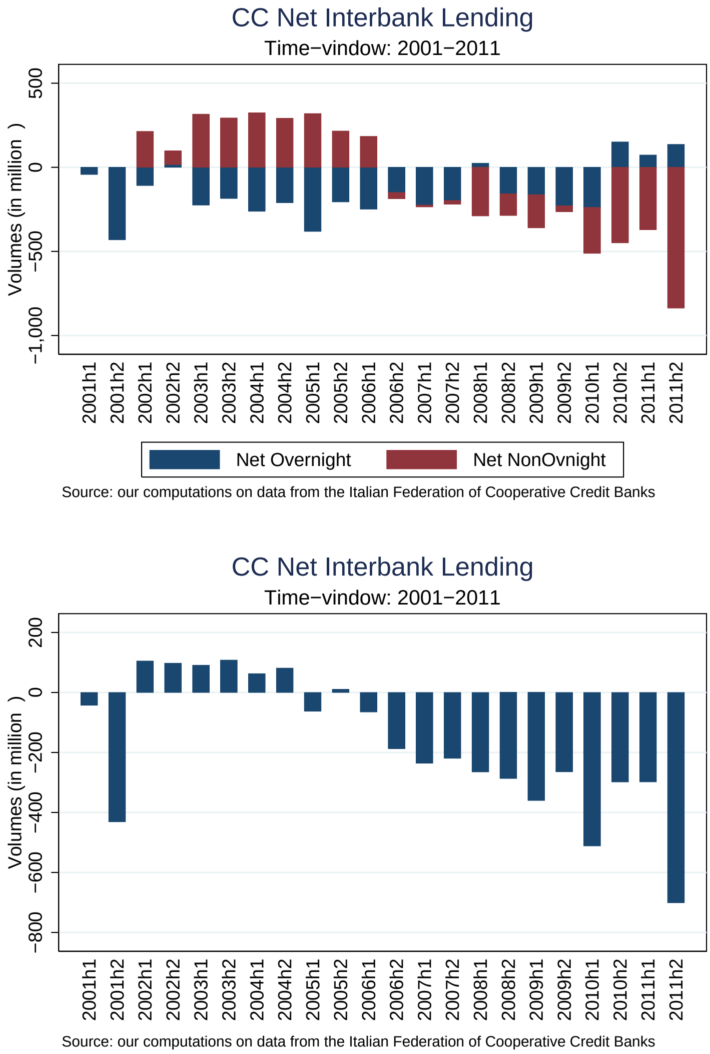

Figure 7: Aggregated Interbank Market - CC node

The more developed the interbank market, the larger the insurance banks can buy against such a threat. A well-functioning interbank market does therefore improve the efficiency of the financial system as a whole since, *ceteris paribus*, it requires less bank-level liquidity hoarding.[7] This in turn entails positive direct effects on the provision of credit to the real economy, by allowing a smooth interaction of the qualitative asset transformation functions recalled above. Nonetheless, large interbank exposures are also associated with both direct (counterparty) and indirect (systemic) risks, that manifest themselves either when one or more borrowing banks are not able to fully repay their debt at the due date, or when creditors recall their interbank assets, *de facto* imposing a funding shock on their debtors. The very existence of such a trade-off poses a dilemma of no easy solution, whose prongs can be identified only once the structure of interlinkages among intermediaries is fully

[7] Silva et al. (2016) show that also the bank-level efficiency is affected by the structure of the interconnections linking financial intermediaries.

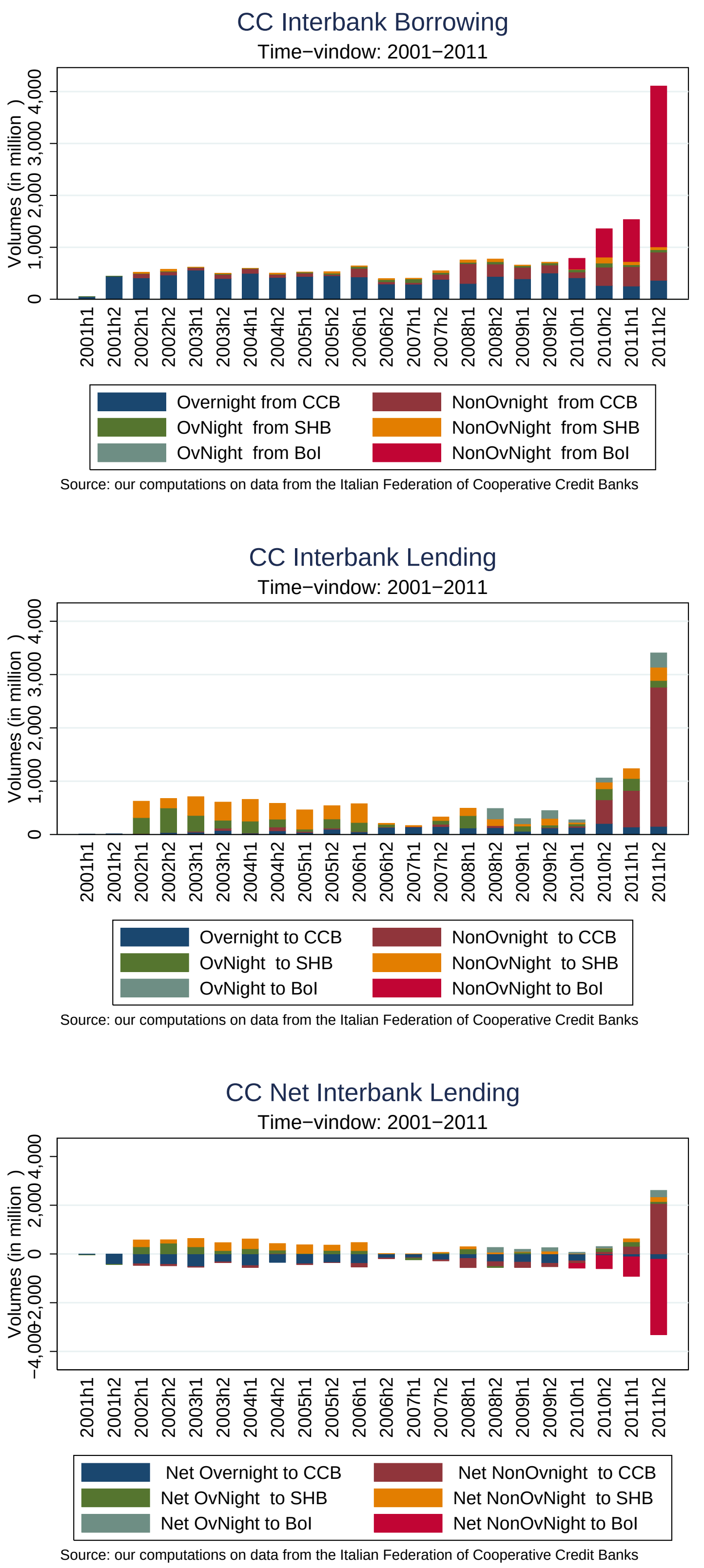

Figure 8: Disaggregated Interbank Market - CC node

factored in. This clearly leaves us with the question of what network topology is best as far as systemic risk and efficiency are simultaneously concerned.

According to the functional perspective of financial intermediation, while the institutional structure of a financial system - i.e., existing institutions, markets, contracts and products, as well as their interconnections - evolves and adapts over time, the core economic functions performed by financial intermediaries remain basically the same. Financial innovations and competition among intermediaries then imply that the institutional structure should follow functions, in that developments of the former should ultimately result in greater efficiency of the performance of the financial system as a whole. Does a star-shaped interbank network represent the ending point of such an endogenous structural evolution towards efficiency?

Theoretical arguments from different methodological approaches suggest that the response is likely to be in the affirmative. In a recent paper, Castiglionesi and Eboli (2015) maintain that, in a banking system hit by a symmetric shock, the presence of a money center like CC can ensure full coverage of liquidity risks with a minimum amount of interbank deposits. The very presence of a hub pooling liquidity minimizes the expected loss due to the default of a debtor, and makes the smallest shock capable to cause a failure of the whole system to be larger than the one needed for other topologies. As a result, a star-shaped network should be superior to other topologies in terms of both efficiency and systemic resilience.

Interestingly enough, the literature on endogenous network formation (Feri, 2007; Bala and Goyal, 2000; Hojman and Szeidl, 2008) shows that when the costs of link formation are incurred only by the actor who initiates the link and the value of the external benefits associated to indirect links decay with network distance, a star-shaped network is not only robust and efficient but also dynamically stable, since it is the structure towards which players, if free to revise their links, will converge over time. The intuition for such a result is straightforward. Suppose that each one of a population of N banks can choose to link itself with any subset of the others. A link going from bank a to bank b secures to a liquidity services offered by b. The creation of a link comes with cost δ to a, which can be interpreted as the price of counterparty risk. The payoff to bank a is then given by the liquidity services it can get less the costs it pays to form links, $\pi_a = \#[banks_{accessed}] - \#[links]\delta$. To prove that a star network is optimal one can simply combine the two following arguments. First, in a star network a player is accessing everyone with just one link, and everyone is close by. So it is optimal not to form additional links. Second, supposing to take any two end-players in a tree network, note that they have an incentive to get closer to the center, as soon as long paths are bad due to higher counterparty risks. A bank will then severe links pointing towards the periphery, substituting them with links pointing towards someone closer to the center. Starting from any arbitrary architecture, therefore, the dynamics of link formation converges towards a star network.

As discussed at length by Lee (2013), however, if deposit cross-holdings are not symmetric we must distinguish between banks which are in a structural surplus or deficit position as regard liquid assets - due for instance to different business models - in order to take into account how they interact in the interbank market. By recurring to simulations, he shows that the amount of systemic distress occurring when liquidity shortages percolate through the financial system depends on the topological structure of the network and the possibility that matches were only well-behaved (i.e., a deficit bank can open a link towards a surplus bank only, and vice-versa) or also misbehaved (deficit or surplus banks, respectively, which are linked among themselves). In a star network, in particular, the net liquidity position of the hub is key. Unless the latter is fully balanced, heterogeneity in the liquidity position of banks in the periphery means that the network is ill-matched by definition.[8]

Lee finds that a star network with a deficit money center bank gives rise to the highest level of systemic liquidity shortages in comparison to many alternative structures, and that in ill-matched networks the number of ill-matched links increases with the number of nodes. In order to assess which of these arguments is applicable to the interbank market operated by CC, we perform some counterfactual computational experiments by creating artificial histories to be compared with the actual one, with the aim of obtaining comparative results by means of a stress testing procedure. In particular, we use real data on borrowing and lending flows, as well as data on the liquidity injections orchestrated by the BoI, to feed models in which the actual links we observe are reshuffled to obtain alternative network topologies. By introducing suitable metrics, we can advance an answer to a set of policy-related "what-if" question. How does a star-shaped topology fare against other network architectures with respect to its ability of minimizing the risk of aggregate disruptions due to liquidity shocks? What kind of outcomes would have we achieve if the central bank's liquidity injections had been made directly to peripheral banks instead of having it distributed through the money center as it actually occurred? How important was the liquidity injection of BoI in safeguarding financial stability of this banking ecosystem? In other terms, is a star-shaped network really the most efficient institutional structure to support the flows of liquidity exchanges actually occurred?

4 Counterfactual Simulations

The perspective commonly adopted in the analysis of how financial systems work can be termed institutional. The basic idea is that of taking the structure of the financial system as given, in order to define what policy actions should be deployed to induce the institutions currently in place to be safer and perform better. This viewpoint applies to the vast majority of research effort put forth in the field of financial network theory as well. As matter of example, Roukny et al. (2013) recur to simulations to evaluate how the e-MID interbank market would had fared if hit by exogenous shocks causing default cascades. Their exercise takes as given the topological structure actually observed over the period 1999-2011, and estimates the maximum potential dislocation one would have obtained for hypothetical different levels of banks capitalization and market illiquidity. In stressing the usefulness of a functional perspective to analyze financial systems, in this paper we argue for a reversed methodological approach. Instead of taking the network structure as

[8] If the hub is a deficit bank and the periphery is composed by one half of deficit and one half of surplus banks, 50% of the links are misbehaved. A similar result holds if the hub is a surplus bank.

given and generate through simulations artificial market data, we take the latter as given and use them to generate counterfactual histories aimed at evaluating the systems resilience to external shocks as the underlying network structure is artificially modified. It must be pointed out that we only have a complete record of all aggregate biannual bank-level interbank assets and liabilities, but we do not have full balance-sheet information. We must hence make some assumptions in order to simulate contagion dynamics in a stock-flow-consistent framework. More in detail, we assign a value to the items that make up for total assets and liabilities in such a way that the formal accounting identity holds up for all banks. To this end, we follow a procedure that draws upon Gaffeo and Molinari (2015) and yields the baseline bank balance-sheet typically assumed in the banking network literature *à la* Nier et al. (2007) and follow-up articles. For each bank, interbank liabilities (IL) are set proportional to the bank's external assets (EA). One rationale for this assumption is that interbank funds are obtained upon collateral, proxied by bank (non-interbank) assets. Bank equity or net-worth (NW) is computed as a fraction of total assets. Finally, the value of customer deposits (D) is computed to preserve the liabilities-assets equilibrium condition. Our control parameters are calibrated to yield a non-weighted leverage ratio of 4 percent and a 16 percent aggregate share of interbank assets (IA) with respect to total assets.[9] The bank-level balance-sheet identity reads as follows:

$$EA_i + IA_i = NW_i + D_i + IL_i \tag{1}$$

We trigger contagion by assuming a system-wide shock. The exogenous shock can be thought of as a sudden collapse in confidence that translates into a bank run on deposits. As a consequence of that, banks must face an unforeseen withdrawal request. A sizeable shock is needed to pose a systemic threat to the system, and we assume it as large as 30 percent of total deposits for each bank. Banks must meet this demand by either recalling their interbank assets, if available, or directly resorting to other assets, which we simply label external assets. Had the banking system been completely disconnected (i.e. if there was no interbank market), the exogenous shock would have been instantaneously transferred to the external assets (i.e. non-interbank assets) with each bank fully absorbing its idiosyncratic shock. Shall this be the case, aggregate losses must simply amount to the size of the exogenous shock.

When banks can operate in the interbank market though, they will instead pass on, to some extent, the exogenous shock first to their interbank borrowers, and will only bear the residual shock (i.e. the shock in excess of their interbank claims) as a direct loss to their external assets. Shall this be the case, contagion can spread through the interbank market and the magnitude of the disruption for the banking system as a whole may substantially be amplified. This occurs because banks respond to these unexpected liquidity shortages by recalling their interbank assets, and these orders work as a funding shock to their interbank borrowers, who, in turn, will also call in their interbank claims. This contagion cascade simply transfers liquidity shocks from one bank to the next, and the process can only stop when it

[9] The calibration of the non-weighted leverage ratio is the same as Gai and Kapadia (2010) . This 16 percent is in line with the relative size of the interbank market in Italy, as shown by Manna and Iazzetta (2009).

eventually knocks down on the banks' external assets. In fact, even in this case the liquidation of the latter ones must, in aggregate terms, be of the same amount as the initial money withdrawal (Lee, 2013, p.3). Formally, let us call the exogenous trigger shock ω defined as the sum of the deposit withdrawals at time t. The following condition must hold in aggregate terms at the end of the contagion process at time T:

$$\omega = \sum_{i=1}^{n} \Delta D_i(t) = \sum_{i=1}^{n} \Delta EA_i(T) \tag{2}$$

where ΔD_i represents the change in bank-level retail deposits due to the initial money withdrawal, and $\Delta EA_i(T)$ captures the cumulated loss in terms of each bank's external assets. The magnitude of disruption though will exceed the initial run on deposits ($\sum \Delta D$), and its exact amount will also depend on the interbank losses (IbL), the size of which can be determined by solving the following fixed-point equation (Lee, 2013, p.4):

$$IbL_i = \Delta IA_i = min[IA_i, \sum_{j=1}^{n} \phi_{ij} \Delta IA_j + D_i] \tag{3}$$

where $\phi_{ij} = IA_{ij}/IA_j$ is the share of total interbank assets of bank j channeled to bank i. Hence $\phi_{ij}\Delta IA_j$ shall also be read as the value of interbank assets recalled by bank j from bank i, and this amounts to an interbank loss for bank i.

In this context we are interested in understanding how the network topology affects: 1) the fraction of the exogenous shock diverted to the interbank market; 2) the extent to which this direct interbank shock unravels to bring about higher-order losses in the market. In order to provide a meaningful comparison, our experiments are designed in such a way that the size of the interbank market is kept constant, so that any detected differences in contagion dynamics are attributable to network effects.

We first compare contagion dynamics that arise in the actual star network with those that would be recorded, had we used an alternative topology that preserves some key features of the actual one. The alternative topology is obtained by reshuffling the original interbank asset matrix using a constrained maximum entropy approach that can be described as follows. We start from a full adjacency matrix, and we remove links on the main diagonal. In addition, any $link_{ij}$ is removed whenever bank $i(j)$ is not lending (borrowing) at all in the interbank market in the actual network. Finally we equally split among the remaining links the total sum lent by each bank in the actual network. The result is a matrix that preserves the lending/borrowing status of the original network. All banks that were active in the interbank market in the actual network as lenders, are still so in the new configuration. All banks that used to borrow still act as borrowers, and those that did not resort at all to the interbank market are kept inactive in the new network as well. We also keep constant the total amount that each lending bank distributes via the interbank market. The main difference with respect to the original network is that now satellite banks are no longer forced to directly lend to or borrow from CC. They can of course still do so, but can also have direct interactions with other banks as well. Whilst the role of CC as a hub is preserved in the new configuration (its aggregate interbank lending is the same as that in the actual network), it is no longer the sole institution in charge of distributing liquidity across the system (one of the key function analyzed in the first part of the paper). It is worth pointing out that such redistribution of interbank funds has another important effect, namely that of directly connecting the central bank (BoI) with the peripheral banks. Indeed, these latter ones can now borrow directly from BoI without the intermediation of CC.

We assess the resilience of the two networks by comparing the extent of aggregate dislocated interbank assets (henceforth, DIA) under the two topologies. Let us formally define our measure of distress as follows:

$$DIA/Shock = \frac{\sum_{i=1}^{n} IbL_i}{\omega} \tag{4}$$

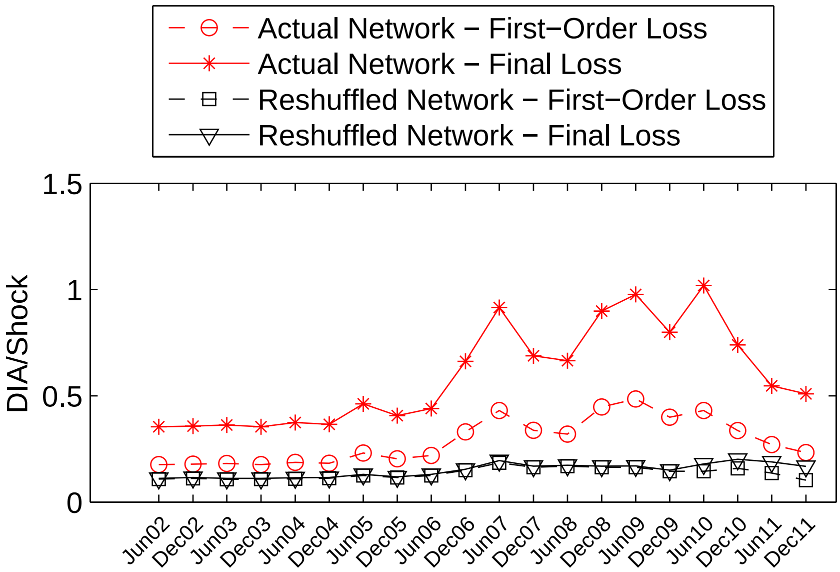

Figure 9: Disruption in the Interbank Market

The evolutions over time of this distress metric for the actual history and the counterfactual one are shown in Figure 9. We show the first-order interbank loss simply measured as the fraction of the initial shock directly distributed across interbank claims. This is then compared to the final loss recorded once contagion has come to a halt. The distance between the two profiles gives us a measure of the severity of higher-order losses in the system.

There is a striking difference between the two topologies both in terms of levels and patterns over time. The degree of interbank disruption is definitely higher under the actual star-configuration, where CC is the only institution in charge of distributing liquidity across the other market participants. Moreover, its evolution over time is also quite different. Whilst our measure of disruption for the artificial topology is pretty constant over time, the severity of distress for the actual one has been relatively stable (although higher than in the alternative scenario) up until mid 2006. The time window spanning from the end of 2006 to mid 2010 can be described as a destabilizing phase in which systemic risk builds up and remains at high levels. Finally the last observation period is consistent with a relative reduction of contagion dynamics.

This observed pattern can be rationalized on two grounds. First, aggregate interbank losses seem to co-evolve with the nature of its money-center (i.e. CC). As a matter of fact, the interbank market records limited stress up until CC operates as a net lender in the market. As CC gradually strengthens its position as a net-borrower (starting from 2006 - see Figure 9 top panel), systemic risk starts to build up. This result provides, to our best knowledge, the first empirical evidence in support of Lee (2013) theoretical analysis pointing at the destabilizing role of the presence of a deficit hub in a core-periphery model. Second, we observe that, interestingly enough, such risk starts to fade out once the BoI injections of liquidity were put in place. It must be noticed that these injections were LTROs bearing no liquidity risk for the debtor. This analysis shows that the benefits (discussed in the previous Section) associated with the presence of a liquidity hub, such as CC, is to be pondered against the higher systemic liquidity risk spreading through the interbank market.

We now continue our analysis by expanding the set of counterfactual scenarios and distress metrics. We shall start by first outlining the main features and objectives of the three additional network experiments. We then move on to discuss the construction and purpose of two new metrics, and comment on our results.

In addition to the actual star network and the first alternative topology (henceforth called A1a), we consider a third possibility, labeled network A1b. This is obtained in a similar fashion to that used for A1a. The network generating process is that same as the one outlined earlier, as both cooperative and shareholder banks can directly borrow from other banks. The only difference is that now we have added an additional restriction, namely that only CC can borrow from BoI, as it actually occurred. A1b is hence a hybrid case in between A1a and the real network, and allows us to evaluate the importance of CC as a transmission device for monetary policy. Does the injection of additional liquidity to the system add a systemic risk if carried out directly via CC, or does it enhance its stability?

The fourth configuration (A2) is obtained by simply reshuffling around the interbank loans, so that the total amount of funds exchanged is kept constant, but both the recipient and the lender may differ with respect to the actual network. This is, in other words, a completely decentralized system (with exactly the same density as the actual one) in which every bank can suffer a run. This experiment can be useful to counter-factually evaluate how the institutional setting affects the resilience of the system. The previously analyzed network architectures had an institutional setting that restrained the scope of the exogenous shock. More in detail, we assumed that CC and BoI could not be directly shocked as they simply do not accept deposits from the general public. With configuration A2, instead, we assess the stability of an alternative system in which the same volume of liquidity is attainable and exchanged without the direct intervention of BoI and CC. This makes it *ex-ante* the most fragile market, as every bank in the system can now suffer a run.

The final exercise (called A3 in Figure 10 and 11) is motivated by the need to shed further light on the importance of the liquidity injections by BoI. A monetary authority is obviously interested in continuously monitoring the degree to which the banking system's functioning and survival relies on its interventions. A possible route one can take to evaluate this is to ask what would happen if BoI were to recall at some point in time the liquidity previously injected. In our star-shaped system, this would trigger a massive funding shock to CC, which would then have to recall its interbank assets as well and fuel contagion to the periphery. We hence model these dynamics as follows. We retain the topology of the actual network and trigger contagion by applying a targeted shock rather than a homogenous shock as before. In particular, we only select as shock-takers the banks that took out a loan from CC. The aggregate amount of the shock is set equal to the total amount of liquidity provided by BoI (L_{BoI}), and each bank j receives a shock ω_j that is proportional to its relative exposure to CC. Formally:

$$\omega_j = \phi_{CC,j} L_{BoI}. \tag{5}$$

where $\phi_{CC,j} = L_{CC,j} / \sum_j L_{CC,j}$.

The exercise is interesting for two reasons. On the one hand, we can interpret it as the level of distress that would be induced without the intervention of BoI. On the other hand, we ask ourselves whether targeted shocks to borrowing units pose a stronger threat to the viability of the interbank market than common shocks.

The choice of the counterfactual experiments we performed is subject to an important caveat. Had CC simply worked as a liquidity-distributing device, it would have been possible to take it out from the system, and consider the stability properties of a network in which the sum of inflows and outflows intermediated by CC could be re-allocated via direct exchanges. Such an exercise, that corresponds to a reduction of the network dimensionality, is however not a feasible one. The reason is that CC is an active participant of the interbank market - sometimes contributing additional liquidity and sometimes hoarding it - so that its net interbank position is never a perfectly balanced one. Thus, one cannot simply consider an alternative financial network in which there are N-1 banks only (i.e. without CC). This would in fact require the sum of CC's inflows to be equal to the sum of CC's outflows at all times, a condition which is always violated.

In order to provide a comprehensive assessment of the associated systemic liquidity risk, the performance of these alternative network settings is assessed against the first metric introduced earlier, and two other alternative distress metrics that allow us to gradually broaden the scope of our analysis. These are formally defined as follows:

$$DIA/IA = \frac{\sum_{i=1}^{n} IbL_i}{\sum_{i=1}^{n} IA_i} \tag{6}$$

$$DA/IA = \frac{\sum_{i=1}^{n} DIA_i + DEA_i}{\sum_{i=1}^{n} IA_i} \tag{7}$$

where DA stands for dislocated assets computed as the sum of dislocated interbank assets (DIA) and dislocated external assets (DEA). The three distress measures are to be read sequentially, as they attach an increasing weight to the size of the initial shock. This in turn depends on the institutional settings and the endogenous distribution of deposits. With the first measure, we fully control for the heterogeneity in the size of the exogenous shock, so that we capture a pure network effect. With the second measure, the size of the initial shock is only accounted for by its disruptive effect on the interbank market, whereas the final measure detects its disruptive impact for the banking system as a whole. The choice of which stress-measure is the most appropriate depends on the scope of the policy goal.

If the regulator is only concerned with the per-unit shock resilience of the interbank market, she/he should choose the first one. The second measure is preferable if one aims at monitoring the viability of the interbank market as a whole. Finally, the third measure should be favored when the main concern of the regulator is the stability of the entire banking system, whose collapse is likely to impact on the non-financial sectors of the economy.

For ease of comparison, we show again in Figure 10 and 11 the dislocated assets for the actual network and the first alternative scenario inspected in the previous section. Our analysis shows the A1b line is slightly above that of A1a (see Figure 10) , at the end of the observation period when BoI actively intervenes in the market. Although quite marginally, the direct injection of new liquidity from BoI appears to be potentially more destabilizing for the interbank market alone when channeled directly to the hub (CC) rather than to the peripheral banks. Intuitively, the channeling of the liquidity injections from BoI directly to CC increases their interbank liabilities and hence worsen its interbank deficit position (given that its lending is kept constant in the reshuffling process). The result is hence consistent with the Lee's model, according to which the presence of a deficit hub contributes to render the system weaker. Nonetheless, the desirability of keeping CC as the preferred channel of monetary policy transmission increases when we considered our third measure of distress (see Figure 11 - bottom panel). This is due to the fact that a larger hub must be offset by a smaller size of the other satellite banks, which translates into a smaller exogenous shock in absolute terms. Although this is driven by our assumptions, this result clearly speaks to the importance of the institutional setting in a core-periphery banking system where the core tends to become larger and larger.

According to the first metric, network A2 (i.e. the fully decentralized system) performs quite similarly to the actual network in per-shock-unit disruption (see Figure 10) at the beginning of the time-span, but it does not display the hump in later periods. When the larger size of the shock is fully factored in, the fragility of this system clearly manifests itself in a higher share of disrupted assets (see Figure 11). Although further research is clearly needed, this experiment serves as a first attempt to embed in financial network models an aspect - i.e. the role of institutional settings - that have so far been left out of the picture.

Finally the performance of network A3 makes clear that the importance of BoI's liquidity injections is remarkable, confirming even more the crucial role played by the central bank in stabilizing the banking system (and the interbank market in particular). This also suggests that targeted attacks to deficit units could pose a stronger threat to the viability of the system than common shocks, which suggests that the former institutions should be more closely monitored and possibly required to hold higher liquidity buffers.

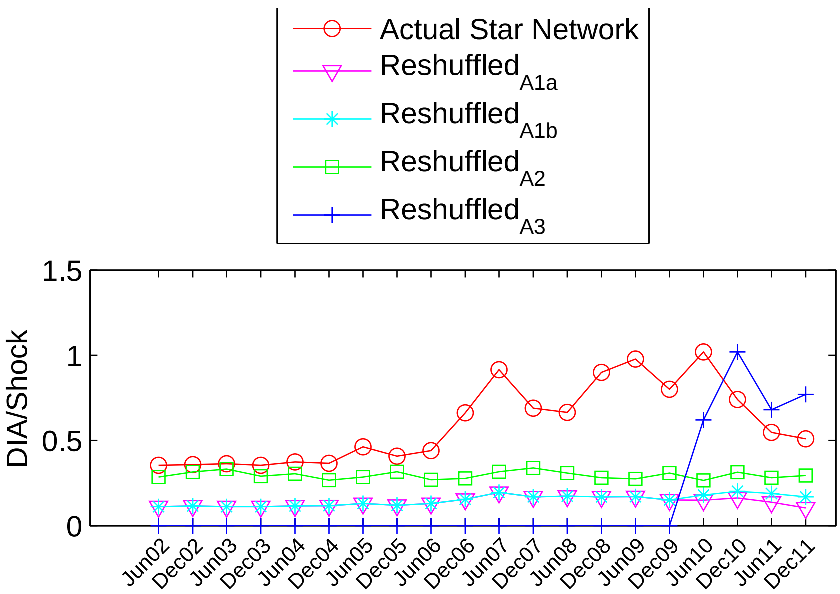

Figure 10: Disruption in the Interbank Market

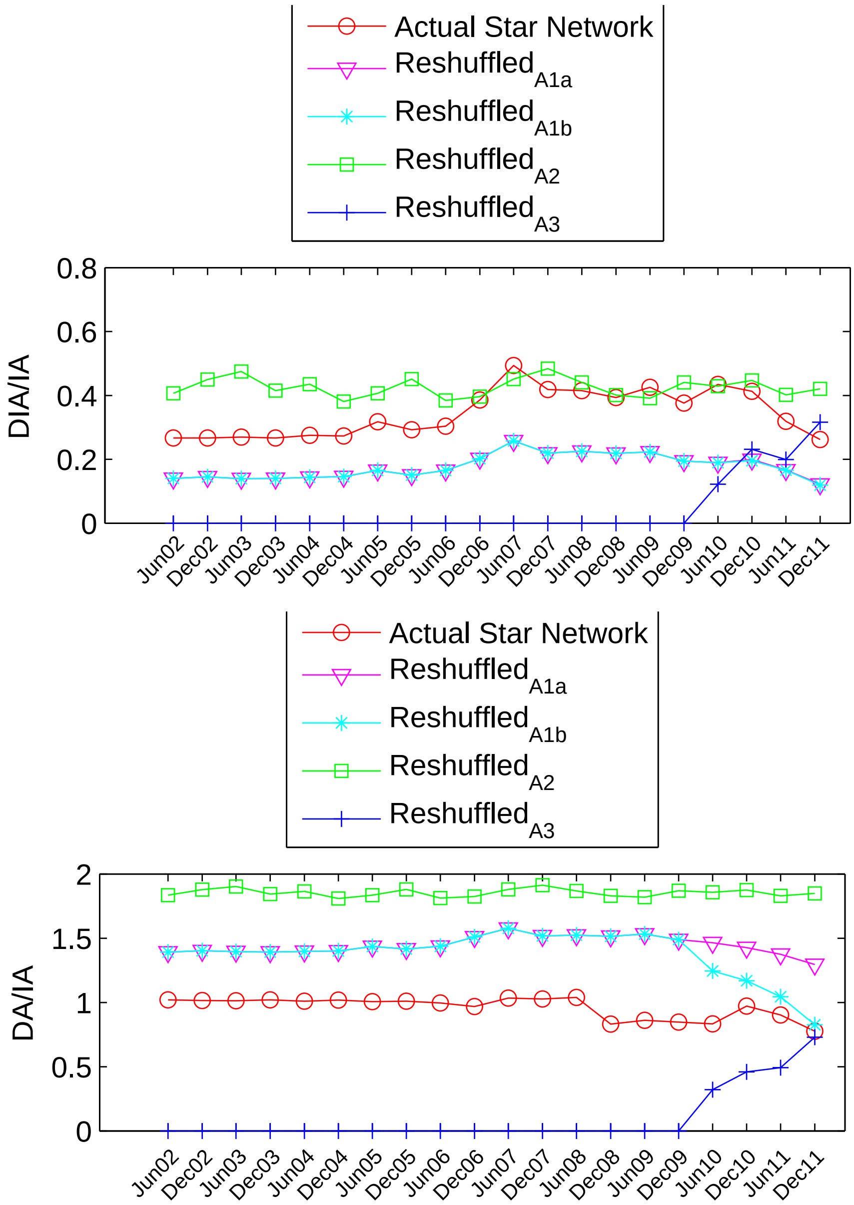

Figure 11: Dislocated Interbank Assets (DIA) and Dislocated Total Assets(DA)

5 Final Remarks

During the last 15 years, the approach based on network theory in finance has experienced a real outburst of studies. The bulk of interest has been focused towards a finer understanding of the relationship between the structure of financial inter-linkages and the emergence of financial instability and systemic risk. To date, such a research effort has mainly followed an institutional perspective: taking as given the actual institutional structure of financial systems, theoretical and empirical investigations are aimed at providing insights on how the system can be made safer through capital and liquidity regulations, optimal taxation and sounder risk-management practices.

In fact, as long emphasized by Merton and Bodie the crucial purpose of the financial system as a whole is to serve as a network within which its component elements - financial institutions, products and markets - perform key economic functions. Read in the light of the functional perspective to financial intermediation, therefore, the focus should be directed on the actual services each component of the network actually offers, in order to assess whether the actual institutional structure is able to efficiently deliver the core economic functions a financial system must perform to facilitate the allocation of resources, both spatially and temporally, in an uncertain environment.

This paper has to be read as a first attempt to import the functional perspective into the literature on financial network. That is why our analysis is susceptible of several potential extensions. First, it would seem worthwhile to extend the range of counterfactual histories used for welfare comparison to situations in which the degree of interconnectedness can vary, in order to control for network structures characterized by different level of deepness. Second, in addition to funding liquidity shocks one could be interested in assessing also the role of disruptions in market liquidity, by taking into account the feedbacks associated to fire-sell externalities. Third, a model in which different segments of the interbank market - namely, overnight and non-overnight - are explicitly considered could significantly help us to further understand how the interaction of liquidity and maturity transformations performed by a financial network contributes to aggregate outcomes.

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