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Assessment of EU banking network regionalization during post-crisis period

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Abstract
Research background: Recent financial crisis of 2007–2008 has influenced global banking system and led to reduction of cross-border bank lending in the EU and worldwide. Global banking network has been analysed extensively in prior or post-crisis periods, but the literature on regionalization is scarce, especially with regard to the banking sector in the EU. Moreover, in previous empirical research evaluation of banking sector regionalization using network analysis methodology has not been yet applied.
Purpose of the article: The aim of the article is to map the EU banking network and to assess its regionalization during post-crisis period.
Methods: the paper employs comparative literature analysis and synthesis; BIS bilateral interbank cross-border claim yearly flows matrix data and network analysis method (including network mapping, structural and comparative analysis and the data of intraregional and

interregional banking network matrices) to assess the changes in regionalization of the EU banking system.
Findings & Value added: The results of the research show that during post-crisis period both, EU 12 and EU 28, banking networks became more clustered and more decentralized; also the level of regionalization within the EU banking network increased. Such results prove that the EU banking network has undergone structural changes with respect to bilateral interbank cross-border claims. This research adds to the knowledge of regionalization processes within the EU banking network during the post-crisis period and intends to be beneficial for market participants, EU level governmental bodies and financial policy makers.

Introduction

Globalization and connectedness within the world has led to the formation of the global financial system, one of the most international and interconnected networks in the world. Global banking network as a network of financial institutions, connected via cross-border positions attracted attention of many researchers. Previous research of banking networks could be classified into network structure analysis, network resilience analysis and causal network analysis (Kanno, 2015). Network structure analysis includes drawing the graph of network, calculating and analysing various network indicators like clustering coefficient, in-degree, out-degree, degree centrality, etc. (Minoiu & Reyes, 2013; Arribas *et.al*., 2011). Network resilience analysis concentrates on determining how fast contagion caused by a chain of defaults may spread within the network and what network characteristics make it more resilient to shocks (Čihák *et al*., 2011; Garratt *et al*., 2014). Causal network analysis aims to reveal the factors which are influencing particular allocation of cross-border bank claims into certain regions over the other ones allowing to explain why particular network is structured the way it is and what influences changes in network structure over time (Caballero, 2015; Tonzer, 2015).

Recent financial crisis 2007–2008 has led to retrenchment from cross-border bank lending, as banks have withdrawn from foreign markets (Bremus & Fratzscher, 2015, p. 32–59). Even though the crisis has ended, in cross-border banking relations the upward trend endured. As suggested by Bremus and Fratzscher (2015), a part of this retrenchment might have been cyclical, however, some aspects seem to be structural, considering the fact that cross-border banking claims have not increased significantly during the recovery of the economy. Connectedness of European banking is assumed to be following the same decreasing trends after the financial crisis and after the more recent Europe sovereign debt crisis. As argued by Bremus and Fratzscher (2015), loan markets had become increasingly segmented and regionalized, especially in the euro zone. Hence, the phenomenon of home bias, which represents the trend of banks to focus more on their national loan markets, may become very salient, thus, implying the loss of beneficial opportunities in international markets.

Previous empirical literature has focused extensively on global banking networks before and after the financial crisis (Čihák *et al*., 2011; Garratt *et al*., 2011), to some extent on the EU banking networks (Betz *et al*., 2016; Bicu & Candelon, 2013; Philippas *et al*., 2015) and on the networks of particular countries (Caccioli *et al*., 2013; Cont *et al*., 2012). Regionalization in banking networks has not been much addressed. Regionalization could be described as increased connectedness at a regional level (Kim & Shin, 2002) and is not a recent phenomenon. Since the beginning of human history, geographical proximity has been a primary condition for inter-societal exchange, because distance acted as a barrier to trade (Kim & Shin, 2002), thus, leading to the regionalization. Regionalization in banking sector during post-crisis period was analyzed by Claessens and van Horen (2015) and Lambert *et al.* (2015). On the other hand, push, pull, regulatory and monetary policy factors, which could influence cross-border bank claims allocation into certain regions over the other ones are widely debated in the literature (Bremus & Fratzscher, 2015; Butkiewicz & Gordon, 2013; Figuet *et al*., 2015). Possible regionalization of the banking network, especially in certain regions, represents a gap in theoretical and empirical banking network's literature and, hence, network regionalization analysis may provide important insights of special characteristics of regional networks within the global context.

The aim of this research is to map the EU banking network and to assess its regionalization during post-crisis period.

The major contribution of this research is its intention to apply network analysis for evaluation of structural changes in the EU banking network. Evaluation of the EU banking network's regionalization during post-crisis period is conducted for a total of 28 EU countries using Bank of International Settlements (BIS) bilateral interbank cross-border claim yearly flows data. The EU is a formal union, which coordinates not only its international trade, but also financial and monetary systems, laws, etc. and includes socially, economically and politically diverse countries, which makes the EU different from global network and a very interesting case for analysis.

The paper is structured as follows. The first chapter presents research methodology, including the research logics, research data and methods used. The second chapter focuses on presentation of the results representing the EU banking network mapping, analysis the EU banking network using network indicators and assessment of regionalization level within the EU banking network. The third chapter offers discussion of the results. Conclusions include the general summary of the article, implications and recommendations, research limitations, and suggestions for future research.

Research methodology

The research problem addressed in this research is the structure and characteristics of EU banking network and the changes in its regionalization during the post crisis period. Since cross-border claims of European banks have dropped in the wake of financial crisis, it might have happened that the EU withdraw from banking relations not only with regard to non-European countries, but also with regard to countries within the EU. This would reveal possible market segmentation within the EU, as it is suggested by Bremus and Fratzscher (2015). It is expected that during post-crisis period the level of regionalization within the EU banking network increased (i.e. its connectedness had decreased).

Research logics and methods

The research is performed in 2 stages, as presented in Table 1. Stage 1 is aimed at mapping the EU banking network. During Stage 2, the level of regionalization in the EU banking network and within the EU banking network sub-regions is performed using structural and comparative analysis methods and the data of intraregional and interregional banking network matrices.

To conduct Stage 1 analysis, a country's banking sector claim exposures to other country's banking sector are represented in a $N \times N$ matrix X^t for every time period t (in this research, two time periods are used, i.e., $t = 2011$ and $t = 2015$), where columns represent lenders and rows represent borrowers. Each element (cell) x_{ij} is a bilateral exposure from country's j banking sector to country's i banking sector. This implies that an element x_{ij} is an asset of country's j banking sector vis-à-vis country's i banking sector and naturally is also a liability of country's i banking sector towards country's j banking sector. We use a directed network, in which the direction of the link matters (borrowing or lending), thus, $x_{ij} \neq x_{ji}$. Network is presented by the matrix presented in formula (1) (adapted from Paltalidis *et al*., 2015):

$$X^t = \begin{pmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1N} & a_1 \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{iN} & a_i \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ x_{N1} & \cdots & x_{Nj} & \cdots & x_{NN} & a_N \\ l_1 & \cdots & l_j & \cdots & l_N & \end{pmatrix} \quad (1)$$

Thus, a country's banking sector total assets are given by the sum of its column using the formula (2):

$$a_j = \sum_{i=1}^{N} x_{ij,} \quad j = 1, \ldots . N \quad (2)$$

By the same rationale l country's banking sector total liabilities are given by the sum of its row using the formula (3):

$$l_i = \sum_{j=1}^{N} x_{ij,} \quad i = 1, \ldots . N \quad (3)$$

Cross-border banking claims matrix is also weighted to capture the relative size of cross-border banking claims exposures among countries. The weighting matrix determines the structure of the spatial dependence between the sample countries. If the weights are constructed from bilateral interbank exposures among N countries, then $N \times N$ spatial weighted matrix W_t for time period t presented by formula (4):

$$W^t = \begin{pmatrix} \ddots & \cdots & \omega_{1j} & \vdots & \omega_{1N} \\ \omega_{21} & \ddots & \vdots & \cdots & \omega_{2N} \\ \vdots & \cdots & \ddots & \vdots & \cdots \\ \omega_{i1} & \vdots & \omega_{ij} & \ddots & \omega_{iN} \\ \omega_{N1} & \cdots & \omega_{Nj} & \vdots & \ddots \end{pmatrix} \quad (4)$$

where ω_{ij} denotes the weight, which corresponds to country pair ij. Weighting is performed on claim (asset) side positions, i.e., during a specified period, w_{ij} is the claims' of banking sector in country j on banking sector in country i proportion of total claims of country j on all countries N in the sample (see formula (5)):

$$w_{ij} = \frac{x_{ij}}{\sum_{i=1}^{N} x_{ij}} \quad j = 1, \ldots . N \quad (5)$$

The weighting matrix is column standardized and in this directed network $w_{ij} \neq w_{ji}$. After that, mapping of the network is performed resulting in visual images of cross-border banking networks. Each country in the dataset is a node within the network. Directional links between nodes represent cross-border banking claim flows from country j to country i and the direction of a link is indicated in the graph with arrows. Links exist for strictly positive flows, i.e., net increases in cross-border bank assets of a reporting country vis-à-vis another country (‘net investments’) channelled through the banking system between the source and the destination country. All negative flows (‘net repayments’) are replaced with zeros and ignored in the analysis, which is in line with the research of Minoiu and Reyes (2013). Visual images of cross-border banking claim flows networks are drawn using network analysis software Gephi, which is used in a number of previous research (Feng *et al.,* 2014; Feng & Hu, 2013). In addition, countries of the EU 12 and EU 28 banking networks are classified into communities, according to community detection algorithm in Gephi — modularity class, created by Blondel *et al*. (2008). Networks are drawn using BIS LBS by residence data (2016). Node colour depends on the community to which it belongs (modularity class algorithm in Gephi). Node size depends on the node degree metric (larger nodes — higher node degree metric). The width of edge indicates its weight.

Stage 2 requires network analysis using various network indicators and analysis of regionalization level within the EU banking network using intraregional and interregional density indicators as described below.

Degree indicator measures the number of other nodes to which a particular node is connected to. In the context of a banking network, degree indicator reveals how many incoming and outgoing cross-border claim connections with other countries a particular country has. The degree of a node j, in a graph is computed using the formula (6) (Martinez-Jaramillo *et al*., 2014):

$$d_j = \sum_{i \in N(j)} x_{ij} \tag{6}$$

where $N(j)$ is the set of neighbors of node j, i.e., the set of nodes, which have an edge with node j. In a directed network, in-degree of a node is the number of links leading to that node (how many incoming cross-border claim connections with other countries a particular country has) and out-degree is the number of links emanating from that node (how many outgoing cross-border claim connections with other countries a particular country has). These are computed using formulas (7) and (8) (Martinez-Jaramillo *et al*., 2014):

$$d_j^{in} = \sum_{i \in N^{in}(j)} x_{ij} \tag{7}$$

$$d_j^{out} = \sum_{i \in N^{out}(j)} x_{ij} \tag{8}$$

where $N^{in}(j)$ is the set of inner neighbours of node j, which is the set of nodes having an arc ending in node j and $N^{out}(j)$ is the set of outer neighbours of node j, i.e., the set of nodes which have an arc starting in node j (Martinez-Jaramillo *et al*., 2014).

Strength of a node measures the intensity (value) of interaction within the network. In a context of banking network, node strength shows the relative strength of value of cross-border lending and borrowing interactions of a particular country with respect to other countries in the network of cross-border lending and borrowing value. It is calculated according to formula (9) (Martinez-Jaramillo *et al*., 2014):

$$s_j = \sum_{i \in N(j)} w_{ij} \tag{9}$$

where $N(j)$ is the set of neighbors of node j, i.e., the set of nodes, which have an edge with node j. Strength in-degree and strength out-degree measures the inner and outer node strength and allows determining whether a country plays important role as a lender or a borrower. The indicators are computed using formulas (10) and (11) (Martinez-Jaramillo *et al*., 2014):

$$s_j^{in} = \sum_{i \in N^{in}(j)} w_{ij} \tag{10}$$

$$s_j^{out} = \sum_{i \in N^{out}(j)} w_{ij} \tag{11}$$

where $N^{in}(j)$ is the set of inner neighbors of node j, which is the set of nodes having an arc ending in node j and $N^{out}(j)$ is the set of outer neighbours of node j, i.e., the set of nodes which have an arc starting in node j.

Centralization of a network was assessed by 3 the most popular indicators: degree centrality, betweenness centrality and closeness centrality.

The rationale behind degree centrality indicator is that if a country is connected to all or the majority of other countries, in some sense it makes that country fairly central to the network (Fafchamps, 2009). Degree centrality of a node is computed based on formula (12):

$$C_j = \frac{\sum_{i=1}^{N} x_{ij}}{N-1}, \quad j = 1, \ldots . N \tag{12}$$

Degree centrality reveals how many actual incoming and outgoing cross-border claim connections with other countries a particular country has as a share of the total number of incoming and outgoing cross-border claim connections each country could potentially have.

Betweenness centrality metric describes a node‘s importance by how important its neighbours are (Fafchamps, 2009). In a context of banking networks, if betweenness centrality metric increases, it reveals that a country appears on shortest paths between countries in the network more often, meaning that this country becomes more central to network. Let $\sigma_{ij} = \sigma_{ji}$ denote the total number of shortest paths between i and j and let $\sigma_{ij}(v)$ be the total number of shortest paths between i and j that pass through node v, then, betweenness centrality is calculated according to formula (13) (Martinez-Jaramillo *et al*., 2014):

$$C_B(v) = \sum_{i \neq v \neq j \in V} \frac{\sigma_{ij}(v)}{\sigma_{ij}} \tag{13}$$

Closeness centrality metric could be described by how a node is close to the rest of the network, thus, a node with high closeness centrality would depend less on other intermediary nodes (Martinez-Jaramillo *et al*., 2014). In a context of banking network, closeness centrality reveals the average distance from a given starting country to all other countries in the network. A decrease in the average distance reveals decreased intensity of interactions of a particular country and, hence, decreased centralization in a network. Closeness centrality is calculated as (Martinez-Jaramillo *et al*., 2014):

$$C_C(v) = \sum_{j \in V \setminus \{v\}} \frac{1}{d_G(v,j)} \tag{14}$$

where $d_G(v,j)$ denotes the length of the shortest path that joins v and j.

Clustering coefficient is a measure of the density of the connections around a node j and is defined by (Martinez-Jaramillo *et al*., 2014) in formula (15):

$$c_j = \frac{2}{d_j(d_j-1)} \sum_{i,h} x_{ij} x_{ih} x_{jh} \tag{15}$$

In the context of banking network, clustering coefficient reveals the density of incoming and outgoing cross-border claim connections around a country. A country with the high clustering coefficient has many incoming and outgoing cross-border claim connections with other countries and, hence, is clustered with them.

According to Caballero (2015), network density indicator allows to measure the connectedness of nodes within a network. In line with Caballero (2015), Martinez-Jaramillo *et al.* (2014) and Hale *et al.* (2011), in this research, density indicator is chosen for analysis, because it describes how many actual connections in a network exist of all possible connections, thus, allowing to identify the level of EU banking sector regionalization. The density of a network is calculated using formula (16) (Martinez-Jaramillo *et al*., 2014):

$$d = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} x_{ij}}{N(N-1)} \tag{16}$$

where N is the number of nodes and d ∈ [0, 1].

For the assessment of the EU banking network, regionalization intraregional and interregional adjacency matrices are used. This is in line with the research by Kim and Shin (2002). Intraregional density is calculated as a simple density (see Formula 16) of a network, which consists only of a certain region's countries' cross-border claim flows. Interregional density is also calculated as a simple density (see Formula 16), but of a network which consists only of between regions' cross-border claim flows. For the whole network interregional density calculation, all between region matrices are treated as one network. In this research, since there is more than one sub-region within EU, average intraregional density is calculated both for EU 12 and EU 28. EU sub-regions, i.e., Northern, Western, Eastern and Southern Europe are distinguished based on United Nations classification of major areas and regions.

Empirical Research Data

EU cross-border banking claim networks in this research are constructed using the data of Bank of International Settlements (BIS) Locational banking statistics (LBS) of the break- and exchange rate-adjusted yearly changes in cross-border banking claims in millions of US dollars. Cross border claims include loans, deposits, debt securities, and other bank assets. Adjusted changes in amounts outstanding are calculated, as an approximation for flows (BIS, About banking statistics, 2017). BIS LBS cross-border banking claims flows data is available only on a quarterly basis, hence, in this research quarterly flows for each country were aggregated up in order to get yearly flows. Changes in cross-border bank claims were calculated based on previous research (Tonzer, 2015) by subtracting changes in cross-border non-bank sectors' claims from changes in cross-border all sectors' claims, because the data of solely banking sector claims is unavailable.

In this research, the EU cross-border banking claim networks are constructed for time periods of 2011 and 2015, representing a gap in the data set. The decision to make this gap is based on research of Kim and Shin (2002) and is grounded on the rationale that network structures are inert and do not change considerably in a relatively short period of time.

A full data set only available for the BIS reporting countries, which report their outgoing bilateral cross-border claim flows to the BIS. Incoming bilateral cross-border claim flows of BIS reporting countries are obtained from the data of other BIS reporting countries, resulting in a full matrix of data. BIS non-reporting countries do not report their outgoing flows to any country. Incoming flows of BIS non-reporting countries are obtained from BIS reporting countries' outflows, resulting in a non-full data set. In addition, there were several cases in the dataset of BIS reporting countries where either banks or non-banks claim flows data was missing (for Germany, non-banks claim flows were missing vis-à-vis all other countries in the sample). The missing data was replaced by all sample countries' averages as proxies. This is considered appropriate since such proxies constituted only 6.61% and 5.42% of all dataset in 2011 and 2015, respectively.

Empirical research sample used in this study consists of 28 EU countries. Based on the availability of their outgoing bilateral cross-border claim flows, 12 EU countries were classified to the core of the EU (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Luxembourg, Netherlands, Sweden, United Kingdom), and the remaining 16 countries (Cyprus, Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain) — to the periphery of the EU. Even though Cyprus, Italy, Portugal and Spain are BIS reporting countries, their outgoing flows data is unavailable. Therefore, these countries were relatively added to EU periphery to keep coherency.

Research results

Mapping of EU banking network

Graphical drawings of EU 12 directed and weighted cross-border banking claim flows networks in 2011 and 2015 are provided in Figure 1. In 2011 the EU 12 banking network is represented by 3 communities, while in 2015 the number of communities increases to 4. In 2011, all 3 communities were comprised of 4 countries each: 'blue' community — Sweden, Denmark, Finland and UK; 'red' community — Germany, Luxembourg, Greece and

Ireland; and ‘green’ community — Netherlands, France, Belgium and Austria. Community decomposition reveals the countries that are more densely connected together. The results revealed that communities reflect regions (border proximity) within the EU, e.g., ‘blue’ community — Northern Europe; ‘red’ community — Central Europe; and ‘green’ community — Western Europe. This suggests that gravity might have been an important factor for communities’ formation within EU 12 banking network in 2011. In 2015, communities’ composition has changed visibly except for the Northern Europe countries. In 2015, ‘purple’ community included Denmark, Sweden, Finland, Netherlands; ‘green’ — Greece, UK, France; ‘orange’ — Austria, Germany, Belgium; and ‘blue’ — Luxembourg and Ireland. Again gravity factor might have been important for communities’ formation in 2015, since communities remained composed of neighbouring or closely located countries, even though the composition of most communities changed.

Distance among nodes in graphical visualisations of EU 12 banking networks in 2011 and 2015 is based on force algorithm in Gephi and closely situated countries have the highest value links. According to the node degree metric, it could be observed that overall in 2011 the mostly interconnected countries considering incoming and outgoing relations were Finland (degree — 15), Luxembourg (degree — 14) and Sweden (degree — 14). In 2015, number of connections decreased and mostly interconnected countries changed into Germany (degree — 11), Belgium (degree — 9), Netherlands (degree — 8) and UK (degree — 8).

The mapping of the EU 12 banking network in 2011 and 2015 suggest that the network has become more clustered (4 communities instead of 3). Clustering and communities’ formation could be explained by the geographical border proximity, which remains an important factor, even when communities’ members or their clustering directions change. Number of interconnections within EU 12 network appears to be somewhat lower whereas mostly interconnected countries also changed suggesting some structural changes within the network.

Graphical drawings of EU 28 directed and weighted cross-border banking claims networks in 2011 and 2015 are provided in Figure 2, and reveal no changes in the number of communities — 4, comparing 2011 and 2015. In 2011, 3 communities consisted of 9 countries, i.e., ‘purple’ community was compiled out of: Bulgaria, Lithuania, Hungary, Sweden, Finland, UK, Denmark, Spain and Portugal; ‘green’ community: Austria, Croatia, Netherlands, France, Belgium, Romania, Slovakia, Cyprus and Slovenia; ‘orange’ community: Germany, Luxembourg, Ireland, Italy, Greece, the Czech Republic, Poland, Malta and Estonia. However, the last, ‘blue’, community includes only Latvia, which appears to be somewhat excluded from the rest. This is due to the fact that in 2011 no increase on banking claims on Latvia from any other EU 28 country was observed. In 2015, 'orange' community consisted of 6 countries — Poland, Denmark, Estonia, Latvia, Sweden and Finland; 'blue' community of 5 countries — Lithuania, France, UK, Greece and Malta; 'purple' community of 10 countries — Croatia, Slovenia, Spain, Portugal, Netherlands, Italy, Ireland, Luxembourg, Slovakia and Romania; and 'green' community of 7 countries — Germany, Belgium, Bulgaria, Cyprus, Austria, Czech Republic and Hungary.

Comparing EU 12 network with EU 28 network in 2011, the clusters of EU 12 core countries remained exactly the same in the EU 12 and EU 28 networks; in the EU 28 network they only connected up EU 16 periphery countries. Almost exactly the same tendency is observed in 2015, except for the Netherlands, which changed its cluster in the EU 28 network. Analysing the clustering of EU 16 periphery countries in the EU 28 network, the importance of border proximity factor cannot be observed as in EU 12 network. In addition, as it could have been expected, most EU periphery countries are less interconnected with the EU 12 core and, thus, are more distant from the centre in EU 28 networks.

The mapping of EU 28 banking network in 2011 and 2015 suggest again that the network has become more clustered (4 communities instead of 3, if not taking into account unconnected Latvia in 2011) and divided into a higher number of smaller communities. Clustering analysis of the EU 16 periphery countries in the EU 28 network did not support the importance of border proximity factor. In addition, most EU periphery countries are less interconnected with the EU core. The number of interconnections within the EU 28 network again appeared to be lower and the mostly interconnected countries had also changed, suggesting structural changes within the network.

Analysis EU banking network using network indicators

Descriptive statistics for 10 network indicators in 2011 and 2015 for 12 EU banking network countries are presented in Table 2. According to mean values, in-degree, out-degree and degree metrics were on average higher in 2011 than in 2015 indicating that the number of interconnections of EU 12 banking network countries' decreased. In-degree, out-degree and degree network indicators' lower maximum and minimum values suggest that both the most interconnected countries and the least interconnected countries within EU 12 banking network decreased their number of interconnections during the post-crisis period, meaning that overall connectedness within the EU 12 banking network decreased and structural changes are observed.

The increase of maximum and decrease of minimum value of strength in-degree metric reveal that countries, which previously attracted most of other countries' cross-border claim flows, started to attract even more of them and countries, which previously attracted least of other countries' cross-border claim flows, started to attract even less of them, thus, resulting in the same average. Therefore, the strength of certain countries within the EU 12 network became even more salient. Standard deviation and variance of strength in-degree indicator reflect that in 2015 this metric became more dispersed around the mean.

The degree, betweenness and closeness centrality metrics allowed evaluating the importance of certain countries within the network. It is observed that the mean values of 2 (degree and closeness centrality) out of 3 centrality measures' decreased in 2015. The lower degree centrality metric revealed that the popularity of the most interconnected countries decreased, thus, they became less important to the network. An increase in the closeness centrality metric indicated that the average distance from a given country to all other countries in the network decreased, which revealed that 'periphery' countries became more interconnected and central to EU 12 banking network. However, the difference between degree centrality and closeness centrality metrics in 2011 and 2015 was very small, revealing that decentralization processes in the EU 12 banking network were happening very slowly. On the contrary, the mean value of betweenness centrality metric increased in 2015 compared to 2011, revealing that, on average, more countries became central to the network, which may potentially influence the spread of information through the network. Overall, all 3 centrality measures on average reveal that EU banking network during post-crisis period has become a little bit more decentralized, with periphery countries becoming more interconnected and central to the network as compared with core countries. These results are in line with the results by Claessen and van Horen (2015) and Lambert *et al.* (2015).

Analysis of regionalization level within EU banking network

The level of regionalization of the EU banking network is evaluated using intraregional and interregional density indicators within EU 28. They allow for measuring the density of connections within sub-regions of EU 28 and among sub-regions of EU 28. The results are presented in Table 3.

An analysis of the regionalization within EU 12 showed that the average intraregional density decreased by 23.33% comparing 2011 and 2015. Interregional density also decreased by 14.63%. However, the average intraregional density was higher than the interregional density only in 2011 (but not in 2015). This reveals that, on average, regionalization existed within EU 12 in 2011 (53.33% > 46.34%), but it disappeared in 2015 (30.00% < 31.71%). The level of regionalization within EU 12 decreased considerably in 2015 (-23.33%). Interregional interactions outside EU 12 sub-regions have also decreased (-14.63%).

The results of the regionalization within EU 28 analysis revealed that the average intraregional density increased by 3.02% comparing 2011 and 2015. This reveals that, on average, regionalization did not exist within EU 28 in 2011 (35.08% < 36.03%), but it appeared in 2015 (38.10% > 28.97%). Thus, the level of regionalization within EU 28 increased (+3.02%) in 2015 and the interregional interactions outside EU 28 sub-regions decreased (-7.06%) in 2015.

Results of the assessment of regionalization in the EU banking sector are ambiguous. In 2011 regionalization was present within EU 12 banking network, but disappeared in 2015. On the contrary, within the EU 28 banking network regionalization was not detected in 2011, but emerged in 2015. The level of regionalization within EU 12 decreased, while the level of regionalization within EU 28 increased in 2015. Interregional interactions outside EU 12 and EU 28 regions had also decreased. This again reflects that EU 12 countries interact less among their regions, which is in line with the research by Bicu and Candelon (2013), but increase their interactions with EU periphery regions.

Discussion

Mapping of EU banking network proved that both, EU 12 (the core countries) and EU 28 (the core and 16 periphery countries), banking networks became more clustered in 2015 if compared to 2011. Changes in EU 12 banking networks could be explained by the geographical border proximity, which remained an important factor in both periods. Clustering analysis of EU 16 periphery countries did not support the importance of border proximity factor. In addition, most EU 16 periphery countries became less interconnected with EU 12. Number of interconnections within EU 12 and EU 28 banking networks became lower; also, structure of mostly interconnected countries had changed. Such findings point out structural changes within the network.

An assessment of the network indicators proved that the connectedness of EU banking networks changed during post-crisis period with respect to out-degree, betweenness and closeness centrality network indicators. Number of outgoing cross-border interbank connections decreased implying that during post-crisis period on the network became more decentralized, with EU 16 periphery countries becoming more interconnected and central to the network as compared with EU 12 core countries.

The results of the conducted analysis confirm that during the post-crisis period the regionalization level within the EU banking network increased. In 2011 EU 28 regions were not more densely connected inside than with outside regions. However, in 2015 the interregional connectedness in EU 28 regions became denser than with outside regions. Also, the average intraregional density of EU 28 sub-regions increased by 3.02%, and the interregional density among EU 28 sub-regions has decreased by 7.06%, proving increased regionalization within the EU. The scope of the decrease suggests that changes in cross-border claims are happening slowly. Our results are in line with previous studies on global banking network during post-crisis period. Lambert *et al.* (2015) and Claessen and van Horen (2015) also concluded that global banking is gaining a more regional focus. This research contributes to previous research in a way that it applies intraregional and interregional network density measures to evaluate EU banking network regionalization. It adds to the knowledge of regionalization processes within the EU banking network during the post-crisis period.

Conclusions

Global banking network has been analysed extensively in prior or post-crisis periods, but the literature on regionalization is scarce, especially with regard to the banking sector in the EU. In this paper, an evaluation of the EU banking network's regionalization during the post-crisis period was performed for the total of 28 EU countries, using network analysis methodology and BIS bilateral interbank cross-border claim yearly flows data.

The results of the research show that during the post-crisis period both the core EU 12 and the EU 28 banking networks became more clustered and more decentralized; also, the level of regionalization within EU banking network increased. Such results prove that the EU banking network has undergone structural changes with respect to bilateral interbank cross-border claims. With respect to reliability of the results and the restrictions of application, it should be noted that conclusions about the EU regionalization should be interpreted with caution, due to the incompleteness of bilateral cross-border claims data and the countries included in the EU banking network.

This research adds to the knowledge of regionalization processes within the EU banking network during the post-crisis period and intends to be beneficial for market participants, EU level governmental bodies and financial policy makers, as it adds knowledge to the structural changes in the EU banking system. The value of the research presented in this article is also reflected in the application of network analysis methodology for the evaluation of connectedness, specifically of regionalization, in global banking system. The conducted research could be further developed to include more complete set of data and a broader range of countries representing the global banking network. This would allow evaluating and comparing regionalization trends in other regions, i.e. Asia, where the most salient regionalization is assumed to happen during the post-crisis period.

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Annex

Table 1. Logics of the research

Stages	Stage 1. Identification of EU banking networks	Stage 2. Analysis EU banking networks' regionalization
Steps	Mapping of EU 12 and EU 28 banking networks	2.1. Analysis of network indicators 2.2. Analysis of regionalization within EU banking network
Methods	Mapping of networks	Structural and comparative network analysis
Data	Bilateral cross-border claim flows	Intraregional and interregional banking network matrices

Table 2. Descriptive statistics of EU 12 banking network indicators

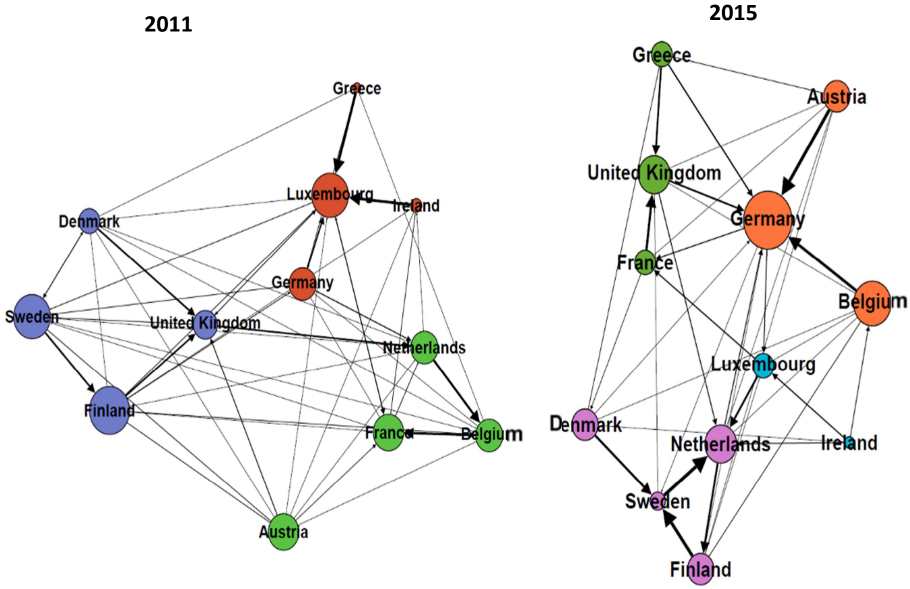
Network indicator	Min	Max	Mean	Std. Dev.	Variance
2011					
In-degree	2.000	9.000	5.420	2.021	4.083
Out-degree	3.000	8.000	5.420	1.505	2.265
Degree	5.000	15.000	10.830	3.040	9.242
Strength in-degree	0.054	2.993	1.000	0.853	0.728
Strength out-degree	0.999	1.001	1.000	0.001	0.000
Strength degree	1.054	3.993	2.000	0.853	0.728
Degree centrality	0.230	0.680	0.492	0.138	0.019
Betweenness centrality	0.420	12.660	6.000	3.495	12.215
Closeness centrality	0.520	0.730	0.654	0.068	0.005
Clustering coefficient	0.400	0.633	0.505	0.072	0.005
2015					-
In-degree	0.000	6.000	3.500	1.679	2.818
Out-degree	1.000	6.000	3.500	1.382	1.909
Degree	4.000	11.000	7.000	1.859	3.455
Strength in-degree	0.000	3.313	1.000	1.034	1.069
Strength out-degree	0.999	1.001	1.000	0.000	0.000
Strength degree	1.000	4.313	2.000	1.034	1.069
Degree centrality	0.180	0.500	0.318	0.084	0.007
Betweenness centrality	0.000	21.850	8.500	6.244	38.983
Closeness centrality	0.370	0.710	0.556	0.088	0.008
Clustering coefficient	0.167	0.367	0.288	0.057	0.003

Table 3. EU 12 and EU 28 Intraregional and Interregional banking networks' density indicators, %

EU 12	EU 12 sub-regions	2011	EU 12 sub-regions	2015	Change
Intraregion al density	Northern Europe	50.00	Northern Europe	20.00	
	Western Europe	56.67	Western Europe	40.00	
	Southern Europe	N/A	Southern Europe	N/A	
	Average	53.33	Average	30.00	-23.33
Interregion al density	Whole network	46.34	Whole network	31.71	-14.63
EU 28*	**EU28 sub-regions**	**2011**	**EU28 sub-regions**	**2015**	**Change**
Intraregion al density	Northern Europe	34.29	Northern Europe	31.43	
	Western Europe	56.67	Western Europe	40.00	
	Southern Europe	14.29	Southern Europe	42.86	
	Eastern Europe	N/A	Eastern Europe	N/A	
	Average	35.08	Average	38.10	3.02
Interregion al density	Whole network	36.03	Whole network	28.97	-7.06

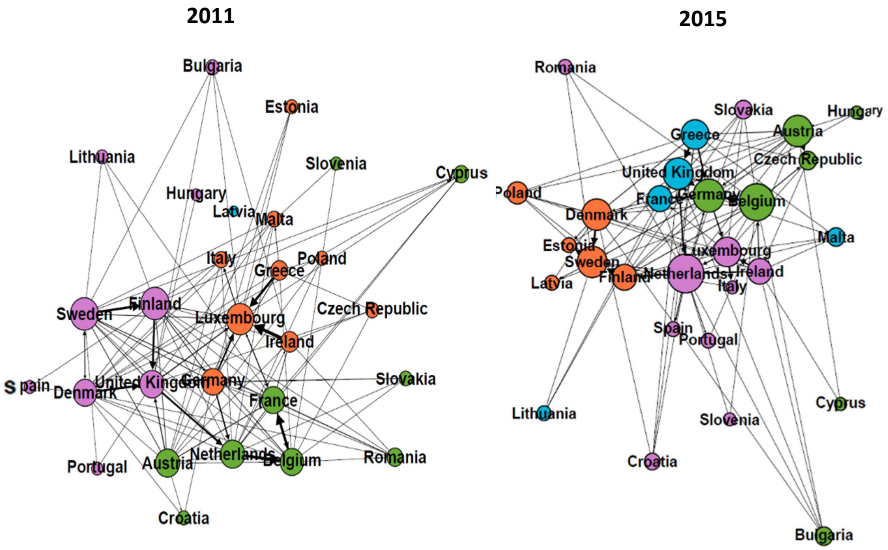
* EU 16 outgoing flows data is unavailable.

Figure 1. EU 12 directed and weighted cross-border banking claim flows' networks



Source: compiled by authors using BIS LBS by residence data (2016) and network software Gephi.

Figure 2. EU 28 directed and weighted cross-border banking claim flows' networks



Source: compiled by authors using BIS LBS by residence data (2016) and network software Gephi.