The euro area money market network during the financial crisis: a look at cross-border fragmentation

Carlos Garcia de Andoain Hidalgo

Florian Heider

Gerhard Rünstler

European Central Bank*
Sonnemannstrasse 20
Frankfurt am Main

September 2015

Abstract

We discuss the evolution of the network of euro area unsecured overnight interbank loans in between 2008 and 2013 using an extensive data set derived from the TARGET 2 interbank payment platform. We inspect the effects of crisis-related events and ECB interventions on the network structure with a particular focus on cross-border flows. Using community detection methods we find that cross-border fragmentation increased twice during crisis periods, but declined to pre-crisis levels after policy interventions. Cross-border lending from core to peripheral banks was the driving factor of these developments. The paper also provides an extension of the modularity approach for community detection to the case of weighted and directed networks.

*Corresponding author: gerhard.ruenstler@ecb.europa.eu.
The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the ECB. The authors would like to thank the participants at the various MaRs workshops of the ESCB Macro-prudential Research network for useful comments. We further owe special thanks to Tatiana Tekusova-Landesberger (TU Darmstadt) for very helpful discussions on community detection methods.

1 Introduction

Disruptions in interbank loan markets were one of the pervasive elements of the financial crisis in the euro area. There is a bulk of informal evidence about funding difficulties of individual banks during the outbreak of the crisis in late 2009 and several episodes of the sovereign debt crisis in the subsequent years. Markets appear to have calmed down only in mid-2012 after several long-term refinancing operations (LTROs) launched by the ECB and a widely recognized speech by the ECB president Mario Draghi on 26, July 2012.[1]

This paper attempts to shed some light on the evolution of the euro area unsecured interbank overnight loan market during the financial crisis. We exploit a new data set on unsecured overnight interbank loans that has been obtained from the TARGET 2 interbank payment system (Frutos et al., 2014). These data give a comprehensive account of the unsecured overnight interbank loan transactions among 412 consolidated euro area banking groups in between June 2008 and February 2014.

Our purpose is to derive some stylized facts on the evolution of the euro area money market network in this period. We are interested in the response of the network structure to particular crisis events and in the effects of ECB interventions. We are particularly interested in the evolution of fragmentation in general and across national borders. One indication of market fragmentation during the sovereign debt crisis is the widening of country-specific risk premia, which has been studies by Garcia et al. (2014). In the present study, we consider transaction volumes and investigate the extent to which these events lead banks to redirect their cross-border activities on the interbank market.

We use community detection methods to assess the degree of market fragmentation. Community detection is widely used in network analysis. The purpose is to partition the network into non-overlapping groups, such that the bilateral trading volumes *within* communities are maximized against trading volumes *between* groups. We adopt the modularity approach of Leicht and Newman (2008) for directed networks and extend it to the case of weighted links, which allows us to

[1] https://www.ecb.europa.eu/press/key/date/2012/html/sp120726.en.html

base the analysis on transaction volumes. The modularity method finds communities to maximize the trading volumes within communities against an expected value that is derived from a random network assumption, taking the total lending and borrowing volumes of individual banks as given.

We also inspect the role of core and peripheral banks in cross-border flows and the flows within and between these groups. Recent studies (e.g. Craig and von Peter, 2014; Lelyveld and int 'Veld, 2012) have shown that interbank loan networks are characterised by a core-periphery structure, which gives rise to a distinction between highly interconnected, mostly large, core banks and smaller peripheral banks. Core and peripheral banks may have behaved differently during the crisis. We use a weighted Bonacich centrality measure to identify core banks.

We aggregate the data to quarterly frequency and apply community and core analysis to each of the 24 quarters in our sample. We then examine the evolution of the resulting communities and their overlap with national borders. We further inspect the evolution of cross-border transactions within and between core and peripheral banks.

Our findings are as follows. First, we find 3 to 4 communities to be present most of the time, but a simple partition into two communities already explains the major part of market fragmentation. Our measure of market fragmentation is subject to sizeable variations in response to crisis events and policy interventions. It increases in late 2008 and temporarily reverts back to lower levels in late 2010, after a set of policy interventions that have been put in place to cope with the first wave of the sovereign debt crisis. However, from early 2011 onwards market fragmentation increases again and peaks only in the final quarter of 2012. Since then they it is on a slight decline.

Second, national borders play an important role in defining the communities, in particular in crisis periods. We construct a cross-border fragmentation index from the correlation between community membership and bank location. We find this index to peak at the heights of the sovereign debt crises in 2009 Q4 and late 2011 Q3, but to decline after the subsequent policy interventions. In particular, contrary to the overall measure of fragmentation, the cross-border fragmentation index drops after the introduction of the LTROs in late 2011 and stays at rather low levels since then.

Third, we find the lending from the core to peripheral banks to be particularly sensitive to the various crisis events. In particular, lending from the core to the periphery experienced a sharp and permanent drop in the second half of 2009, i.e. at the first peak of the sovereign debt crisis. By contrast, high market fragmentation in 2012 arose from a temporary decline in cross-border borrowing of the core from the periphery after the introduction of the LTROs.

The paper is organised as follows. Section 2 presents the community and core detection methods used in our analysis. Section 3 takes a bird's eye view on the cross-border network and inspects a few stylised facts. Section 4 then applies community and core detection methods. Section 5 concludes the paper.

2 Community and core detection

2.1 Community detection

Community detection in networks is about identifying groups of nodes that exhibit an above-average number of links within those groups and a below-average number of links between them. It is a widely used tool in network analysis, but to our knowledge has so far not been applied to interbank loan networks.

We start from the modularity approach due to Newman (2006) and Leicht and Newman (2008) for community analysis in unweighted directed networks and adapt this approach to the case of weighted directed networks. In a recent article, Newman (2013) shows that the modularity approach is very similar to two other widely used methods, i.e. stochastic block models and normalized cut-graph partitioning.[2] The modularity approach has however the advantage of being based on an intuitive objective function, which can be easily adapted to the case of weighted networks.

Overall, the approach finds a partition (bisection) of nodes into two communities such that bilateral trading volumes within communities are maximized against their expected values, the latter

[2] See Schäffer (2007) for a review of a wider range of community partition methods.

being defined from a random network assumption. In order to achieve a deeper partitioning, the method might be applied in a recursive way to obtain a hierarchical binary tree of bisections.

Consider a network consisting of n nodes and weighted adjacency matrix $V = (V_{ij})_{i,j=1}^{n}$ of dimension $n \times n$, such that $V_{ij} \geq 0$ represents the volume of lending of bank i to bank j. The aim is to partition the network into two communities $\mathcal{D}_1$ and $\mathcal{D}_2$. Define vector $d = (d_1, d_2, \ldots, d_n)$ such $d_i = 1$ if node i belongs to community $\mathcal{D}_1$ and $d_i = -1$ otherwise. The partition is found by maximizing modularity $Q_{(1)}$, which is defined as follows.

$$\begin{aligned} Q &= 2\,(|V|)^{-1} \sum_{b \neq j} b_{ij} \\ b_{ij} &= (V_{ij} - \mathbb{E}V_{ij})\,\mathbb{I}(d_i = d_j) \\ \mathbb{E}V_{ij} &= (|V|)^{-1}\, v_i^{out} v_j^{in} \end{aligned} \tag{1}$$

In equation (1), $v_i^{out} = \sum_k v_{ik}$ and $v_j^{in} = \sum_k v_{kj}$ denote the total lending and borrowing volumes of nodes i and j, respectively, while $(|V|)^{-1} = \sum_{ij} v_{ij}$ denotes overall market transaction volume. Further, let $\mathbb{I}(s) = 1$ if statement s is true and $\mathbb{I}(s) = 0$ otherwise.

Hence, modularity Q forms the (standardized) sum of deviations b_{ij} of actual transaction volumes V_{ij} from their expected values $\mathbb{E}V_{ij}$ over for pairs (i, j) of nodes. The sum is formed across pairs of nodes within the same community, $d_i = d_j$. Expected transaction volumes $\mathbb{E}V_{ij}$ are derived from a random network (i.e. assuming the absence of a community structure) with taking total lending v_i^{out} and borrowing volumes v_j^{in} of banks i and j, respectively, as given. Note that if V is replaced with the unweighted adjacency matrix, equations (1) reduce to the original expressions by Newman and Leicht (2008).

Newman and Leicht (2008) consider the case of unweighted networks based on adjacency matrix $A = (A_{ij})_{i,j=1}^{n}$ with $A_{ij} = 1$ if $V_{ij} > 0$ and $A_{ij} = 0$ otherwise. However, their solution method readily extends to the case of weighted networks, as set up above. We briefly describe the algorithm and refer to Newman (2006) for a detailed discussion.

Consider modularity matrix $B = (b_{ij})_{i,j=1}^{n}$ with elements b_{ij} as defined in equation (1). Vector d is found in two steps with an approximate solution obtained from a spectral decomposition, and the subsequent application of an iterative switching algorithm. As to the spectral decomposition, note that Q can be written as $Q = 2\left(|V|\right)^{-1} d^T B d$. This follows from $\mathbb{I}(d_i = d_j) = (1/2)(d_i d_j + 1)$ and the observation that the columns and rows of B sum to zero. The approximate solution starts from finding real-valued vector f that maximizes $f^T B f$. This is given by the first eigenvector of B. As B is non-symmetric, the eigenvectors are complex-valued. Hence, Leicht and Newman (2008) propose using $\left(B + B^T\right)$ instead. The approximate estimate $d^{(1)}$ of partition d is then found from the first eigenvector of $\left(B + B^T\right)$ by setting $d_i^{(1)} = 1$ if $f_i > 0$ and $d_i^{(1)} = -1$ otherwise.

Starting from this partition, an iterative switching algorithm is then applied to objective function Q. At each step s, given partition $d^{(s)}$, one finds index m for which switching the value of $d_m^{(s)}$ gives the largest gain in Q. Partition $d^{(s+1)}$ is then obtained from $d^{(s)}$ by switching the value of $d_m^{(s)}$. The iteration stops once no further gains are made (see Newman 2006).

The algorithm results in the desired partition of the network into two communities $\mathcal{D}_{(1)1}$ and $\mathcal{D}_{(1)2}$. To achieve a deeper partitioning, it may be applied in a recursive manner to further partition $\mathcal{D}_{(1)1}$ and $\mathcal{D}_{(1)2}$ into 2 communities each. For this purpose, denote with $Q_{(1)} = Q$, $B_{(1)} = B$ the modularity value and modularity matrix of the top bisection, obtained from partitioning the entire network as described above. Further, denote the second-layer partition obtained from $\mathcal{D}_{(1)1}$ with $\mathcal{D}_{(2)11}$ and $\mathcal{D}_{(2),12}$, and equivalently for $\mathcal{D}_{(2)1}$.

As discussed by Newman (2006), in recursive application of the algorithm, it would be incorrect to simply delete the edges falling in between $\mathcal{D}_{(1)1}$ and $\mathcal{D}_{(1)2}$ and apply the above algorithm again to each sub-graph. This is because the expressions for v_i^{out} and v_j^{in} appearing in the definitions of equations (1) would change, and hence modularities $Q_{(21)}$ and $Q_{(22)}$, respectively, would represent the wrong quantities. Instead, the correct approach is to write the additional contribution $\Delta Q_{(2k)}$ to modularity, $k = 1, 2$, which amounts to forming modularity matrix $B_{(2k)}$ from the elements of $B_{(1)}$ related to each sub-graph and subtracting the row sums from the diagonal,$b_{(2k),ij} \rightarrow (b_{(2k),ij} - b_{(2k),ii})$.

This process may be continued and results in a binary tree of partitions. At each branch of the tree, the algorithm stops once the contribution to modularity $\Delta Q_{(.)}$ from partitioning $\mathcal{D}_{(.)}$ is smaller than a certain threshold, $\varepsilon > 0$. Further partitions along this branch would not increase the modularity of the partitioning.

2.2 Core detection

The definition of the core-periphery network structure has been introduced by Borgatti and Everett (1999). In the context of an unweighted and undirected network, the core is defined as the maximum subset of nodes that form a complete network. Nodes in the periphery may be linked to some nodes in the core, but not to other peripheral nodes. Craig and von Peter (2014), Lelyveld and int 'Veld (2012), and Fricke and Lux (2012) report that the core-periphery assumption provides a reasonable approximation to national interbank loan networks and gives a better fit than alternative network structures such as preferential attachment and nested split graph models.

The aforementioned studies are based on undirected and unweighted representations of interbank networks. In line with our approach to community detection, we prefer using a measure based on the weighted network. In the weighted case, the dichotomous core-periphery structure is replaced with a continuous measure of the 'core-ness' of a node. Borgatti and Everett (1999) discuss such extension to their basic definition and show that it is equivalent to Bonacich (1987) centrality. The latter measure has been widely used to identify central players in social networks (e.g. Calv´o-Armengol et al, 2009) and to assess contributions to systemic risk (e.g. Battiston et al 2012; Dungey et al, 2013).[3]

The Bonacich centrality measure $c(\beta) = (c_1(\beta), c_2(\beta), \ldots, c_n(\beta))$ for a network defined by adjacency matrix $W = (w_{ij})_{i,j=1}^{n}$ is defined as

$$c(\beta) = \beta W_r c(\beta) + x = (I - \beta W_r)^{-1} x, \tag{2}$$

where $x = (x_1, x_1, \ldots, x_n)$ is the row sums of W, $x_i = \sum_k w_{ik}$, and W_r is obtained from W by normalizing row sums to one, $w_{r,ij} = w_{ij}/x_i$. The key element of Bonacich centrality a self-referential element that relates centrality of a node to the centrality of its neighbors, as defined

[3] see Rombach et al (2013) for an extension of original measure, which is however computationally expensive.

by W_r and decay β, $0 \leq \beta < 1$: that is, a bank's centrality increases if it is connected to banks with high centrality indices.

The measure is suitable for both directed and undirected networks (Bonacich and Loyd, 2001). In the undirected case, the appropriate choice for the adjacency matrix is given by $W = V + V^T$. In this case, w_{ij} represents the trading volume among banks i and j, irrespective of its direction and row sums x_i represent the total trading volume of bank i. In the directed case either V or V^T may be used, depending on whether the focus is on lending or borrowing relationships. For instance, when using V, a banks' centrality would be raised by lending to other banks with high centrality indices, while any borrowing relationship would have no impact.

One drawback of the weighted measure is that the size of the core cannot be estimated but must be set in advance. Studies based on unweighted networks on average find the core to amount to about 15% of the overall network. We define the core to be of this size.

3 A bird's eye view on the network

We start the empirical analysis with a bird's eye view on the evolution of volumes and interest rates, and inspect some basic features of the cross-border network.

3.1 Data

Our data set contains unsecured daily interbank overnight loans transactions among 412 consolidated euro area banking groups located in the euro area. It includes information on bilateral daily loan volumes and the respective interest rates for all recorded trades (ca. $850,000$ transactions). While the data set also includes trades on behalf of clients, we focus on trades that are proprietary to the banks. The data start in June 2008 and end in February 2014. For the purpose of our analysis, we aggregate the data to monthly and quarterly frequencies.[4]

The source of the data is the euro area TARGET2 system, which is used to settle payments con-

[4] The monthly data deliver sufficiently smooth time series to recover the underlying trends, whereas weekly data are rather volatile.

nected with monetary policy operations, interbank payments, and transactions related to other payment and securities settlement systems (see ECB, 2013). As there are different types of payments that can be settled through TARGET2, interbank overnight loans need be identified from certain search criteria. Frutos, Garcia, Heider and Papsdorf (2014) adapt the Furfine (1999) algorithm for this purpose. The algorithm identifies overnight interbank loans from the requirement that a payment flow is matched by a flow in the opposite direction on the following day (with certain limits set on the implied interest rate), and uses further information on the transaction stored in TARGET 2. Frutos et al (2014) also validate the findings against data for the unsecured money market in Spain, which are reported in the MID post-trading structure at Bunco de Espuma and find a high accuracy of their results.

The banking group consolidation used in this paper is based on Garcia, Hofmann and Manganelli (2014), who undertook an effort to identify compositional changes in banking groups during the financial and sovereign debt crisis. Finally, we limit the analysis to transactions that banks undertake on their own behalf. More precisely, the data set includes information on the originators and beneficiaries of transactions, in addition to the sending and receiving banks. We limit our analysis to loans, where senders and receivers coincide with originators and beneficiaries, respectively. This leaves us with about $465,500$ transactions.

3.2 The evolution of money market activity

Figures 1 shows several indicators of aggregate market activity that document substantial shifts in overall transaction volumes. We distinguish five different phases in the evolution of the network. These phases can be related to major crisis events and policy interventions, which are summarized in Table 1.

1. Our sample starts in 2008-6, shortly before the Lehman event in 2008-9. After Lehman, transaction volumes dropped by about 50% until mid-2009, while the share of cross-border transactions fell from 60% to below 40%. At the same time, network density stayed at slightly above 1% and the number of active banks remained pretty stable at close to 300.

The latter statistics does not support the view that certain parts of the network would have been cut off the market. Cross-country dispersion in interest rates rose only moderately (Fig 2).[5]

2. Market activity recovered sharply in June 2010 close to pre-crisis levels, when policy interventions helped to calm down the Greek crisis: in May, the EFSF had been created and the ECB had started the SMP programme. These measures could however not reduce the interest rate dispersion in domestic and cross-border borrowing rates that had emerged in mid-2009. The inspection of country-level data in Fig 3 reveals that the increase in activity took mostly place in the euro area core with banks in France and Luxembourg borrowing heavily form German and Dutch banks.

   From autumn 2010 until the end of 2011, market volume gradually declined while remaining at high levels, while interest rate dispersion gradually increased.

3. Third, as is well-known, the sovereign debt crisis intensified in mid-2011. From mid-2011 onwards, decline in both market activity and network density accelerated, and interest rate dispersion widened strongly. German cross-border lending volumes, in particular, fell by two thirds in the course of 2011. French banks reduced their borrowings gradually, whereas Luxembourg almost vanished from the market in September.

   The data suggest that counterparty risk appears to have increasingly mattered in this period. The decline in market activity was accompanied by a significant narrowing of the aforementioned net lending and borrowing positions. Second, interest rate differentials, which have been virtually absent before mid-2011, have increased for countries that faced sovereign debt crises. Further, and in contrast to the post-Lehman period, network density decreased.

4. The ECB launched LTROs in 2011-12 and 2012-3. After these interventions market volume accelerated its decline. In between 2011-12 and 2012-6 transaction volumes more than

[5] The chart shows the densities of the undirected networks, which is defined as the number of actual links within a period, divided by the number of all possible links, $n(n-1)/2$, where n is the number of nodes in the network.

halved. At the same time, network density and the number of participating banks stabilized in early 2012, while interest dispersion fell back to the levels of 2010.

5. Since, 2012-6, the market appears stable at a subdued level. Overall, transaction volumes remain at about 35% of the levels seen in 2010-6, while interest rate dispersion remains at about the level of 2010-6. Network density stands at 0.5%, compared to slightly above 1% in 2010-6. In 2013, the share of cross-border transactions gradually recovered.

Table 1: Timeline of Events

Date		Description
Sep 15,	2009	Lehman bankruptcy
May 7,	2009	ECB introduces Covered Bonds Purchasing Program First ECB 1-year Long-Term Refinancing Operation (LTRO)
Sep 29,	2009	Greece's Prime Minister admits that Greek economy is in 'intensive care'
Dec 8,	2009	Third ECB 1-year Long-Term Refinancing Operation (LTRO)
Dec 15,	2009	FITCH downgrades Greece's credit rating
Apr 23,	2010	Greece seeks financial support
May 10,	2010	ECB introduces Security Markets Programme (SMP) Decision to set European Financial Stability Facility (EFSF)
Nov 21,	2010	Ireland seeks financial support
Apr 6,	2011	Portugal requests activation of aid mechanism
July 1,	2011	Interest rates on Italian and Spanish government bonds start to rise
Nov 16,	2011	Monti becomes Italy's new prime minister forming a technocrat government
Dec 8,	2011	ECB announces measures to support bank lending and money market activity
Dec 22,	2011	First ECB 3-year Long-Term Refinancing Operation (LTRO)
Mar 1,	2012	Second ECB 3-year Long-Term Refinancing Operation (LTRO)
Nov 20,	2012	General elections in Spain
Jun 27,	2012	Cyprus requests financial support
Jul 20,	2012	Eurogroup grants financial assistance to Spain's banking sector
Jul 26,	2012	'Whatever it takes ' speech by ECB president Draghi in London
Sep 6,	2012	ECB announces technical features of Outright Monetary Transaction Programme

Fig 1: Network activity

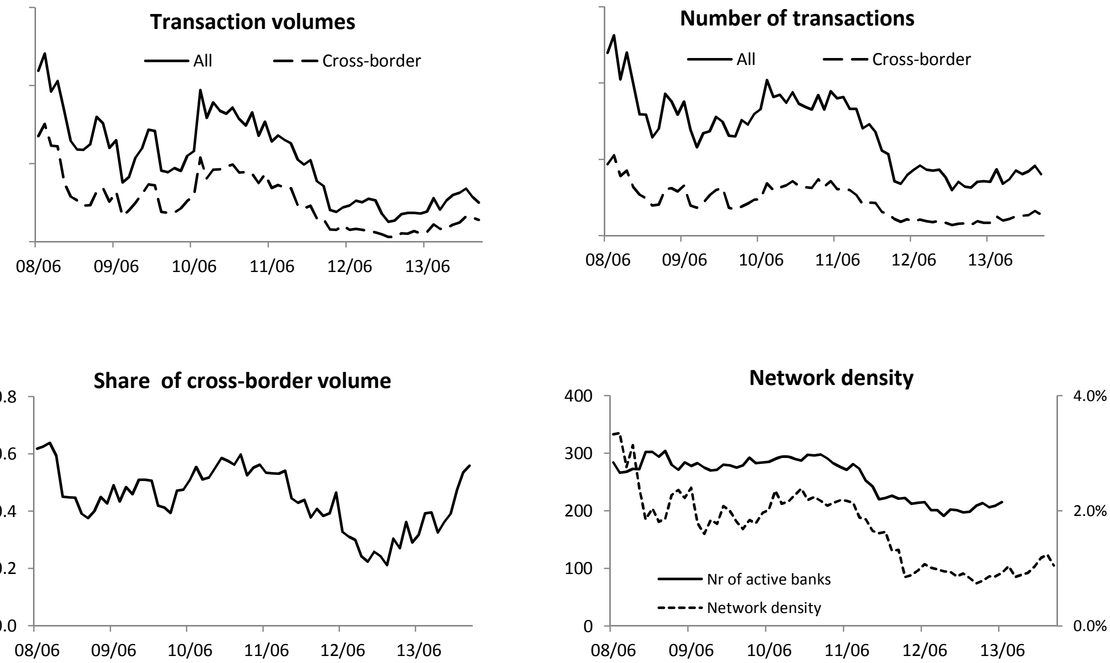
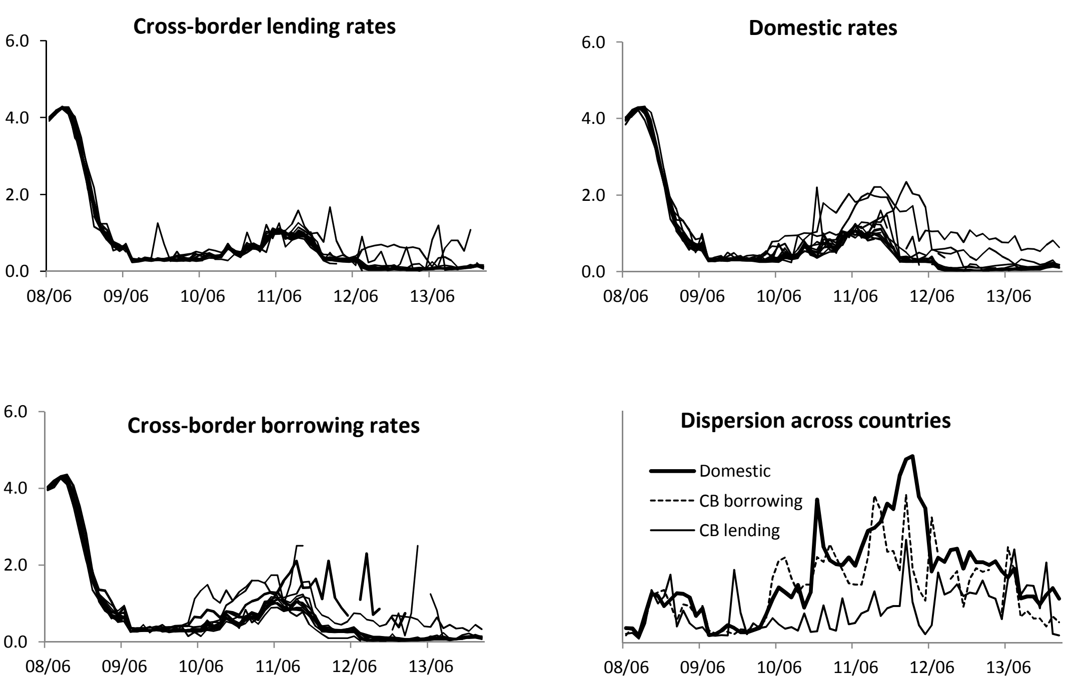


Fig 2: Country level interest rates



The lower charts show cross-border lending and borrowing and domestic rates for each country. The lower right chart shows the standard deviation of interest rates across countries for each period.

Figures A.1 show the evolution of lending and borrowing volumes at individual country levels. The above pattern in activity is shared by most of the countries: after a decline in 2009, activity recovers at mid-2010 only to fall back from mid-2011 on. There are however some important differences in timing and the intensity of shifts in activity. Most notably, the charts show marked booms in either borrowing or lending in Germany, France and the Benelux, whereas shifts in Italy, Spain, and other peripheral countries are more mitigated.

Activity is concentrated among the larger economies: the major 5 euro area economies account for 80% of total activity and 72% of cross-border activity. For these economies, the share of cross-border transactions is at around 40%. Quite interestingly, most of the smaller countries (notably the Benelux, Finland, and Portugal) display rather little domestic activity. Instead, lending and borrowing takes place almost entirely across borders. This suggests the existence of a euro area-wide core that would act as money centre for smaller banks in the periphery.

4 Communities and cores in the network

In order to achieve sufficient stability in the partitions over time, we apply the community and core analysis to quarterly aggregates of the data. One of the advantages of using weighted network data is that temporal aggregation does not systematically affect the network structure, as the weights of the individual links among the nodes would simply increase proportionally. At the same time, temporal aggregation reduces idiosyncratic noise.[6]

To motivate the analysis, the lower panels in Fig. A.2 give some account of the network structure at the bank and country levels for various periods within the sample. The graphs are shown for five quarters, the choice of which is motivated by the results from community analysis, which are presented in section 4.1. The lower graphs plot the adjacency matrix V at the bank level. The size of each bullet reflects the volume of lending from bank row to bank column. Banks are sorted by country and, within country, by size. Hence, within each country, the major part of transaction is plotted in the lower left corner. The upper graphs complement this with network

[6] By contrast, with unweighted adjacency matrices, the density of the network would increase with temporal aggregation with potential systematic effects on modularity and core estimates.

graphs of *net* cross-border flows at the country level. The bilateral relationships among countries are shown in the form blue directed arrows (where thickness represents the strength of the net position). As an example, a blue arrow in the direction France (FR) to Germany (DE) means that French banks are net lenders of overnight funds to German banks.

The graphs highlight some features of the network structure and its changes. Network concentration and density differs substantially within countries. Given that banks are sorted by size, the concentration of mass at the left bottom corner of each country block indicates the concentration of the network. The country networks of Germany and France are heavily concentrated, whereas those Italy and Spain are very dense but show little concentration. This may be related to the presence of trading platforms in those two countries (mid and e-mid, respectively). As already shown in Fig. A.1, cross-border transactions play in important role for banks in smaller countries, and hence domestic markets appear neither particularly dense and concentrated. For instance, Austria is closely connected to Germany, while Belgium has closer ties to France and Italy.

Cross-border transactions differ substantially across countries. Spanish and Italian banks generally are somewhat separated. Perhaps more interesting are some obvious changes in the network structure in between 2010-12 and 2011-6. Some cross-border activities declined substantially, notably lending of German banks to France and Italy. A closer look suggests that the same applies to Dutch banks and lending from France to Spain. Network density within Spain decreased, while borrowing of Spanish banks from various other countries appears to have increased.

At the same time the country network graphs in Figures A.2 show significant shifts in net cross-border flows over time. This is most apparent for Germany and France: while French banks are large-scale net borrowers on aggregate in 2010 Q4, they become large-scale net lenders in 2014 Q1. Generally, the major part of net flows takes place among Germany, France, and the Benelux. Prior to 2011 Q3 Germany in particular played a pivotal role in providing overnight funds on a net basis to banks located in France, Ireland and Italy. While banks in Italy and Spain continued to be net borrowers, their funding costs had increased (see Garcia et al., 2014).

4.1 Community structure and fragmentation

In this section we discuss the evolution of communites, as estimated from the weighted modularity approach (section 2.1), and present measures of overall and of cross-border market fragmentation.

Tables A1 and A.2 summarize the outcomes of community analysis, which is conducted separately for each quarter. We find the number of communities to vary in between 3 and 4 most of the time. The contribution to overall modularity decreases rapidly with the level of the partitioning. With the exception of observations at the end of the sample, the top bisection, i.e. the partition of the whole network into communities $\mathcal{D}_{(1)1}$ and $\mathcal{D}_{(1)2}$, explains close to 70% of overall modularity. Partitioning the larger community $\mathcal{D}_{(1)1}$ into $\mathcal{D}_{(1)11}$ and $\mathcal{D}_{(1)12}$ results in three communities that always explain more than 85% of overall modularity. Hence, we limit our analysis to the top bisection and the partition into 3 communities.

Table A.2 shows two further measures of the degree of partitioning. The ratio of average transaction volumes within communities to total transaction volumes. attains values of in between 0.70 and 0.97 for the top bisection with an average value of 0.87. Second, we decompose the average degree (number of links) of nodes into the average number of links within and between communities. Most of the time, about 80% of links are formed within communities. For instance, in 2014 Q1, 2.8 out of 3.3 links are within communities. In both cases, the corresponding statistics for the 3-community partition is only slightly lower.

Modularity and the share of transaction volumes within communities are measure of the fragmentation of the network. As shown in Figure 3, they are subject very similar patterns. Fragmentation starts to rise with the Lehman event; after a peak at the Greek crisis it falls back in mid-2010 with the various policy measures introduced in the second quarter (see section 3). However, it starts to rise again from mid-2011 onwards and, with the LTROs being introduced at the end of 2011, reaches its peak only in 2012 Q4. During these periods, the number of communities is typically estimated with 4 to 5, and the top bisection explains not more than 70% of overall modularity, altogether indicating heightened fragmentation. Since the first half of 2013, fragmentation measures are on a moderate decline.

Figure 3: Measures of fragmentation

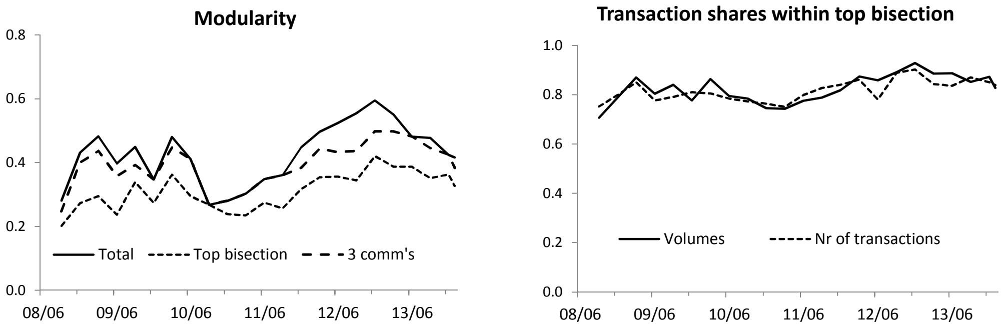


Figure 4: Measures of cross-border fragmentation

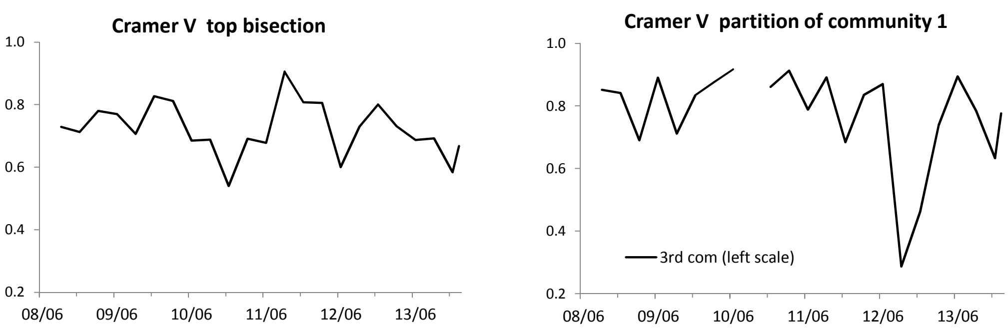
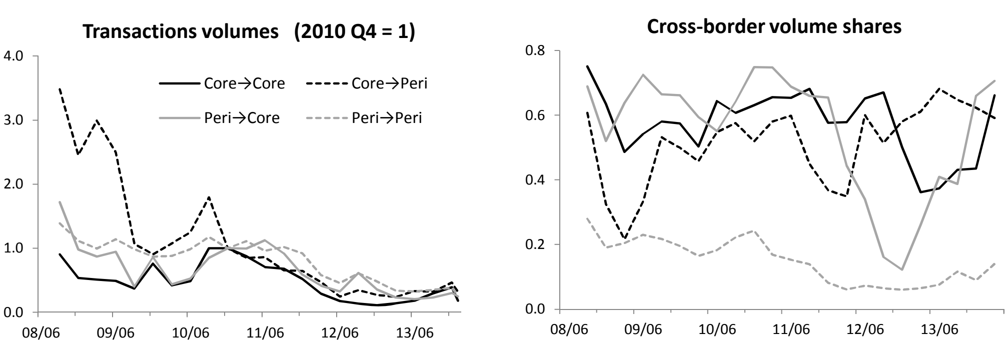


Figure 5: Core and periphery



4.2 Cross-border fragmentation

We turn to cross-border fragmentation. Figure 4 presents the Cramer V statistics of correspondence among community membership (in the top bisection) and the national location of the bank as a measure for cross-border fragmentation of the euro area interbank market.[7] A high value indicates that communities are unevenly distributed across euro area member states. We start with a discussion of the top bisection and turn to the contribution of the third cluster later on.

Table 2: Country allocation to top bisection

Period	2009 Q4		2010 Q4		2011 Q3		2012 Q6		2014 Q1	
Cramer V	0.83		0.54		0.91		0.60		0.67	
Cluster	I	II	I	II	I	II	I	II	I	II
Size	203	96	250	56	167	144	190	71	182	54
AT	1	10	12	1	0	17	23	3	29	0
BE	5	0	3	3	3	2	1	4	3	1
CY	2	3	5	0	4	2	2	0	1	0
DE	5	50	33	25	1	61	35	15	20	30
EE	0	0	0	0	0	1	0	0	1	0
ES	70	1	65	2	54	1	10	32	29	1
FI	0	5	3	1	1	7	3	0	0	2
FR	14	2	8	7	14	2	8	4	5	9
GR	9	1	12	0	12	0	10	2	3	4
IE	0	6	5	1	0	5	5	0	0	4
IT	63	2	62	2	68	0	59	2	57	1
LU	4	0	2	2	0	4	1	3	2	2
NL	10	6	6	10	4	12	7	2	9	4
PT	13	2	18	1	6	10	11	4	12	0
SI	6	3	10	0	0	13	8	0	0	0
SK	1	5	6	1	0	7	7	0	7	0
North	21	82	67	41	6	114	81	23	72	38
South	182	14	183	15	161	30	109	48	110	16

The table shows the number of banks allocated to the top bisections for each country. North consists of AT, DE, EE, FI, LU, NL, SK. South consists of the remaining countries.

[7] The Cramer V statistic is a measure of correspondence among two characteristics in an n x m categorial table. It ranges from 0 to 1 (see Agresti, 2002).

For the top bisection, the Cramer V statistics ranges in between 0.54 and 0.91. There are two episodes of particularly high market fragmentation, associated with the two major episodes of the euro area sovereign debt crisis. The statistics reaches a first peak of 0.83 with the onset of the Greek crisis in 2009 Q4, but declines gradually thereafter to 0.54 in 2010 Q4. However, it increases again and reaches another peak of 0.91 in 2011 Q3. Since then it is on a steady decline.

The decline in cross-border community fragmentation after 2011 Q3 is particular interesting as it goes hand in hand with the decrease in network size and density. Thus, while the network shrank and fragmented as a whole, it partly re-integrated across national borders.

Table 2 shows substantial differences in the community structures at the troughs and peaks of the Cramer V statistics. At the two peaks, the network splits into two communities with a pronounced north-south separation. The northern block is formed by Germany and some further, mostly neighboring, countries, while France, Italy, Spain, and Greece make up the bulk of the southern block. Some countries change their block between the two peaks: Netherlands and Slovenia move to the northern block.

At the troughs of the Cramer V statistics, the size of the two communities is more uneven. The north-south divide is much less prevalent. German and Dutch banks, in particular, are spread across communities. The larger part of German banks forms a large community together with Spanish and Italian banks. The smaller community consists of a subset of German banks together with French and Dutch banks. In 2012 Q2, the majority of Spanish banks also join the second community.

Figure 4 also shows the Cramer V statistics for the second layer of the 3-community partition, which arises from the partition of the larger community from the top bisection. This shows little variation with the exception of some decline in late 2012, and there appears no systematic relation to major crisis events. For most periods, this partition singles out the Italian and/or Spanish banks from the remainder of the community.

Table 3 presents some counter-factual exercise, which suggests that community structures at peaks and troughs differ to a sufficient extent to warrant the above interpretations. Unfortunately, attaching any probabilistic significance values to the above statistics is infeasible, as the underlying probability measure is not well-defined.

Table 3: Counter-factual analysis of bisections

	2009 Q4	2010 Q4	2011 Q3	2012 Q2	2014 Q1
2009 Q4	1.00	.53	.69	.15	.46
2010 Q4	.72	1.00	.69	.37	.72
2011 Q3	.47	.65	1.00	.44	.60
2012 Q2	.61	.39	.61	1.00	.33
2014 Q1	.42	.57	.51	.29	1.00

The table shows the modularity values of applying the bisection that is derived from period row to the actual data from period column. Modularity values are shown relative to the values for the appropriate period. The diagonal of the table is therefore equal to one.

However, some indication on the economic significance of the results is given by a counter-factual exercise, where the partition obtained in period s is applied to the network data in period t. The loss in modularity as compared to the original partition t gives an indication of the extent to which the community structures of the networks in period s and t indeed differ from each other. Table 5 shows the outcome of this exercise for the troughs and peaks of the Cramer V statistic. Modularity values are shown relative to the values for the original partition. Losses in modularity range from 30% to 70%. For instance, application of the top bisection partition from 2011 Q3 (when cross-border fragmentation peaked) to the network data from 2012 Q4 and 2014 Q1 results in relative modularity values of .44 and .66, respectively. This amounts to losses of 56% and 40%, respectively. Overall, the findings suggest that the community structures at troughs and peaks are sufficiently different to warrant the above conclusions.

4.3 The role of core and peripheral banks

We calculate Bonacich centralities $c_t(\beta)$ for the weighted undirected network at each quarter, We set decay $\beta = 0.6$. We also inspected centrality measures based on the directed network. We found the correlation among lending and borrowing centrality measures to be very low and little grounds to choose among them. We have also experimented with applying the dichotomous core detection algorithm due to Borgatti and Everett (1999) for the unweighted network representation. This gave however implausible results. Due to the high density of the Italian and Spanish domestic networks, banks from those two countries were clearly overrepresented in core estimates.

Core estimates are rather stable over time. We therefore keep the core fixed for the entire sample by forming the average of centralities $c_t(\beta)$ and selecting the 15% banks with highest average centrality, which results in a core size of 41.

The core is composed mainly of German (15) and French (11) banks, but it also contains banks from the Netherlands (4), Italy (3), Spain (2), Belgium (2), Austria, Finland, Luxembourg and Ireland (1). Table 4 shows the evolution of transaction volumes (see also Table A.3). The transaction shares confirm the earlier findings of a high concentration of interbank networks. The core, which consists of 15% of the banks in the network, accounts on average for 56% of overall lending and for 65% of overall borrowing, with 46% of transaction volume taking place within the core. By contrast, only 26% of transaction volumes flow within the periphery, which amounts to 85% of banks.

Our major interest is the evolution of the shares of core and periphery in cross-border transactions during the financial crisis. The left-hand panel of Fig. 5 shows the evolution of trading volumes between and within the core and the periphery. Trading volumes are normalized to $2010Q4 = 100$. The indices move largely in parallel during the various episodes of the sovereign debt crisis, but they differ strikingly in the early part of the sample. During the second half of 2009, lending from the core to the periphery dropped to less than 30% of pre-crisis levels within 2 quarters. The recovery in mid-2010 proved to be temporary. In 2013 Q4, the volume of core-periphery lending stood at 20% of the level in 2008 Q4. By contrast, transaction volumes within the core remain rather stable.

Table 4: Core (C) and periphery (P)

	Volumes				Average Degrees	
	C↔C	C→P	P→C	P↔P	C	P
2008 Q4	0.807	.352	.393	.520	40.6	13.1
2009 Q4	1.144	.130	.344	.406	38.6	11.6
2010 Q4	1.507	.143	.400	.466	44.9	13.0
2011 Q4	0.787	.092	.234	.430	30.9	9.6
2012 Q4	0.164	.039	.142	.224	13.3	5-6
2013 Q4	0.587	.067	.121	.179	21.9	5.9

The left-hand panel of the table shows transactions volumes (in 1000 bln euro) within and between the core and the periphery. The core consists of 41 banks, while the size of the entire network declines from 295 in 2008 Q4 to 242 in 2013 Q4 (see Table A.3). The right hand panel shows the evolution of the average degree of core and peripheral banks.

The shares of cross-border transactions in core-periphery lending and borrowing are shown in Fig 5. Within the core, cross-border transactions account for about 40% most of the time: a temporary drop in 2012 is reverted towards the end of the sample. Cross-border transactions account only for a small share of overall transactions among peripheral banks. However, there is substantial cross-border lending from the core to the periphery and vice verse. As to the effect of crisis events, the cross-border share in lending from the core to the periphery dropped after the Lehman event and gradually recovered thereafter.Another temporary decline takes place durign the sovereign debt crisis Lending from the periphery to the core remained pretty stable until the end of 2012, but dropped markedly after the introduction of the LTROs in late December 2012.

Overall, the results indicate that lending from the core to the periphery was highly sensitive to market stress, while transactions within the core remained rather stable. Overall, while the decline in overall transaction volumes after the Lehman event amounted of 50% is already substantial (see section 3), the aggregate numbers mask an even larger permanent decline in lending from the core to the periphery. Afonso et al. (2012) conclude for the U.S. that markets were '*stressed not frozen*', but some peripheral segments in the euro area money market may in fact have been severly impaired. Another interesting finding is the large but temporary decline in lending from the periphery to core after the introduction of the LTROs. The above findings also apply to cross-community transactions and are robust against different values of core size and decay β.

5 Conclusions

The paper inspected the evolution of the network of euro area unsecured overnight interbank loans during the financial crisis. We took an exploratory approach and used basic networks statistics together with community and core detection methods to distil changes in the network structure in between mid-2008 and 2013.

We found that such changes the interbank loan market were quite closely aligned with episodes of sovereign debt stress and the related policy interventions.

Community analysis shows some increase in both general market fragmentation and cross-border fragmentation after the Lehman event and the first phase of the sovereign debt crisis. The decline in transaction volumes until the end of 2009 was particularly sharp in lending from the core to the periphery, suggesting that aggregate numbers understates the liquidity shortages that were faced in peripheral market segments. The policy intervention of mid-2010 appear to have been reasonably successful in reversing these adverse developments.

Market fragmentation re-emerged in the course of 2011. The first phase until the end of 2011 was characterised by a general decline in market activity and a hike in cross-border market fragmentation, as the community structure of the network was mostly determined by national borders. Our measure of market fragmentation continues to increase after the LTROs launched in December 2011 and February 2012 and peaks only in mid-2012. However, at this time this is mostly due to reduced borrowing of the core from the periphery, which appears to have been substituted by LTROs, while *cross-border* fragmentation declines. This suggests that even if the LTROs may have contributed to the decline in market activity, as argued by some observers, they have at the same time reduced market fragmentation in the more stressed market segments.

References

Afonso G., A. Kovner and A. Schoar, 2011, Stressed not frozen: the Federal Funds market in the financial crisis, The Journal of Finance 66(4):1109–1139.

Agresti A.,2002, Categorical Data Analysis, John Wiley & Sons, NJ.

Battiston S., M. Puliga, R. Kaushik, P. Tasca. and G. Caldarelli, 2012, DebtRank: too central to fail? Financial networks, the FED and systemic risk, Scientific Report 2: 541.

Bonacich P., 1987, Power and centrality: a family of measures, The American Journal of Sociology, 92 (5):1170-1182.

Bonacich P. and P. Loyd, 2001, Eigenvector-like measures of centrality for a-symmetric relations, Social Networks 23: 191–201.

Borgatti S.P. and M.G. Everett, 1999, Models of core-periphery structures, Social networks 21:375-395.

Calvo-Armengol, A., E. Patacchini, and Y. Zenou, 2009, Peer effects and social networks in education, Review of Economic Studies 76, 1239-1267.

Craig B. and G. von Peter, 2014, Interbank tiering and money center banks, Journal of Financial Intermediation 23(3): 322-47.

De Frutos M., J.C. Garcia, F. Heider and P. Papsdorf, 2014, Stressed interbank markets: evidence from the European financial and sovereign debt crisis, mimeo, European Central Bank.

ECB, 2013, TARGET 2 annual report, European Central Bank
http://www.ecb.europa.eu/pub/pdf/other/targetar2013en.pdf.

ECB, 2014, Final report of the ESCB Macro-prudential Research Network, European Central Bank,
http://www.ecb.europa.eu/pub/pdf/other/macroprudentialresearchnetworkreport201406en.pdf.

Furfine C., 1999, The microstructure of the Federal Funds market, Financial Markets, Institutions, and Instruments, 8(5), 24-44.

Garcia C., P. Hoffmann and S. Manganelli, 2014, Fragmentation in the euro area interbank market, Economic letters forthcoming.

Leicht E.A. and M.E.J. Newman, 2008, Community structure in directed networks, Physics Review Letters 100(11):118703.

Lelyveld I. and J. int 'Veld D., 2012, Finding the core: network structure in interbank markets, de Nederlandsche Bank working paper 348.

Lux T. and D. Fricke, 2012, Core-periphery structure in the overnight money market: evidence from the e-MID trading platform, Kiel Institute for the World Economy working paper 1759.

Newman M.E.J., 2006, Modularity and community structure in networks, Proc. Natl. Acad. Sci. USA 103:8577-8582.

Newman M.E.J., 2013, Spectral methods for network community detection and graph partitioning, Physics Review Letters arXiv:1307.7729 [physics.soc-ph]

Rombach M.P., M.A. Porter, J.H. Fowler and P.J. Mucha, 2013, Core-periphery structure in networks, mimeo, Oxford Centre for Industrial and Applied Mathematics.

Soramäki K., M.L. Bech, J. Arnold, R.J. Glass and W.E. Beyeler, 2006, The topology of interbank payment flows, Federal Reserve Bank of New York, Staff Report no. 243.

Schäffer S.E., 2007, Graph clustering, Computer Science Review 1:27-64.

Dungey M., M. Luciani and D. Veredas, 2013, Ranking systemically important financial institutions, mimeo.

Fig A.1a: Overall borrowing volumes of individual countries

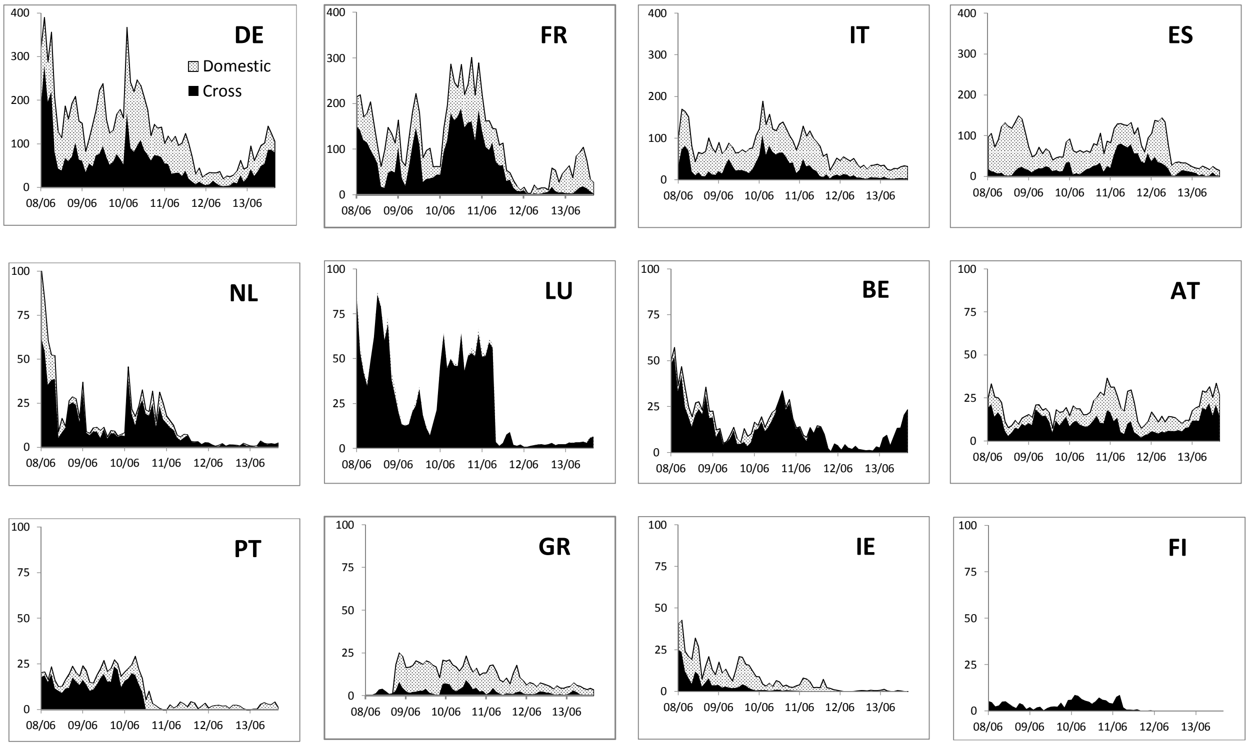


Fig A.1b: Overall lending volumes of individual countries

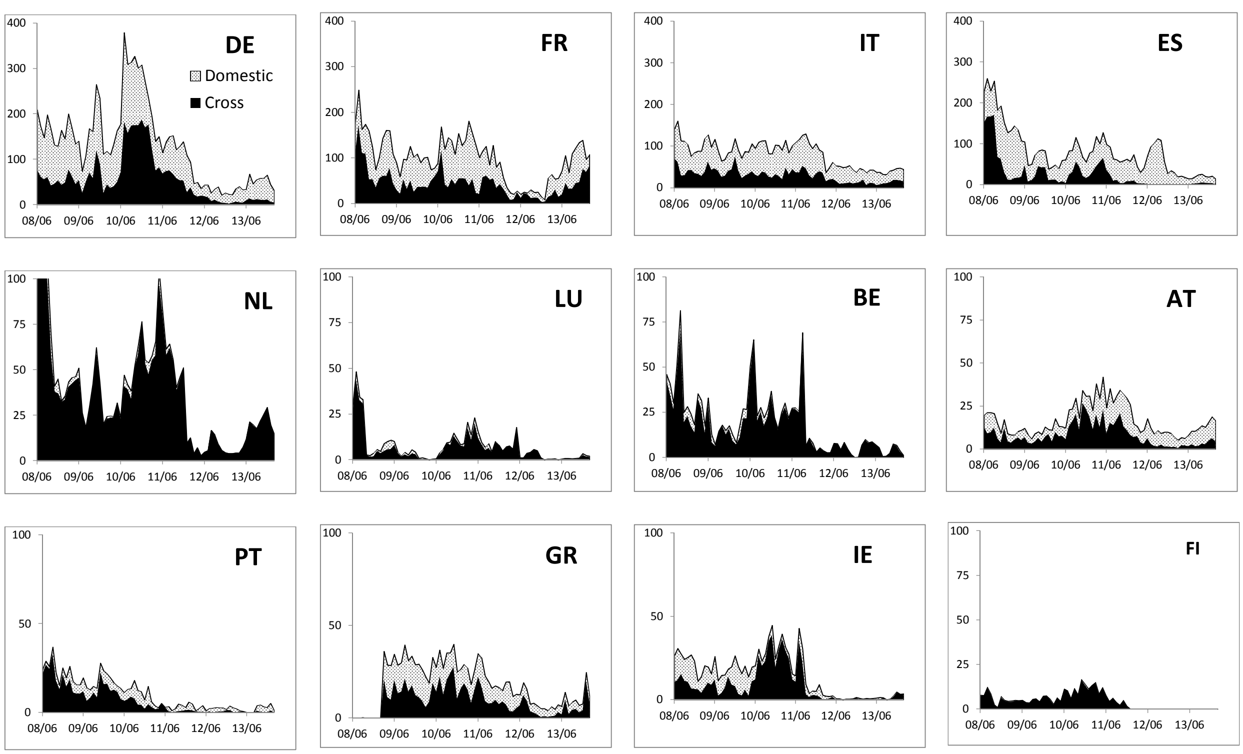
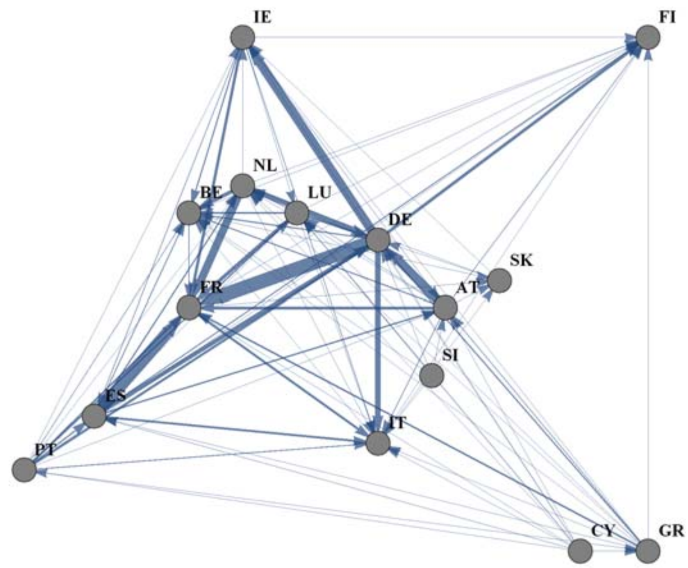
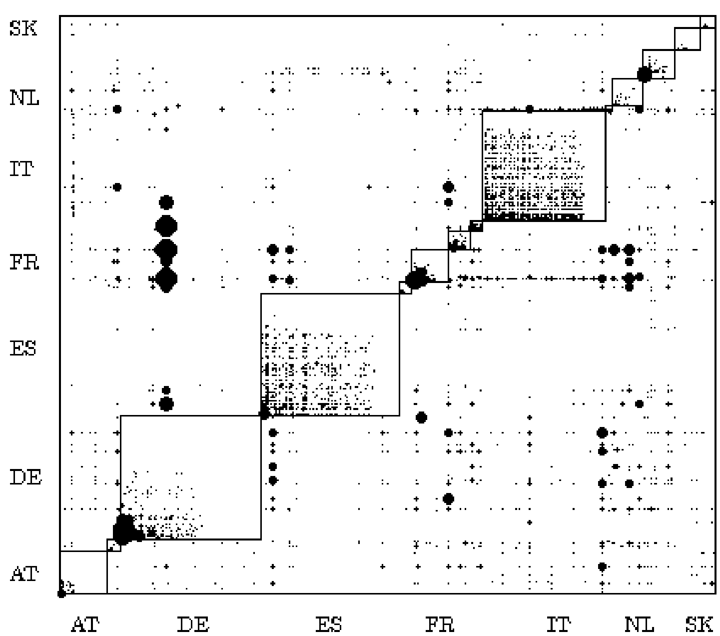


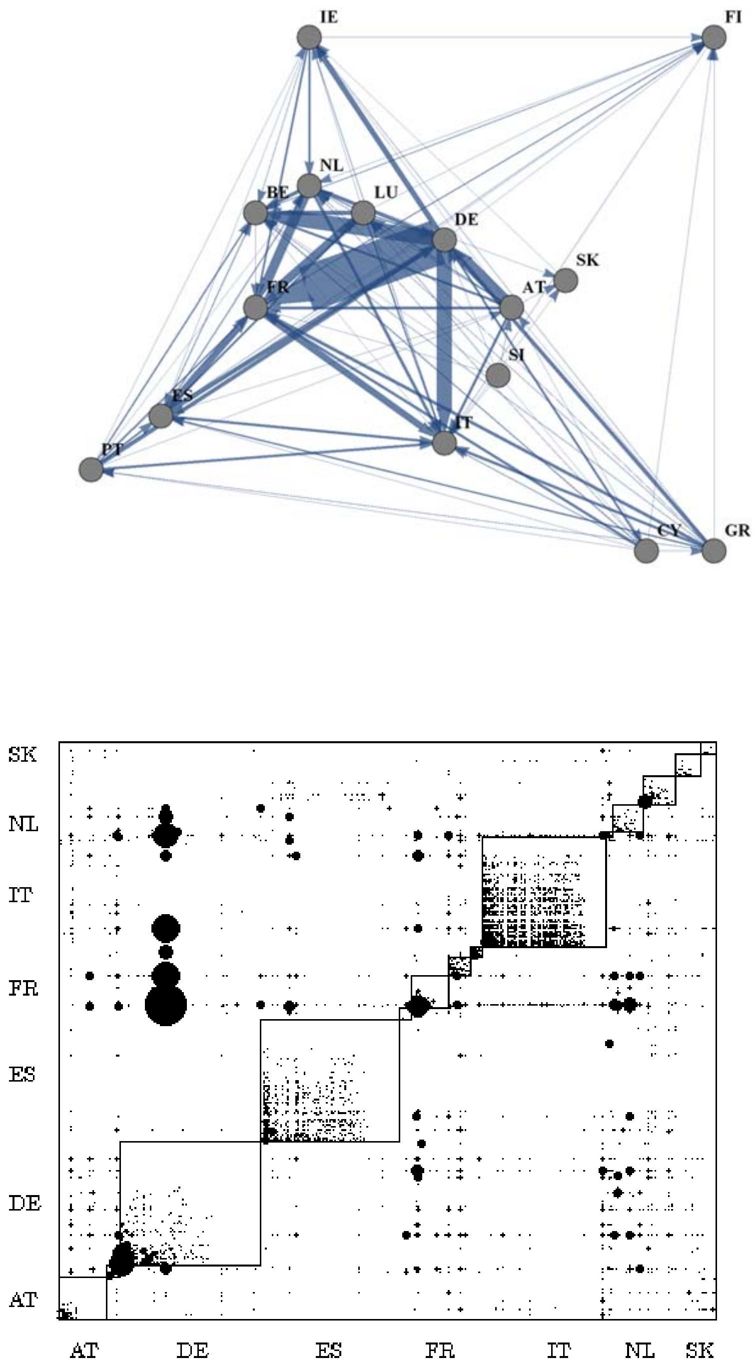
Figure A.2a: Network graphs, 2009 Q4





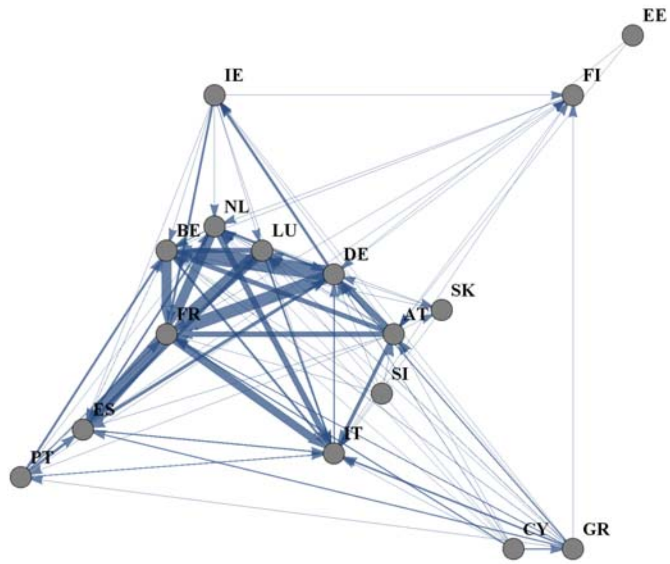
The upper graph shows the net lending flows across countries. The lower graph shows the volumes of bilateral lending among banks. The size of the circle indicates the volume of lending from bank row to bank column.

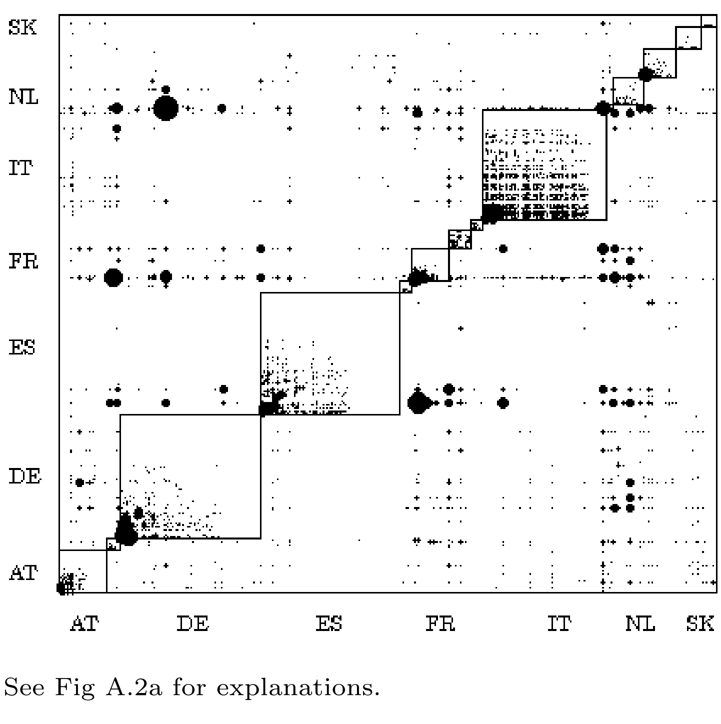
Figure A.2b: Network graphs, 2010 Q4



See Fig A.2a for explanations.

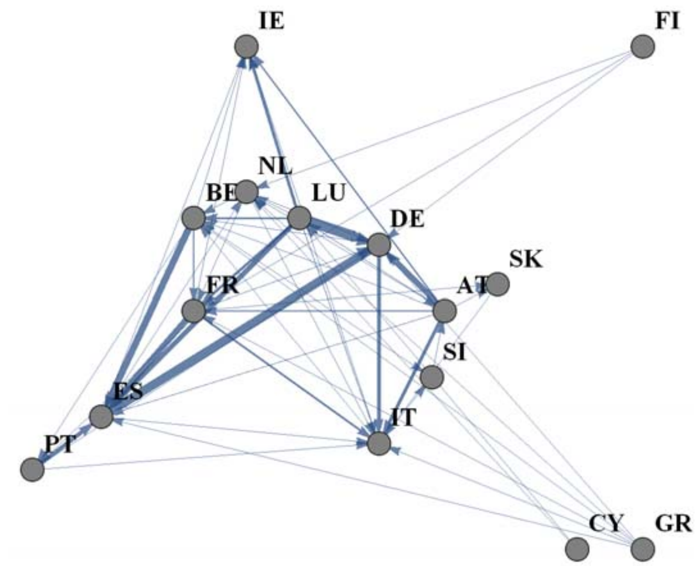
Figure A.2c: Network graphs, 2011 Q3

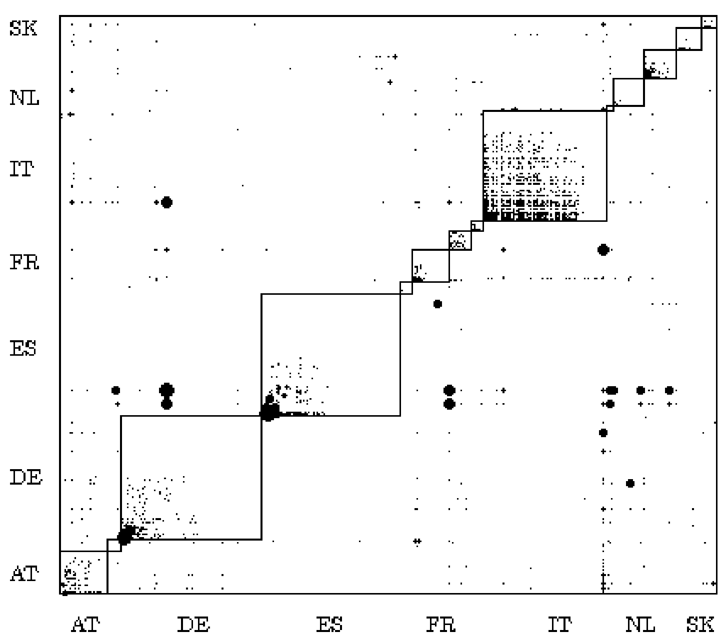




See Fig A.2a for explanations.

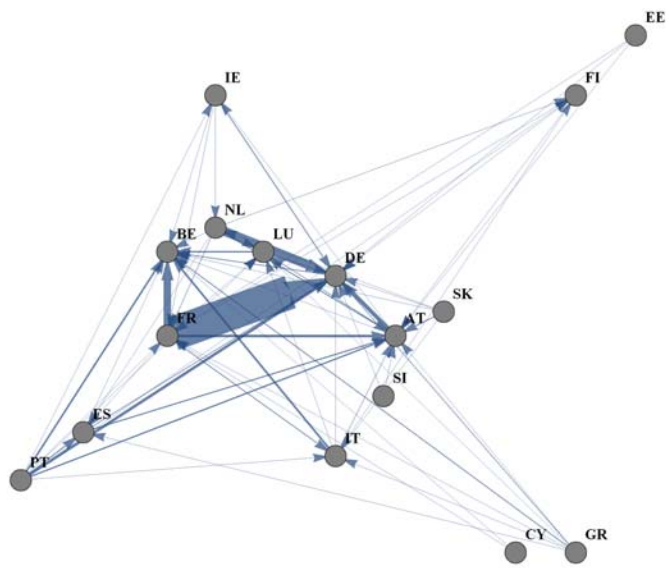
Figure A.2d: Network graphs, 2012 Q2

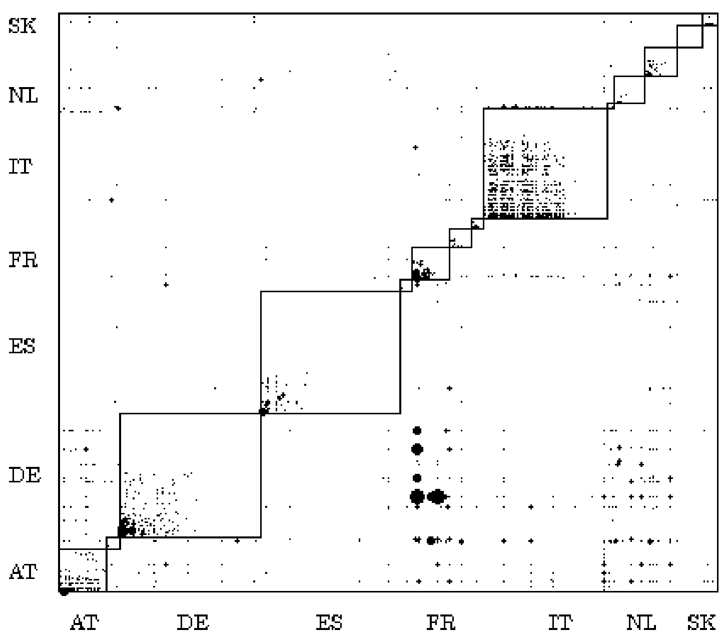




See Fig A.2a for explanations.

Figure A.2e: Network graphs, 2014 Q1





See Fig A.2a for explanations.

Figure A.3a: Cluster membership, 2009 Q4

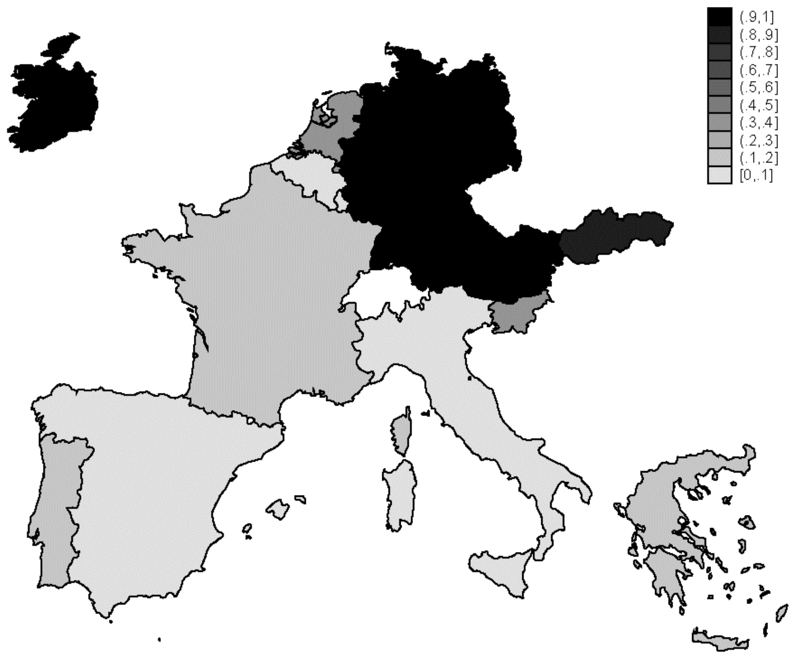
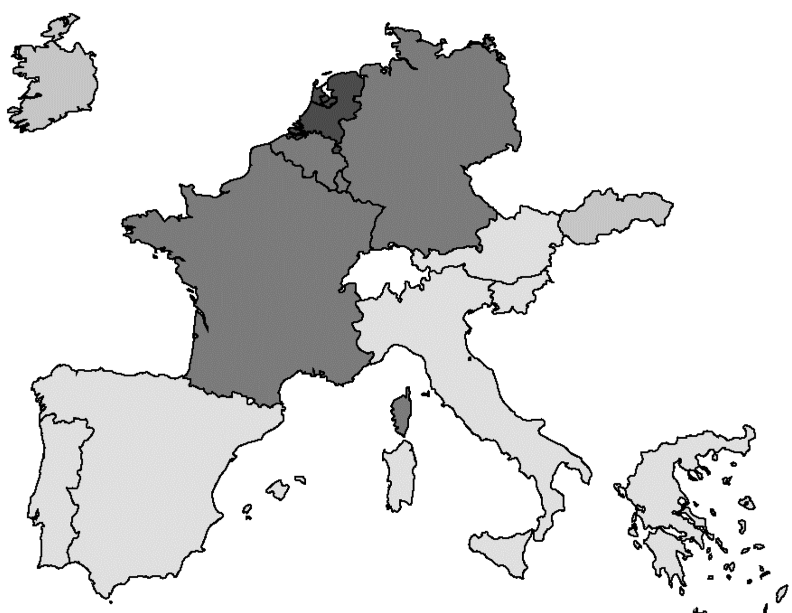


Figure A.3b: Cluster membership, 2010 Q3



The graphs show community membership of banks per country. Dark shaded-areas indicate a high share of banks in top bisection 2.

Figure A.3c: Cluster membership, 2011 Q3

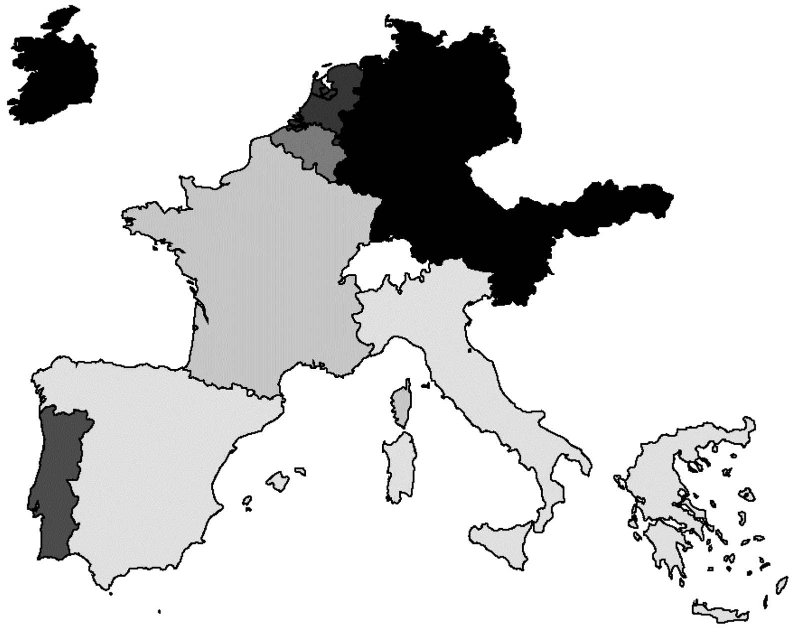
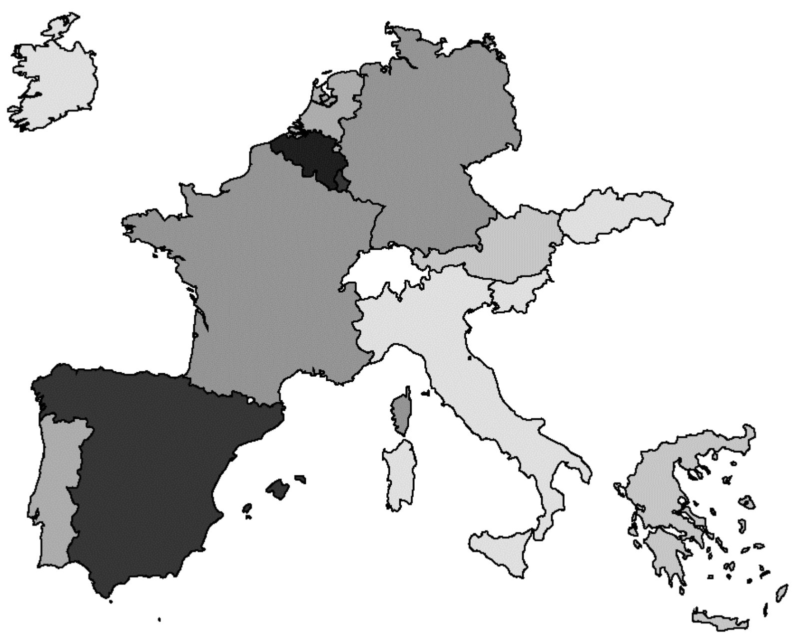
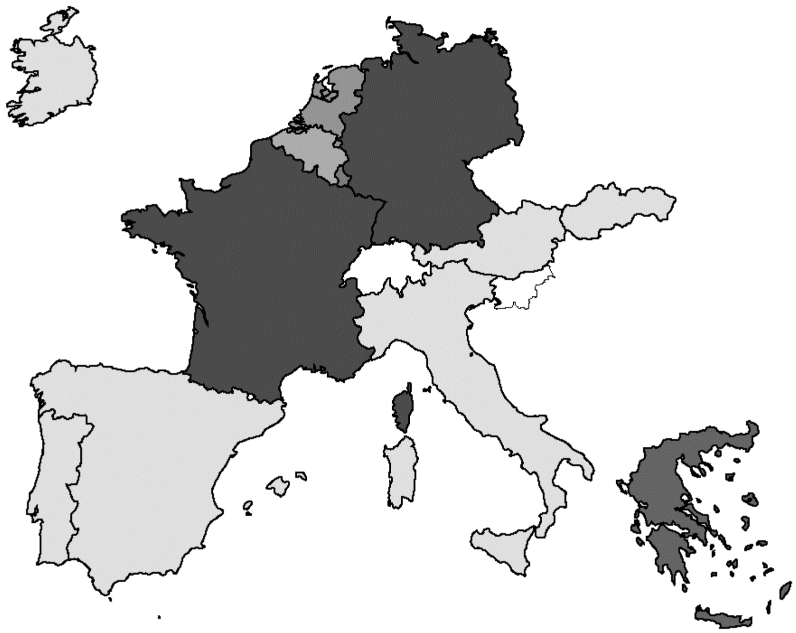


Figure A.3d: Cluster membership, 2012 Q2



The graphs show community membership of banks per country. Dark shaded-areas indicate a high share of banks in top bisection 2.

Figure A.3e: Cluster membership, 2014 Q1



The graphs show community membership of banks per country. Dark shaded-areas indicate a high share of banks in top bisection 2.

Table A.1: Basic properties of partitioning

	Network size	Nr of com's	Modularity			Community size				Cramer V	
			Total	Top bisection	3 Com's	1	2	11	12	Top bisection	3 Com's
				(%) of total							
2008-09	298	4	0.281	*0.72*	*0.88*	139	159	48	91	0.73	0.85
2008-12	295	4	0.431	*0.63*	*0.93*	206	89	42	164	0.71	0.84
2009-03	316	3	0.482	*0.61*	*0.90*	231	85	181	50	0.78	0.69
2009-06	316	4	0.398	*0.63*	*0.91*	169	147	67	102	0.77	0.89
2009-09	302	4	0.449	*0.75*	*0.87*	211	91	12	199	0.71	0.71
2009-12	299	3	0.347	*0.79*	*1.00*	203	96	162	41	0.83	0.83
2010-03	297	4	0.480	*0.75*	*0.93*	181	116	153	28	0.81	0.88
2010-06	298	3	0.411	*0.72*	*1.00*	214	84	85	129	0.69	0.92
2010-09	306	2	0.268	*1.00*	*1.00*	237	69	na	na	0.69	na
2010-12	306	3	0.280	*0.85*	*1.00*	250	56	76	174	0.54	0.86
2011-03	306	3	0.303	*0.77*	*1.00*	216	90	125	91	0.69	0.91
2011-06	315	3	0.348	*0.79*	*1.00*	249	66	129	120	0.68	0.79
2011-09	311	3	0.361	*0.71*	*1.00*	167	144	114	53	0.91	0.89
2011-12	298	4	0.448	*0.71*	*0.86*	149	149	63	86	0.81	0.68
2012-03	270	4	0.496	*0.71*	*0.89*	110	160	69	41	0.81	0.83
2012-06	261	5	0.525	*0.68*	*0.82*	190	71	83	107	0.60	0.87
2012-09	244	4	0.554	*0.62*	*0.79*	208	36	206	2	0.73	0.29
2012-12	237	5	0.595	*0.71*	*0.84*	177	60	175	2	0.80	0.46
2013-03	234	4	0.550	*0.70*	*0.90*	158	76	132	26	0.73	0.74
2013-06	228	3	0.482	*0.80*	*1.00*	169	59	81	88	0.69	0.89
2013-09	232	4	0.477	*0.74*	*0.94*	197	35	112	85	0.69	0.78
2013-12	242	3	0.424	*0.86*	*1.00*	202	40	47	155	0.58	0.63
2014-01	237	4	0.416	*0.79*	*0.92*	182	55	80	102	0.67	0.78

Table A.2: Quality of partitioning

	Share in Volume		Average Degrees (Top bisection)			Average Degrees (3 Comm's)		
	Top bisection	3 Comm's	Total	Within	Between	Total	Within	Between
2008-09	0.71	0.64	11.1	8.3	2.8	11.1	7.3	3.7
2008-12	0.79	0.74	7.9	6.3	1.6	7.9	5.7	2.2
2009-03	0.87	0.79	7.4	6.3	1.1	7.4	5.3	2.1
2009-06	0.80	0.69	8.5	6.6	1.9	8.5	5.9	2.6
2009-09	0.84	0.83	6.4	5.1	1.3	6.4	5.0	1.4
2009-12	0.78	0.70	7.2	5.8	1.4	7.2	5.2	2.0
2010-03	0.86	0.84	6.4	5.2	1.3	6.4	4.9	1.5
2010-06	0.79	0.78	6.9	5.4	1.5	6.9	5.2	1.7
2010-09	0.78	na	7.9	6.1	1.8	na	na	na
2010-12	0.75	0.72	8.1	6.2	1.9	8.1	5.8	2.3
2011-03	0.74	0.72	7.8	5.8	1.9	7.8	5.5	2.2
2011-06	0.77	0.74	7.5	6.0	1.5	7.5	5.4	2.1
2011-09	0.79	0.71	6.9	5.7	1.2	6.9	5.2	1.7
2011-12	0.82	0.76	5.9	4.9	0.9	5.9	4.5	1.3
2012-03	0.87	0.78	4.5	3.8	0.6	4.5	3.7	0.8
2012-06	0.86	0.85	3.6	2.8	0.8	3.6	2.7	0.9
2012-09	0.89	0.88	3.6	3.2	0.4	3.6	3.2	0.4
2012-12	0.93	0.93	3.2	2.9	0.3	3.2	2.9	0.3
2013-03	0.89	0.88	2.9	2.4	0.5	2.9	2.4	0.5
2013-06	0.89	0.85	3.2	2.7	0.5	3.2	2.6	0.7
2013-09	0.85	0.82	3.4	2.9	0.4	3.4	2.7	0.7
2013-12	0.87	0.85	3.7	3.2	0.6	3.7	3.0	0.8
2014-01	0.83	0.76	3.3	2.8	0.5	3.3	2.5	0.9

Table A.3: Transaction volumes core and periphery

	Network size	Core size	Volumes (*10^12)				Average degrees	
			Core → Core	Core → Peri	Peri → Core	Peri → Peri	Core	Peri
2008-09	298	41	1.362	0.499	0.688	0.648	66.5	17.2
2008-12	295	41	0.807	0.352	0.393	0.520	40.6	13.1
2009-03	316	41	0.769	0.429	0.350	0.464	36.9	12.4
2009-06	316	41	0.741	0.358	0.378	0.532	48.4	13.5
2009-09	302	41	0.557	0.153	0.161	0.459	31.0	10.8
2009-12	299	41	1.144	0.130	0.344	0.406	38.6	11.6
2010-03	297	41	0.631	0.154	0.175	0.411	29.8	11.0
2010-06	298	41	0.732	0.179	0.210	0.460	31.6	11.9
2010-09	306	41	1.510	0.257	0.341	0.548	43.3	12.7
2010-12	306	41	1.507	0.143	0.400	0.466	44.9	13.0
2011-03	306	41	1.320	0.122	0.399	0.519	46.2	12.2
2011-06	315	41	1.067	0.123	0.451	0.449	47.0	11.4
2011-09	311	41	1.024	0.094	0.369	0.477	41.7	10.8
2011-12	298	41	0.787	0.092	0.234	0.430	30.9	9.6
2012-03	270	41	0.440	0.068	0.168	0.270	20.3	7.7
2012-06	261	41	0.262	0.036	0.130	0.212	15.9	6.3
2012-09	244	41	0.208	0.049	0.246	0.284	14.0	6.4
2012-12	237	41	0.164	0.039	0.142	0.224	13.3	5.6
2013-03	234	41	0.211	0.035	0.093	0.156	13.3	4.9
2013-06	228	41	0.272	0.047	0.083	0.152	16.9	5.3
2013-09	232	41	0.444	0.046	0.093	0.164	18.8	5.4
2013-12	242	41	0.587	0.067	0.121	0.179	21.9	5.9
2014-01	237	41	0.272	0.046	0.098	0.121	19.9	5.2