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Theophilos Papadimitriou
Department of Economics, Democritus University of Thrace, Greece

Periklis Gogas
Department of Economics, Democritus University of Thrace, Greece
The Rimini Centre for Economic Analysis, Italy

Georgios-Antonios Sarantitis
Department of Economics, Democritus University of Thrace, Greece

EUROPEAN BUSINESS CYCLE SYNCHRONIZATION: A COMPLEX NETWORK PERSPECTIVE

European Business Cycle Synchronization: a Complex Network Perspective

Theophilos Papadimitriou, Periklis Gogas*†, Georgios-Antonios Sarantitis**

Department of Economics
Democritus University of Thrace, Komotini 69100, Greece

†Rimini Centre for Economic Analysis

Abstract

In this paper we attempt to provide empirical evidence on the issue of business cycle synchronization within Europe. The issue of business cycle convergence is important and very topical as it is a prerequisite for the implementation of an effective and successful monetary policy within a monetary union. We employ for the first time in this context (to the best of our knowledge) Complex Network metrics and we identify the corresponding Minimum Dominating Set of countries in terms of their GDP growth. An obvious focal point for our comparison of business cycle convergence is the adoption of a common currency (the euro) in 1999. By doing so, we reveal the evolution of GDP growth co-movement patterns of European economies before and after the introduction of the euro. The main findings from our empirical analysis provide evidence in favor of macroeconomic convergence after the introduction of the common currency.

1. Introduction

The project of a European Monetary Union (EMU) has received a lot of debate since its conception from the "Delors Committee" in 1988 and launching of its first phase in 1990. The basic goal underlying the EMU was the formation of a Mundell (1961)-type Optimum Currency Area (OCA).The OCA theory proposes that it may be more efficient from an economic point of view for a group of countries to abdicate their sovereign currency and adopt a common one. The main advantages include a) lower costs of international transactions that boost international trade, b) abolition of the exchange rate risk and c) increased price transparency between members of the union since all commodities are priced in a common currency, enhancing in this way competition within the union. Finally, another advantage is the increased risk sharing between member-states due to wider absorption of exogenous shocks through the exertion of monetary policy in a centralized manner. Nonetheless these advantages do not come without costs associated with the participation in a monetary union. A major disadvantage that stems from the abolishment of a sovereign currency for a common one is the resulting inability to implement an independent monetary policy. This includes: a) manipulating the exchange rate in order to achieve certain macroeconomic goals such as improving international competitiveness (through currency depreciation) and b) the inability to set the short-term interest rate and the money supply to deal with inflation, unemployment and growth.

A basic condition for the benefits to exceed the costs in a monetary union is macroeconomic convergence, i.e. the synchronization of the business cycles. In such an ideal case, the economies participating in the union will exhibit symmetric cycles of GDP contraction and expansion. As a result the central, transnational, monetary authority will be able to implement a monetary policy that is efficient for all member-states in both cases. However, in his work, Krugman (1991) states that the formation of monetary unions with a higher order of trade integration may have 2 diverging results regarding business cycle synchronization: a) the optimistic scenario is that economies will further integrate due to extended intra-industry trade and b) the negative case where due to industrial specialization, idiosyncratic shocks will be induced.

Stepping from a theoretical to the empirical framework there already exists a vast literature contemplating with the macroeconomic convergence between member-states of monetary unions. The most commonly used method of comparing business cycles is the detrending of some aggregate of output (with some filtering method) and the comparison of the cyclical component through time using some correlation or regression function. The most commonly used filters, each with its inherent advantages and weaknesses, are the Hodrick- Prescott (1998) filter, the Baxter-King (1999) filter and in a lesser extend the Phase Average Trend (PAT- Boschan and Ebanks, 1978).

Apart from the differentiation of the detrending procedure, the literature has followed varying paths to compare the stationary component of the time series: in their work Wynne and Koo (2000) document similarities and differences using a group of 15 countries from the European Union and the 12 Districts of the US. Applying the Baxter and King filter for the detrending of the series and a generalized method of moments approach for the comparison of the cyclical component, they conclude that the US districts present far more synchronized cycles than those of the European economies.

Another approach is proposed by Altavilla (2004). The author applies a Markov switching model in EMU member states and concludes that the establishment of a common currency in Europe has led to increased business cycle harmonization between E.U. economies. In their study, Canova *et al* (2007) use data from the G7 countries and within a Bayesian VAR context they reach to the conclusion that apart from an incline of business cycles in the late-90s, no uniform European cycle can be traced. Silva (2010), in his paper, uses annual GDP data to test for convergence between 25 OECD countries. He extracts the cyclical component using a Hodrick-Prescott filter and applies a correlation coefficient for two time periods before and after the establishment of the European Monetary Union. His results provide evidence in favor of increased business cycle synchronization after the integration of the examined economies. In yet another path, Lee (2012) uses a dynamic factor model to check for convergence between 25 OECD countries for the time period 1970-2010. His results indicate an increase in the synchronization of the examined economies for the time period 1985-1998 while no signs of further convergence can be observed for the period following, i.e. 1999-2010.

More recently, Gogas (2013) collects GDP data for 14 European economies spanning two periods (1992-2001 and 2002-2007) that correspond to the pre- and post-euro era. He applies the HP filter for the detrending of the series and then measures business cycle synchronization through linear regressions and a proposed sign concordance index. The author finds evidence in favor of weaker business cycle synchronization after the adoption of a common currency in Europe.

Despite the already wide and ever growing number of studies on the subject of business cycle convergence, the literature has not yet reached a consensus since some authors provide evidence in favor of business cycle convergence within specific country groupings (e.g. the EMU or the G7) while others provide conflicting results. The reasons for this dispute pertain to differences in the selection of countries, period under investigation and the macroeconomic variable under consideration.

In this paper we follow a novel approach. Departing from econometric methods and models, we apply tools and metrics from Graph Theory, representing countries as nodes and their GDP growth similarity intensities as edges linking these nodes. By constructing and comparing the GDP growth networks of 22 European economies before and after the introduction of the euro in 1999 we are able to provide evidence regarding the effect of the introduction of a common currency on the macroeconomic convergence between the examined countries. Furthermore, we apply the Minimum Dominating Set (MDS), a technique mainly used in wireless network analysis (see e.g. Cheng *et al*, 2003; Wu *et al*, 2006), in order to study the topology and evolution of GDP growth correlation patterns through time.

The rest of the paper is organized as follows: in section 2 we describe the collected data and we analyze the methodological context. Section 3 includes the results of our empirical analysis while section 4 revises and concludes.

2. Data and Methodology

The main goal of this paper is to study the effects of the introduction of the euro in the synchronization of business cycles of countries that constitute the Eurozone i.e. the countries that a) participated in the third stage of the EMU and b) have adopted the common currency. Moreover, in order to study the cascading effects of the economic and monetary union to the rest of the European economies, we include in the study countries that are not members of the Eurozone. These countries might be in the process of fulfilling convergence criteria in order to move to phase three of the EMU or may have already met these requirements but they choose not to participate in the Eurozone. Such countries are

Denmark and the UK who have obtained an exclusion claw, allowing them to participate in the Exchange Rate Mechanism (ERM II) without being obliged to adopt the euro. Furthermore, Frankel and Rose (1998) claim that it is possible for a country to fulfill convergence criteria ex- post rather than ex- ante the joining of a monetary union, caused by the increased trade that the economic integration induces. For these reasons seven non-Eurozone countries have also been included in the study. The period under examination should include adequate observations before and after the introduction of the euro in 1999. Our full data span the period 1986-2010, in annual rates. This sample is separated in two sub-samples: the one that covers the thirteen years before the introduction of the euro (1986-1998) and the other that covers the thirteen years after the new currency (1999-2010).The countries involved in the study are 15 Eurozone countries (namely Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Luxemburg, Malta, Netherlands, Portugal, Slovak Republic and Spain) and 7 non-Eurozone countries (Bulgaria, Denmark, Hungary, Latvia, Romania, Sweden and the United Kingdom), which are presented in Table 1. The source of our dataset was the World Bank. The GDP growth was calculated using Eq. 1.

$$GDPgrowth_{i,t} = \frac{GDPlevel_{i,t} - GDPlevel_{i,t-1}}{GDPlevel_{i,t-1}}, \quad (1)$$

where i is the index for the country under consideration (i=1,2,…22) and t is a time operator.

Our methodological context strays from the "classical" literature of econometric models in business cycle co-movement analysis. In order to analyze the patterns of business cycle synchronization evolution in Europe we employ the tools of Graph Theory. Graph theory is a branch of mathematics and computer science that studies complex systems (or networks) by representing them as Graphs. A Graph is a depiction of the system's agents as nodes and their inter-relations as edges linking these nodes. Whereas it would be hard and time-consuming to analyze a complex system by studying the bilateral relations between each pair of agents outside the Graph theory context, a Graph is analyzed by calculating specific measures (called metrics in Graph theory terminology) in order to collectively extract relevant information on the topology (characteristics) of the entire system. The merits of Graph Theory were initially explored by Leonhard Euler (1741) in his attempt to solve the "Puzzle of Konigsberg", i.e. to find a unique path that drives through the seven bridges that connected the individual parts of the town of Konigsberg. Since this premature study, the context of Graph Theory was expanded, improved and applied in many scientific fields including path rooting problems, metabolic-biological networks, social network analysis, chemistry, physics etc. In the last decade or so, renewed interest in the field of Graph Theory was revived in order to be applied in social and computer networks while it has also been integrated in the analysis of complex economic systems.

In representing an economic dataset as a network (G), economic agents are defined as nodes (N) and the similarity measure of the examined variable under consideration takes the form of edges (E) that link these nodes; in mathematical terms $G = (N, E)$. In this study, the nodes of the network represent the 22 European countries and the edges that connect them are delivered by the calculation of the cross-correlations of the GDP growth rates. The cross-correlations are calculated using the Pearson correlation coefficient $r_{i,j}$ through the following equation:

$$r_{i,j} = r_{j,i} \triangleq \frac{cov\left(GSP_i, GSP_j\right)}{\sqrt{var(GSP_i)var\left(GSP_j\right)}}. \tag{2}$$

The coefficient r takes values in [-1, 1]: values near -1 indicate a strong negative correlation whereas values close to 1 indicate a strong positive correlation. In the case of $r \cong 0$ the states are uncorrelated. Our interest lies in the high positive correlations of GDP growth therefore we impose an arbitrary threshold p (in our simulations we alternatively used $p = 0.7, 0.75\ and\ 0.8$), below of which we assume that the two nodes are practically uncorrelated and the edge connecting them is removed from the network. In the opposite case of r being equal to or larger than the given threshold p, the nodes are positively correlated and the edge between them is kept in the network. This step may result in smaller subnetworks and/or isolated nodes i.e. nodes without any connection to the other nodes in the network. An optical example of this procedure is illustrated in figure 1a and 1b. We observe that before the threshold imposition every node is connected to every other in the network; the network is complete. After the thresholding procedure though, only the strong positive correlations (and thus the corresponding edges) remain in the network which, in this hypothetical case, leads to the emergence of a main network constituting of five nodes, a small sub-network of only 2 nodes composed by nodes 6 and 8, while node 1 becomes an "isolated" node since every edge connecting it with the rest of the initial network collapsed.

We break the full period of 1986-2010 in two equal in length sub-periods i.e. 1986-1998 and 1999-2010, since 1999 is the year of the introduction of the common currency and we apply the aforementioned methodology in each individual period separately. We end up with 2 unweighted, undirected networks representing the topology of correlations between the 22 European countries in terms of GDP growth before and after monetary integration.

In order to gain insight on the evolution of business cycle synchronization in Europe we need to study the topology of the network of GDP growth before and after the implementation of euro. The tools we are going to use for this purpose are the network Density and the Minimum Dominating Set.

Density is a Graph theory metric that describes how well connected a network is and is given by the following equation:

$$d = \frac{\sum_{i=1}^{n} k_i}{n(n-1)/2} \tag{3}$$

where k_i stands for the degree of node i, i.e. the number of edges incident to node i and n is the total number of nodes. Thus, network density is calculated by dividing the number of actual edges existing in the network to the maximum theoretical number of edges a complete network of n nodes would contain. The metric of network density takes values in [0, 1] and can assist our study in the following way: values near zero indicate a sparse network while greater values refer to a more connected network with the case of $d = 1$ representing a complete network where every node is connected to any other. As a result, when network density increases with time, it can be interpreted for our purpose as a strong indication of higher GDP growth co-movement correlations, i.e. with time more GDP growth correlations are higher than threshold p. This will, in turn, provide evidence in favor of increased macroeconomic convergence between E.U. countries.

Finally, the Minimum Dominating Set (MDS) is calculated for both networks. A subset S of the initial set of nodes ($S \subseteq N$) is a Dominating Set (DS) of (G) if every node $u \in N$ is either included in S or is adjacent to one or more nodes of S. The MDS is simply the minimum cardinality DS (that is the dominating set with the minimum number of nodes). We first consider the simple DS concept, where the only assumption made is that every node is either a DS node or adjacent to one or more DS nodes. Let's consider a binary parameter $x_i, i = 1, \dots, n$ for every node of the network such that $x_i = 1$ when the node i is a Dominating Set node and $x_i = 0$ in the opposite case, then the DS assumption takes the mathematical form of:

$$x_i + \sum_{j \in \mathrm{N}(i)} x_j \geq 1, i = 1, \dots, n, \tag{4}$$

where $\mathrm{N}(i)$ stands for the neighboring node set of node i. The assumption is straightforward to follow: the node i can be either a) a node of the DS ($x_i = 1$) or b) adjacent to at least a node of the dominating set ($\exists j \in \mathrm{N}(i): x_j = 1$). In any case the l.h.s of the constraint is equal or greater than 1.

Additionally, the MDS concept imposes that the DS cardinality is minimum. Mathematically, this means that

$$\min_{\boldsymbol{x}} f(\boldsymbol{x}) = \sum_{i=1}^{n} x_i. \tag{5}$$

So the calculation of the MDS is transformed into estimating the binary vector $x = [x_1, x_2, \dots, x_n]$, from Equation (5) under the constraints in (4).

By definition, every isolated node (created by the imposition of a threshold) belongs to the MDS. From our point of view though, it is important to distinguish the isolated nodes from the other MDS nodes because the two subsets have different and independent features: their topological characteristics should not be examined as a cohesive network. A node is considered totally uncorrelated in our study when all of its correlations with the rest of the network nodes fall short of the given threshold. In other words, for the purposes of our analysis, the definition of totally uncorrelated node includes not only the ones with Pearson coefficients close to zero value but also the node/countries with Pearson coefficients below the respective threshold. The economic interpretation of an isolated node in our work is that the country represented by this node presents a totally dissimilar behavior with the rest of the countries in terms of GDP growth. For this reason we exclude all isolated nodes from the MDS calculation and study them separately. The countries that are represented by isolated nodes should be given special attention from economists and policy makers in order to be brought into synchronization with the rest of the network.

In general, any network can appear (*inter alia*) in two extreme instances; a *complete* form where every node is connected to every other forming a network with $n(n-1)/2$ edges, and a totally disconnected one where zero edges exist and all nodes are isolated. In both cases the calculation of MDS is futile; in the first case the MDS size will be 1 as every node can form an MDS by itself while in the second case the MDS size will equal the number of nodes in the network. These facts though lead to the formation of a methodology; if the MDS is calculated for the same network in two different time instances and the more recent MDS has a smaller size then this would mean that the network has become denser, more connected and that the nodes that constitute it present more similar behavior in the second instance. If the MDS size decreases with time, it is a strong indication of higher GDP growth co-movements and thus indicates macroeconomic convergence between the E.U. countries after the introduction of the euro.

3. Results

We apply the methodology described in the previous section and construct the networks that describe the cross-country relations of the 22 European countries in terms of their GDP growth co-movement for various thresholds p. The imposing of the threshold is an arbitrary procedure and its choice lies upon the purpose and focus of the study. Table 2 presents the results from our empirical analysis for threshold values of $p = 0.70, 0.75\ and\ 0.8$.

The first promptly observable fact is that the number of network edges increases when we compare the periods before and after the introduction of the euro, for every threshold value. As a direct result the network density also increases significantly for every imposed threshold. More specifically, when studying the topology of the network for both periods in the case of $p = 0.70$, we observe that the number of edges increases from 30 in the pre-euro period to 134 in the period following the adoption of the common currency. Consequently the metric of network density increases from 13% in the first period to 58% in the euro period. In the case of an imposed threshold of $p = 0.75$ the number of edges increases by more than five-fold, from 22 to 115. The respective metric of network density for this instance increases from a "poor" 9.5% to 49.8% in the period after the introduction of the euro. The same pattern is observed for the case of an imposed threshold $p = 0.80$ where the number of edges that "survive" the threshold increases from 19 to 87 in the euro period and thus the metric of density accordingly increases from 8.2% to 37.7%. The interpretation of a denser network with more edges and consequently higher density in the second time period is that GDP growth correlations are higher in the euro period and thus more edges survive the imposed threshold. The macroeconomic interpretation of these results is that the GDP growth of the 22 European countries is becoming more synchronized in the period 1999-2010. These empirical findings provide clear evidence in support of macroeconomic convergence.

Next, we compare the MDS size for the two time periods under examination for each imposed threshold value. Table 2 presents the MDS size before and after the adoption of euro for each applied threshold. We observe that in all three cases the MDS size remains stable or decreases as the number of edges increases. For the case of a threshold $p = 0.70$ we observe that the MDS size remains the same in the two periods under consideration (however the number of edges increases significantly in the same threshold case) while in the other two instances of $p = 0.75$ and $p = 0.80$ the MDS size decreases from four in the pre-euro period to three in the euro period. This findings indicate that in the two latter threshold cases the collective behavior of the entire network of 22 countries can be represented by a set of only three countries in the post-euro era (in contrast to four countries in the pre-euro era). This is informative of a denser network in the second time period and confirms the network density metric discussed above, providing additional evidence in favor of higher GDP growth correlations in the second time period under examination i.e. a greater degree of business cycle co-movement in the period after the introduction of the euro.

The empirical results from both the metric of network density and the MDS are indicative of business cycle convergence in Europe. These findings are in contrast with Aguiar and Soares (2011) who find that, from a business cycle convergence point of view, there is a core-periphery status in Europe. All countries that were included in our experiment (except Malta) multiplied their edges in the after-euro period. This result indicates that a) both Eurozone and non-Eurozone have achieved a better degree of convergence and b) both newcomers as well as "old" EMU countries have increased their synchronicity and thus there are multilateral and not one-sided advantages from the monetary integration for just one portion of EU countries. These results correspond with those of Savva *et al* (2010) who find that EMU newcomers (after 2004) have doubled their correlations with former EMU members or have passed from a negative to a positive correlation sign during the period 1980-2010.

Another important result arises from the analysis of the topology of the isolated nodes. By imposing a threshold we intend to highlight the most robust relations between E.U. countries, with respect to their GDP growth co-movement. The formation of isolated nodes means that the countries represented by those nodes do not display similar behavior with any other country of our network. From a macroeconomics point of view this is an important finding. For a successful currency union, macroeconomic convergence is a critical factor. Only in this case the implementation of the uniform monetary policy will be beneficial to all member countries both in times of growth or economic decline. Examining the network for the case of an imposed threshold $p = 0.75$ we observe that in the period 1986-1998 there are 7 totally uncorrelated countries in terms of their GDP growth co-movement, namely Malta, Greece, Cyprus, Denmark, Ireland, Romania and Luxembourg. In the post-euro period we observe that most of these countries (all but Malta) become substantially integrated in the network by considerably increasing their number of edges. This is interpreted as evidence that these economies have converged to the rest of the euro network. Thus, monetary, fiscal and other reforms implemented in these countries have succeeded in increasing their cycle synchronization with the other fellow-members. Nevertheless the node that corresponds to Malta remains isolated in the post-euro period. Thus, Malta has been unable to integrate in the procedure of macroeconomic convergence (with regard to the variable under examination, i.e. GDP growth). By observing Figure 2a and 2b (which represent the network in the time periods 1986-1998 and 1999-2010 with a threshold of $p = 0.75$ respectively) we can also observe additional countries with low node degree i.e. with few connected countries. The macroeconomic interpretation of this finding is a rather small degree of convergence between this country and the rest of the network. Our results thus stress the need for policy makers to implement the appropriate monetary and fiscal policies, in order to increase the convergence not only of the already connected countries but also of those that are (totally) uncorrelated with the rest of the network.

4. Conclusion

Economic integration and business cycle synchronization is a crucial prerequisite for a monetary union. In order for the policy makers to be able to implement an effective monetary policy, the members of a monetary union must achieve macroeconomic co-movement. The euro is the most significant attempt at creating a common currency area in terms of the number of countries involved, their share of the global GDP they represent and the significance of the national currencies it substituted. This made the birth of the euro a world-class experiment for the theory of Optimum Currency Areas. There is a strong debate on whether the policies in terms of the legal, economic and regulatory frameworks implemented all these years within the E.U. and the Eurozone have actually helped in strengthening the synchronization of national economies. In this paper, using Graph Theory metrics and the Minimum Dominating Set approach we provide empirical evidence in favor of business cycle convergence between European countries after the introduction of the common currency, the euro. We showed that due to higher GDP growth correlations in the time period after the adoption of euro, the economic network that consists of 22 European countries became denser and as a result the MDS size was reduced. Furthermore by including countries that have not yet adopted (or will not adopt) the euro, we have highlighted the cascading effects of the implementation of a common currency in Europe to non-Eurozone countries as well, indicating the formation of an Optimum Currency Area in the region which was the original purpose of the establishment of the European Monetary Union. This study enriches the existing literature of business cycle co-movement by providing 2 main contributions: the indication of possible macroeconomic convergence in Europe with a novel method and the utility of the MDS in complex economic networks.

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Appendix

Table 1: The 22 European countries involved in the study

Eurozone	Non-Eurozone
Austria	Bulgaria
Belgium	Denmark
Cyprus	Hungary
Finland	Latvia
France	Romania
Germany	Sweden
Greece	United Kingdom
Ireland	
Italy	
Luxembourg	
Malta	
Netherlands	
Portugal	
Slovak Republic	
Spain	

Table 2: Summary of network metrics for the two time periods under examination

	1986-1998			1999-2011		
Threshold	0.70	0.75	0.80	0.70	0.75	0.80
Network Edges	30	22	19	134	115	87
MDS size	3	4	4	3	3	3
Isolated Nodes	6	7	8	0	1	2
Remaining Nodes	16	15	14	22	21	20
Network Density	0.130	0.095	0.082	0.580	0.498	0.377

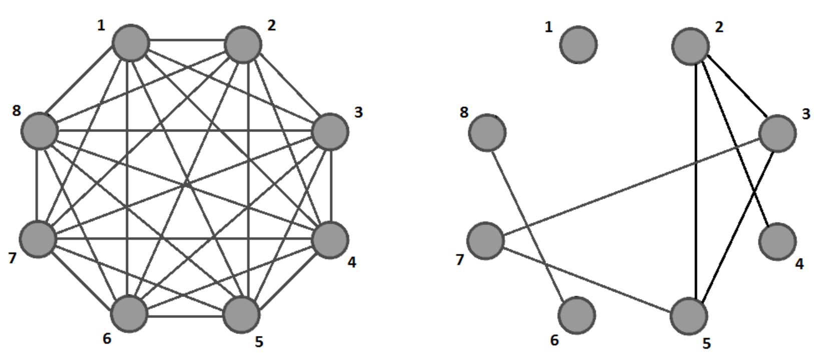

Figure 1a and 1b. Example of a network illustration before and after the implementation of a threshold respectively.

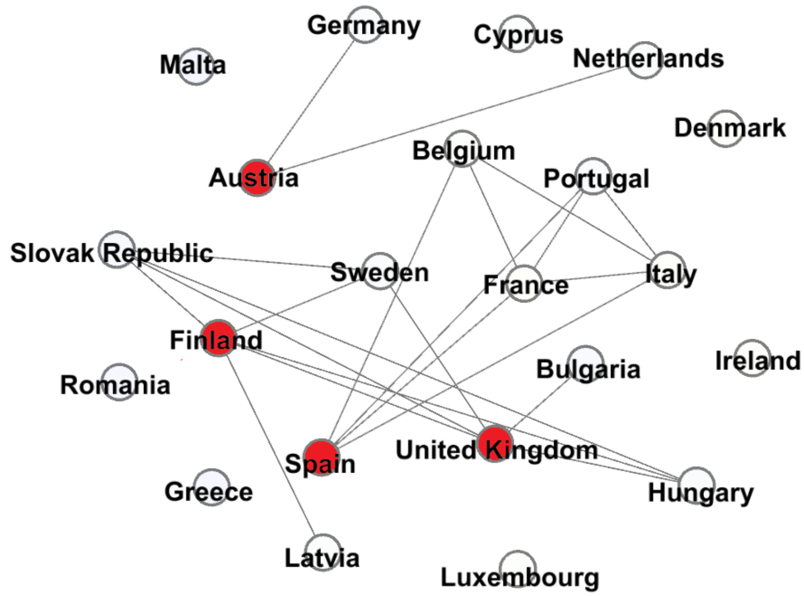

Figure 2a. Network topology and Minimum Dominating Set for the pre-euro period (1986-1998) and threshold $p = 0.75$

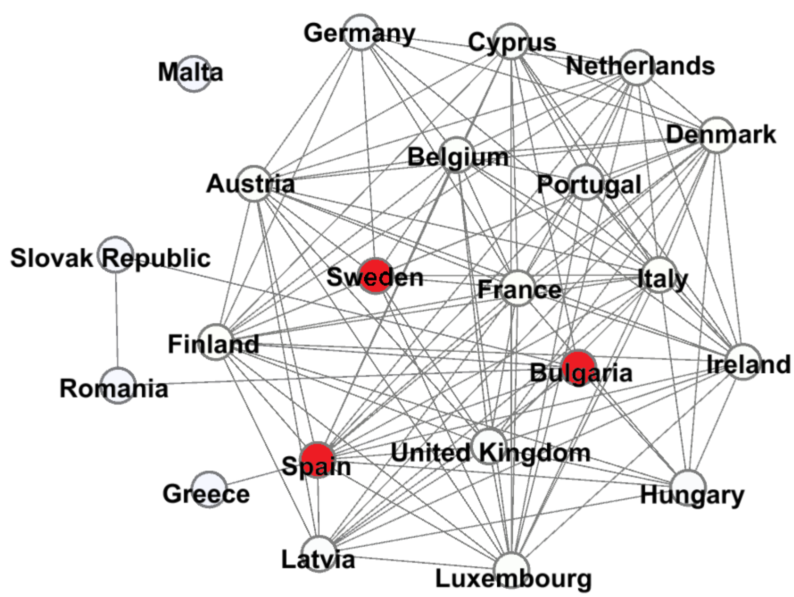

Figure 2b. Network topology and Minimum Dominating Set for the post-euro period (1999-2010) and threshold $p = 0.75$